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Assessing the impact of climate on annual and seasonal discharges at the Sremska Mitrovica station on the Sava River, Serbia

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ABSTRACT

Flood frequency analysis was performed on annual maxima series for 90 years (1928–2017) of discharge data recorded at the Sremska Mitrovica gauging station on the Sava River. The three-parameter distributions (PearsonIII, Log-PearsonIII) are more suitable for modelling annual maxima than distribution functions with only two parameters (Normal, Log-normal, Gumbel). The Mann–Kendall test statistic indicated that there is no statistically significant trend identified in annual maximum discharges or average annual discharges. A positive increasing trend was observed in annual temperature, while annual precipitation shows a decreasing trend which is non-significant. The seasonality analysis found a statistically non-significant weak negative trend in discharge in spring, summer and autumn and a statistically non-significant weak positive trend in winter. During winter, spring, and summer a non-significant negative trend in precipitation was observed, while autumn has experienced a statistically significant increasing trend. Temperatures show a positive trend in all seasons, but only temperatures during the warm period show a statistically significant increase. The results demonstrate that decreasing discharges of the Sava River at the Sremska Mitrovica gauging station are mainly the consequence of decreasing precipitation and increasing temperature (increasing evaporation), which is consistent with the results of other studies of the region.

Key words: discharge, flood frequency analysis, L-moments, seasonality, trends

HIGHLIGHTS

- Innovative flood frequency.
- Linear regression analyses.
- Trends in annual maximum series.
- Free parameter distributions.
- Significant trend in mean annual discharge data.

INTRODUCTION

Reliable estimation of extreme floods is one of the major challenges faced by hydrologists (Leščešen & Dolinaj 2019). Floods are one of the deadliest and most damaging natural hazards. They can damage infrastructure, lead to huge economic losses and even loss of human lives. Reliable estimation of selected variables of the chosen hydrologic risk becomes even more problematic with climatic variability (Šraj *et al.* 2016b; Blöschl *et al.* 2019).

Over the past several decades, many studies world-wide have undertaken flood frequency analysis and investigated the trends in extreme river flow and explored their correlation with global climate change (Pinter *et al.* 2008; Petrow & Merz 2009; Bormann *et al.* 2011; Šraj *et al.* 2016b; Blöschl *et al.* 2017, 2019). The main goal of this research is to provide practical and reliable tools for flood estimation to inform flood management and civil engineering designs, as well as to provide a better understanding of flood characteristics (Wilcox *et al.* 2018). Although global and regional spatial-temporal patterns of hydrological extremes have been intensively studied over the last decades, no uniform changes around the globe have been found (Bower 2010). Nonetheless, evaluations of historical data series worldwide have observed a high range of both decreases and increases in extreme discharges (Kundzewicz *et al.* 2005; Bower 2010; Condon *et al.* 2015). Kundzewicz *et al.* (2005) have

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detected trends in annual maximum river flows on a planetary scale and discussed an absence of a universal growth of high flows worldwide. Increasing discharges were identified for the rivers in North and South America and Asia, while decreasing discharges were identified for Africa (Labat *et al.* 2004). A recent study conducted by Blöschl *et al.* (2019) demonstrated that for European rivers there is no uniform trends in flood discharges. They argued that changing climate both increases and decreases European floods and identified three regional trends, namely increasing floods in northwestern Europe, and decreasing floods in southern and eastern Europe. Researchers have argued that the identification of discharge trends is strongly dependent on the geographical location of the river, its basin characteristics, the length of the discharge data series (Robson *et al.* 1998) and the presence of anthropogenic influences in the study basin (Bezak *et al.* 2016).

Global changes which increase discharges primarily as a consequence of the intensification of the hydrological cycle caused by the global warming are expected to increase flood hazards (Hirabayashi *et al.* 2013; Arnell & Gosling 2016). This can be exacerbated by the degradation of land due to anthropogenic activities (Brath *et al.* 2006; Elmer *et al.* 2012). Factors that reduce flood hazards include reductions in precipitation and implementation of flood protection measures (e.g. dams, levees). In some regions, changes in flood frequency are observed, in other regions, there are no changes (Villarini *et al.* 2009). Milly *et al.* (2002) found that the magnitude of floods with the return period of 100-years increased significantly during the 20th century in river basins that are larger than 200,000 km^2.

In the Sava River region, several papers that analyze the long term changes in discharge in the rivers in Slovenia have been published (Frantar & Hrvatin 2005; Ulaga *et al.* 2008; Bezak *et al.* 2016). All authors reported that there is a general decrease in the mean and maximum discharge in almost all Slovenian rivers. In Croatia, the discharge trends in major rivers have been researched in the last few decades. In the Croatian part of the Sava River basin, most research has been conducted at the Zagreb gauging station. Changes in long-term flow regimes in the Sava River were also researched by Bonacci & Ljubenkov (2008). The discharge regime of the Sava River in the middle reach was also investigated at Slavonski Brod gauging station (Bonacci 2014); however, this paper mainly considered flooding. Šegota & Filipčić (2007) concluded that changes in the discharge regime in the Sava River are a consequence of climate change. In Bosnia and Herzegovina, limited hydrological research has been undertaken of the discharge regimes in the Sava River (Ministry of Agriculture Forestry and Water Management 2015). At the regional level, a short but valuable report by Lawrence *et al.* (2009) identified that a trend of decreasing discharges can be observed in southeastern Europe. A similar conclusion was reached by Blöschl *et al.* (2019), who identified decreasing floods in medium sized and large basins in southern Europe as a result of decreasing precipitation and increasing evaporation. The possibility of a significant decrease in river discharges in Central, Southern and Eastern parts of Europe was reported also by Hagemann *et al.* (2013) and Stahl *et al.* (2010). The largest flood on record of 6,600 m^3/s was experienced at the Sremska Mitrovica station on the Sava River on May 17th, 2014. This discharge was 56.1% greater than the peak flow for the month of May averaged over the period 1928–2017.

The main aims of the study are as follows: (I) to conduct a detailed flood frequency analysis applying different distribution functions and to assess the results, (II) to detect a possible statistically significant trend in the discharge, precipitation, and temperature data and to assess the possible reasons for such a trend and (III) to identify seasonal characteristics in the discharge, participation and temperature data series.

STUDY AREA

The Sava River basin is the second-largest sub-basin of the Danube River basin with a total area of around 97,000 km^2. It is shared by Slovenia, Croatia, Bosnia and Herzegovina and Serbia (ISRBC 2014). The Sava River is fed by two mountainous streams, Sava Dolinka and Sava Bohinjka which rise in Slovenia. The length of the river is 945 km from the confluence of these two streams to its confluence with the Danube River in Belgrade (in Serbia). Around 8 million people live in the Sava River basin.

The Sremska Mitrovica station is located 139.2 km upstream from the Danube River confluence. The catchment area that drains to the station is 87,996 km^2, which is 91% of the total basin area. The Sava River basin and the location of the Sremska Mitrovica gauging and meteorological stations are presented in Figure 1 and Table 1.

The Sava River basin is subject to a temperate continental climate with a clear distinction between the cold and warm seasons. Summers are usually long and warm, while winters are harsher with snowfalls. The average air temperature over the whole Sava River basin, is 9.5 °C, with the lowest temperatures experienced in January (around –1.5 °C), and the highest

Figure 1 | The Sava River basin and the location of the Sremska Mitrovica gauging and meteorological stations.

Table 1 | Location and altitude of the Sremska Mitrovica stations used in this study

Station	Latitude (φ)	Longitude (λ)	Altitude (m)
Hydrological station	44°96 N	19°60 E	72.22
Meteorological station	45°06 N	19°33 E	82.0

experienced in July (around 20 °C) (ISRBC 2017). At the Sremska Mitrovica meteorological station, the average air temperature is 11.1 °C with the lowest temperatures during January (–0.2 °C) and highest temperatures during July (21.4 °C).

The average annual precipitation in the basin is approximately 1,100 mm (ISRBC 2017), while average annual precipitation recorded at the Sremska Mitrovica meteorological station is 577 mm. The highest precipitation occurs during June (average of 84.1 mm), while the lowest amount occurs during February (average of 38.6 mm).

The Sremska Mitrovica gauging station on the Sava River has been classified as a Pannonian pluvial-nival river regime (Čanjevac & Orešoć 2018; Leščešen & Dolinaj 2019). The highest average monthly discharge is measured during April (around 2,433 m^3/s), while the lowest discharge occurs during August (around 637 m^3/s). The average maximum discharge is highest during the spring (April) (around 3,154 m^3/s), and lowest during the summer (August) (around 980 m^3/s). The spring maxima are generally higher than the autumn maxima. However, the low summer discharges are more significant than the low winter discharges.

METHODS

Data

Discharge data for the Sremska Mitrovica gauging station was obtained from the Republic Hydrometeorological Service of Serbia. To obtain the most reliable results, a time series of 90 years (1928–2018) was used in the study. Kundzewicz & Robson

(2000) suggest that for hydrological trend analysis a time series of at least 50 years is required in order to distinguish between trends and variability. Corresponding meteorological data, including air temperature, and precipitation data were obtained from the Sremska Mitrovica meteorological station for the period 1949–2017, which was the longest period of meteorological data available.

The entire data set (1928–2017) was divided into seven parts, each containing 30 years of annual maximum discharge values. A 10–year moving window was used to investigate changes in data over the period of measurements. Statistical characteristics of these data sets and of the whole period are presented in Table 2. Flood Frequency Analysis (FFA) was undertaken of the entire data set as well as for the seven 30–years data sets.

Flood frequency analysis

The Annual Maximum Series (AMS) method is the most frequently used sample definition method for flood frequency analysis. This method is an example of the block maxima method of the extreme value theorem (Haile 2011). The maximum extreme event within each block is selected, where a block is expressed as a year. Thus, the highest discharge value within each block/year is selected (Hailegeorgis & Alfredsen 2017). Using the AMS method, there is usually no problem with the independence criteria, threshold selection and the distribution of exceedances (Bezak *et al.* 2014). The AMS method was applied to the data set comprising annual maximum discharges (Q_{max}).

In some countries, the distributions applied for FFA are defined by official guidelines; for example, in the USA, the log-Pearson type III distribution is suggested (USWRC 1982); in the UK, Generalized Extreme Value (GEV) or Generalized Logistic (GL) are recommended (Robson & Reed 1999); in Poland, the Pearson III distribution is suggested (Bogdanowitz *et al.* 2018), while in Russia a three-parameter generalized gamma distribution (GGIII) is usually applied (Urošev *et al.* 2016). In Serbia, there are still no official guidelines regarding FFA, but it is common practice to apply five common distributions, namely: (i) normal (N), (ii) log-Normal (LN), (iii) Gumbel (G), (iv) Pearson type III (PIII) and (v) log-Pearson type III (LPIII). These five distributions were used for AMS modeling in this study.

The parameter values for each of the distributions were estimated using the method of L–moments. Detailed information regarding the L–moments method can be found in Hosking & Wallis (1997). This method is a modified version of the Probability Weighted Moments (PWM) method that was presented by Greenwood *et al.* (1979). The ability to characterize a wide

Table 2 | Statistical characteristics of the seven 30-year data sets

	Period			
Parameter	**1928–1957**	**1938–1967**	**1948–1977**	**1958–1987**
Mean annual discharge (m^3/s)	4,251.33	4,321.33	4,284.60	4,162.77
Standard error (m^3/s)	130.47	132.03	154.15	155.27
Median (m^3/s)	4,205.00	4,215.00	4,190.00	3,985.00
Standard deviation (m^3/s)	714.60	723.18	844.32	850.47
Kurtosis	0.99	0.98	0.98	0.96
Skewness	0.23	0.34	0.67	1.10
Minimum annual discharge (m^3/s)	2,980.00	2,980.00	2,980.00	3,029.00
Maximum annual discharge (m^3/s)	5,700.00	5,850.00	6,359.00	6,359.00
	1968–1997	**1978–2007**	**1988–2017**	**1928–2017**
Mean annual discharge (m^3/s)	3,984.47	3,981.63	4,058.80	4,157.63
Standard error (m^3/s)	147.90	126.51	150.82	83.71
Median (m^3/s)	3,813.00	3,845.00	3,853.00	4,002.50
Standard deviation (m^3/s)	810. 08	692.92	826.07	794.16
Kurtosis	0.96	0.97	0.95	0.96
Skewness	1.35	0.44	0.83	0.73
Minimum annual discharge (m^3/s)	2,690.00	2,690.00	2,690.00	2,690.00
Maximum annual discharge (m^3/s)	6,359.00	5,520.00	6,420.00	6,420.00

range of distributions is the advantage provided by L–moments over the conventional moments (Urošev *et al.* 2016). Furthermore, Sankarasubramanian & Srinivasan (1999) demonstrated that the method of L–moments can be used for all sample sizes and is more suitable for data with higher skewness. The PWM method w presented by Hosking & Wallis (1997) was used for the L–moments calculations as follows:

$$\beta_r = E\{X[F_x(x)]^r\} \tag{1}$$

where β_r is the rth order PWM and $F_X(x)$ represents the cumulative distribution function of X. Sample estimators (β_i) of the first four PWMs are specified by Hosking & Wallis (1997) as follows:

$$\beta_0 = m = \frac{1}{n}\sum_{j=1}^{n} X_j \tag{2}$$

$$\beta_1 = \sum_{j=1}^{n-1}\left[\frac{n-j}{n(n-1)}\right]x_{(j)} \tag{3}$$

$$\beta_2 = \sum_{j=1}^{n-2}\left[\frac{(n-1)(n-j-2)}{n(n-1)(n-2)}\right]X_{(j)} \tag{4}$$

$$\beta_3 = \sum_{j=1}^{n-3}\left[\frac{(n-j)(n-j-1)(n-j-2)}{n(n-1)(n-2)(n-3)}\right]X_{(j)} \tag{5}$$

where X(j) is the rank of AMS with X(1) that is the highest value and X(n) that is the lowest value.

The first four L–moments are expressed as linear combinations of PWMs and can be calculated as follows (Hosking & Wallis 1997):

$$\lambda_1 = \beta_0 \tag{6}$$

$$\lambda_2 = 2\beta_1 - \beta_0 \tag{7}$$

$$\lambda_3 = 6\beta_2 - 6\beta_1 + \beta_0 \tag{8}$$

$$\lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0 \tag{9}$$

One of the advantages of the L-moments is that they can be more directly interpreted as measures of location (λ_1), scale (λ_2), shape (t_3) and kurtosis (t_4) of the distribution functions. The L–moments ratios can be calculated as (Hosking & Wallis 1997):

$$L-\ C_v = t_2 = \frac{\lambda_2}{\lambda_1} \tag{10}$$

$$L-\ C_s = t_3 = \frac{\lambda_3}{\lambda_2} \tag{11}$$

$$L-\ C_k = t_4 = \frac{\lambda_4}{\lambda_2} \tag{12}$$

where L–Cv is the L–coefficient of variation, L–Cs is the L–coefficient of skewness and L–Ck is the L–coefficient of kurtosis.

The best-fitting distribution function for the 30–year data series was determined using chi-squared (x^2), Kolmogorov-Smirnov (K–S) and Cramer-von Misese (CvM) tests (Urošev *et al.* 2016). To check the agreement of the empirical and theoretical distribution of flood occurrence rates the Hi-square (x^2) test was used:

$$x^2 = \sum_{k=1}^{K}\frac{(f_{e,k} - f_{t,k})^2}{f_{t,k}} \tag{13}$$

where $f_{e,k}$ represents the empirical frequencies, $f_{t,k}$, are the theoretical frequencies, and K is the number of classes of random variables. The statistic x^2 follows the x^2 distribution with $v = K - p - 1$ (p is the number of parameters in the theoretical distribution).

For further affirmation, a K–S test was used. The null hypothesis of this test is that the theoretical distribution does not differ from the empirical one, that is, H_0: $F_e \approx F_t$, and the alternative H_a: $F_e \neq F_t$. The criterion of the test is the statistics that represent the maximum difference between the theoretical and empirical distributions:

$$D_{max} = \max|F_e(x) - F_t(x)| \tag{14}$$

when comparing two or more theoretical distributions, the best fit with the empirical one is the distribution with lower values of the D_{max} statistics.

The Cramer–von Mises test also compares empirical and theoretical distributions, the smaller the value of $N\omega$ the better the distribution agrees with the empirical data:

$$N\omega^2 = \frac{1}{12N} + \sum_{i=1}^{N} [F_e(x) - F_t(x)]^2 \tag{15}$$

Furthermore, L–moment ratio diagrams were applied for the visual determination of the best fitting distribution. This method is often used for the selection of the most appropriate probability distribution (Santos *et al.* 2011). The selection of the best-fitting distribution was made by comparing the closeness of the sample values L–Cs and L–Ck to the theoretical line of individual distributions in case of the three-parameter distributions, or sample means to the theoretical points in case of two-parameter distributions (Malekinzenhad *et al.* 2011).

Trend and seasonality analysis

The Mann-Kendall (MK) test is a rank-based, non-parametric test that is usually used for the detection of trends in a hydrological and climatological time series (Bezak *et al.* 2016; Gavrilov *et al.* 2018). The basis of this test is Kendall statistics (Kendall 1975). In this test, the null hypothesis (H_0) is that there is no trend in the series while the alternative hypothesis (H_A) is that there is a trend (either positive or negative) in the tested series. In this study, a significance level of 0.05 was applied. The MK trend test was applied to two sets of discharge data, mean annual discharges (Q_{avg}) and maximum annual discharges (Q_{max}) as well as on precipitation and temperature data.

Hydrological and meteorological seasons were defined as suggested by Milošević *et al.* (2016); namely, winter is defined as December-January-February, spring as March-April-May, summer as June-July-August and autumn as September-October-November. Winter discharges and precipitation are experienced in January-February of the calendar year and in December of the preceding year. Data for other seasons were obtained from the specified months in the calendar year.

RESULTS AND DISCUSSION

Flood frequency analysis

AMS based on the maximum discharge (Q_{max}) series were used for the flood frequency analysis. For each 30 year data set, test statistics were calculated and box plots were created for each of the five distribution functions and all of the applied statistical tests (see Figure 2). The lower the value of the test statistics (x^2, K–S, and CvM), the better the fit between the data and the

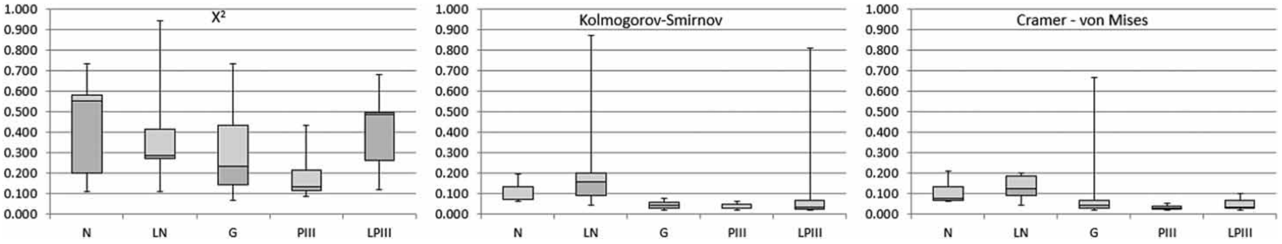

Figure 2 | The chi-squared (x^2), Kolmogorov-Smirnov and Cramer-von Mises test results for the five distribution functions.

tested distribution function. Figure 2 shows there is a large dispersion among the test statistic values for the N, G and LN distributions, which indicate that these distributions have a good fit for some samples, but not for the others. The PIII and LPIII distributions demonstrated a good fit to the data and consistent test statistics for all of the applied tests.

As suggested by Hosking (1990) the L–moments ratio diagram was also applied for visual determination of the best fitting distribution (see Figure 3). The PIII, LPIII and LN distributions fitted the data fairly well. On the other hand, the worst fit to the data was obtained using the G distribution. It is noticeable that there is a variation of L–Ck and L–Cs values in different periods; however, most data points show a tendency to group around the PIII distribution, especially data with lower values of L–Ck which were near both PIII and LN distributions. In such cases, the mean value of L–Ck can provide a good indication of the best-fitting distribution (Peel *et al.* 2001). In this study, the mean value of L–Ck fits well to the PIII distribution. These results are in good agreement with the results presented by Morlot *et al.* (2019), where the same PIII distribution was selected as the best-fitting distribution for the Sremska Mitrovica station, as well as for the Orljava-Pleternica station (in Croatia) located upstream of the Sremska Mitrovica station. Morlot *et al.* (2019) highlited that for the downstream reach of the Sava River the PIII distribution is the best-fitting distribution, while in the upstream reach of the Sava River the GEV and GL distributions are recommended. The same study demonstrated that the PIII distribution was the best fit for the Bogojevo gauging station (in Serbia) located on the Danube River just north of the Sremska Mitrovica gauging station. Additionally, Leščešen & Dolinaj (2019) concluded that the PIII distribution is the best-fitting distribution for all stations located on the largest tributary of the Danube River, namely, the Tisza River.

The design discharges for return periods of 10 years to 500 years for all of the seven 30–year data sets and the entire 90–year dat set were calculated. The results of the flood frequency analysis of each 30-year period as well as for the entire period of data using PIII distribution are presented in Figure 4. The results of the first two 30–year periods (1928–1957 and 1938–1967) are among the lowest three of all considered periods. Comparing to the entire period (1928–2017), the design discharges with the return period of 10 years for these two periods are lower by 11.1 and 9%, respectively. On the other hand, the highest design values were exhibited for the periods 1958–1987 and 1968–1997. Comparing to the entire period (1928–2017), the design discharges with the return period of 10 years for these two periods are higher by 17 and 8%, respectively. The difference in discharge values between the highest (1958–1987) and the second-highest period (1968–1997) for the 10-year return period is 5.6% (520 m^3/s). The difference between the highest and the lowest design discharge values with the return period of 100 years is 27.4% or approximately 2,947 m^3/s.

These results demonstrate that there is evidence of changes in the influence of climate change on designed values in the last half of the measured period 20th century, which could be the consequence of the influence of the climate variability. The only

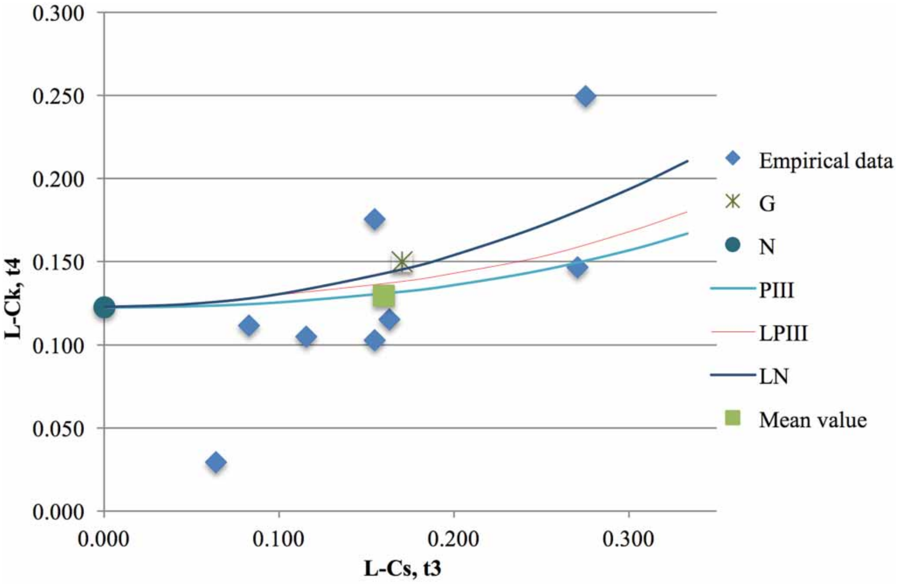

Figure 3 | L-moments ratio diagram for the seven 30–year data series.

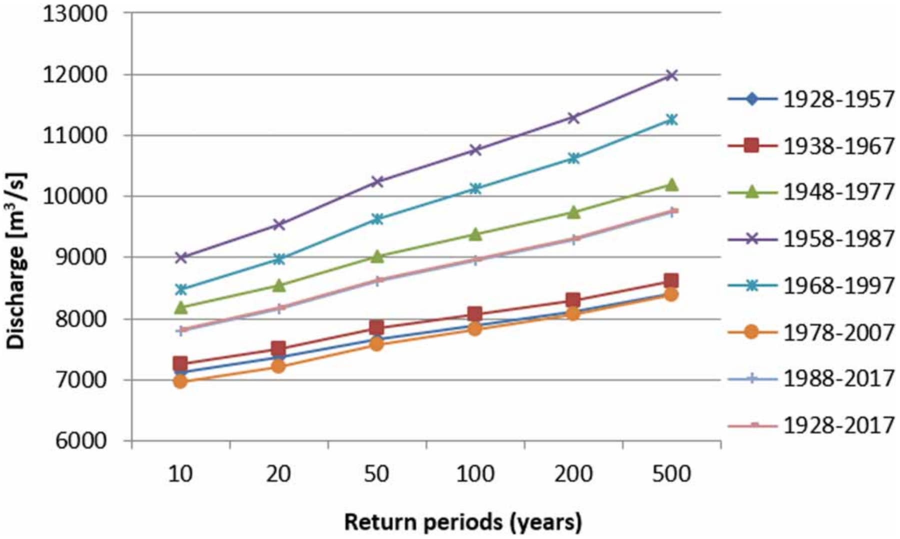

Figure 4 | Flood frequency analyses for all data sets based on the Pearson III (PIII) distribution.

exception is the period 1978–2007, which demonstrates the lowest design values among all considered periods. This data set has a skewness value of approximately zero (Table 2).

Statistical trend analysis

The trends in discharge for the Sava River at the Sremska Mitrovica gauging station were analysed using the Mann–Kendall trend test. These results suggests that the H_0 cannot be rejected at the significance level of 0.05 ($p = 0.159$), which means that there is no statistically significant trend in the mean monthly discharge data at the Sremska Mitrovica gauging station. The risk of rejecting the $H_{0,}$ while it is true is 16%. Similar results were reported by Kovačević-Majkić & Urošev (2014), who highlighted that there are no statistically significant decrease of annual discharges in the basins of the Danube, Sava and Tisza Rivers. Pandžić *et al.* (2009) mostly attributed a negative trend to global warming and low-frequency oceanic processes, which resulted in decreasing precipitation and increasing evaporation in the region (Blöschl *et al.* 2019).

The negative trend is illustrated also by the 5-year moving average of the mean monthly discharge series (see Figure 5). The moving average values show that the variation between wet and dry periods decreased over recent decades, especially in the last 20 years. Furthermore, the variation between wet and dry periods was significantly larger at the beginning of the investigated period. The difference between mean discharge values at the beginning and the end of the observed period is approximately 117 m^3/s. Mann–Kendall trend analysis of the 5-year moving average of the mean monthly discharge series shows that the H_0 should be rejected ($p = 0.0009$) at the significance level of 0.05, and the H_a should be accepted, suggesting a statistically significant trend in the 5-year moving average of the mean monthly discharge data at the Sremska Mitrovica gauging station. The risk of rejecting the H_0 while it is true is 0.09%. In the case of the AMS, the Mann–Kendall test statistic shows that there is no statistically significant trend ($p = 0.229$).

The inconsistency of the Mann–Kendall test results and detected changes in the design discharge values can be recognized. The same findings were reported also by other researchers (Bezak *et al.* 2014; Šraj *et al.* 2016a). Bezak *et al.* (2014) demonstrated that Mann–Kendall test results depend also on the chosen method of the sample definition; however, the inconsistency of the results in our study is demonstrated also for the same sample definition. Trends in annual and seasonal precipitation and temperatures provide a general overview of the temporal changes in precipitation and temperatures at the station. A positive trend ($p = 0.0001$) in average annual temperature can be observed, while precipitation shows a decreasing non-significant ($p = 0.458$) trend. The risks of rejecting the H_0 while it is true are 0.01% and 45.86%, respectively. The results clearly demonstrate a general tendency for a decrease in precipitation over the i90 year period. Furthermore, Gajić-Čapka (1993) reported that eastern parts of mainland Croatia have experienced a downward trend in precipitation over the last four decades. These findings are consistent with the finding of Blöschl *et al.* (2019), who reported that decreasing discharges in the Balkan region are mostly the consequence of decreasing precipitation and increasing evaporation (due to higher temperature). Similar temperature trends were reported also by Dimikić (2018) for the north-west parts of Serbia, where a clear

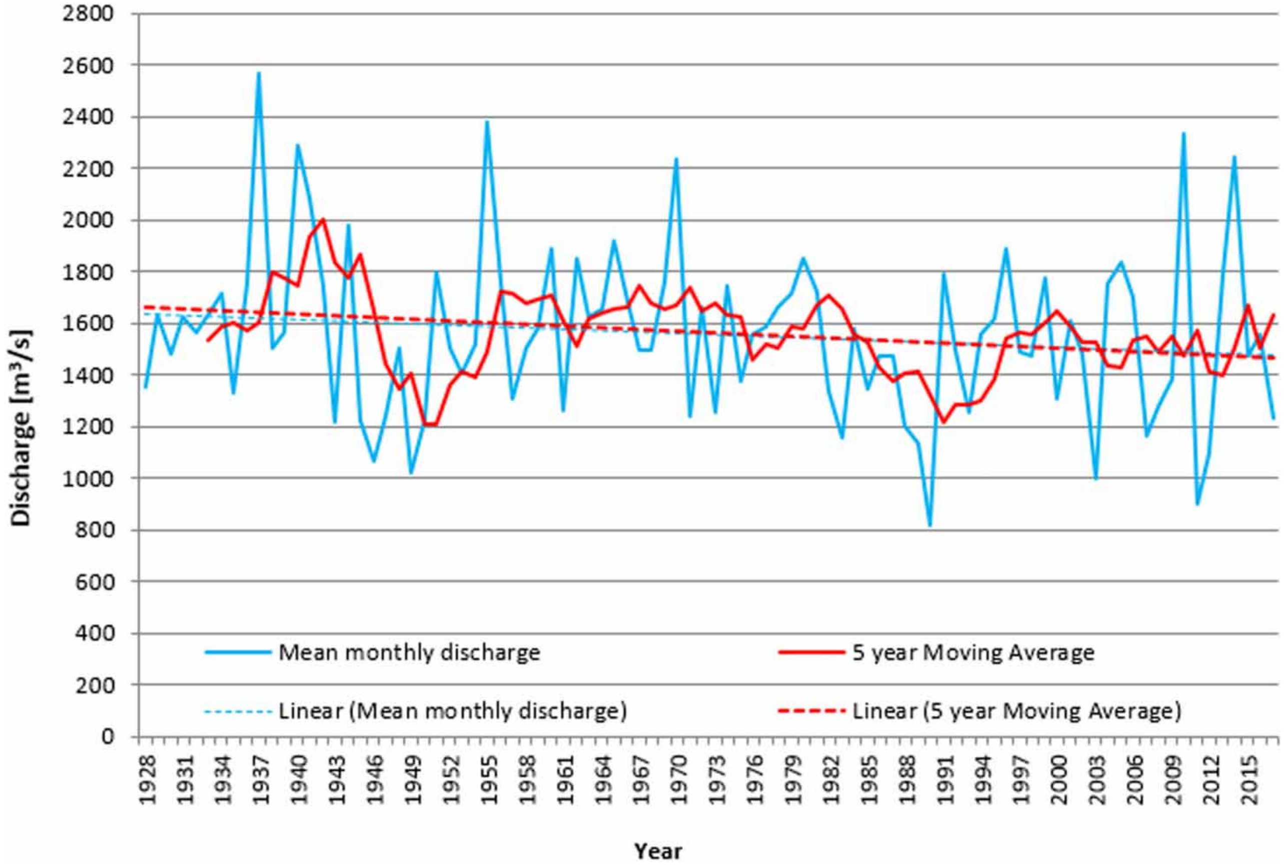

Figure 5 | The mean monthly discharge values with the linear trend line indicating the negative trend and the 5–year moving average for Sremska Mitrovica station for the 1928–2017 period.

positive trend is observed. Milovanović (2015) also presented results that indicate a clear increase in temperatures over Serbia during 1949–2008 period.

Seasonality

The discharge at the Sremska Mitrovica gauging station on the Sava River decreased during the summer, autumn and spring months, while a weak positive trend can be observed during winter months (see Figure 6). The high spring discharges usually result from the combination of precipitation and snowmelt in the mountain range of Dinaridic upstream of the Sremska Mitrovica gauging station.

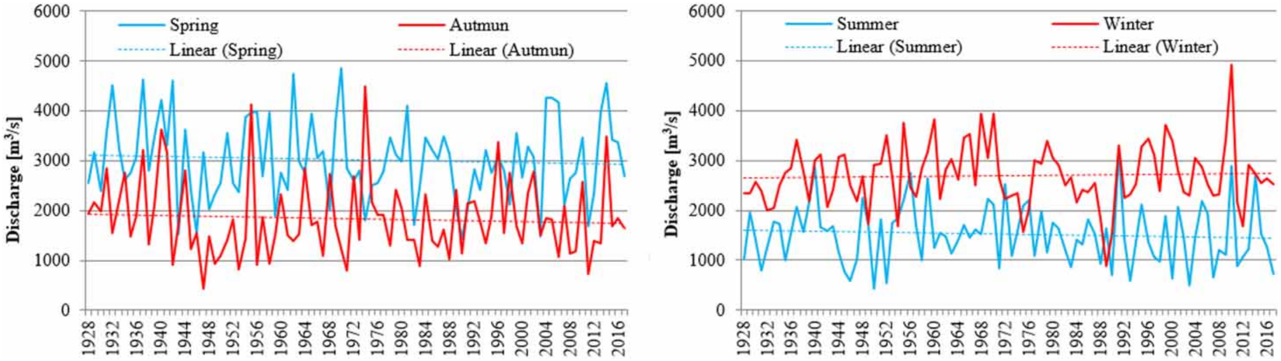

Figure 6 | Seasonal maximum discharge series at the Sremska Mitrovica gauging station (the Sava River) for spring, autumn, summer, and winter, respectively.

The Mann–Kendall test was performed on the four series of seasonal maxima. A weak negative trend was detected for three seasons (spring, summer, and autumn), but the trend was not statistically significant for any season. These results are confirmed by the study conducted by Stojković *et al.* (2014), where seasonal discharge trends for the 1926–2008 period were analyzed. Changes in seasonality could be as a result of the climate changes upsteam of the Sava River, primarily in Slovenia and Croatia (Brilly *et al.* 2007; Ulaga *et al.* 2008; Čanjevac & Orešoć 2018). The decreased discharge in spring and summer can be viewed as a consequence of a reduced annual precipitation (see Figure 7) in the Sava River basin. The decrease in discharge during the summer months can be a result of atmospheric pressure changes, a decreasing precipitation and rising rates of evapotranspiration (Šegota & Filipčić 2007). The same trends were detected for the Sava River in Slovenia by Frantar (2003) and in Croatia by Čanjevac & Orešoć (2018).

The seasonal precipitation and temperature at the Sremska Mitrovica meteorological station are presented also in Figures 7 and 8. During winter, spring, and summer a non-significant negative trend in precipitation was observed (winter $p = 0.116$; spring $p = 0.962$; summer $p = 0.198$), while for autumn a statistically significant increasing trend in precipitation was observed ($p = 0.047$). These decreasing trends for winter, spring and summer precipitation also prevail in eastern Croatia. Only during autumn is there a statistically significant increase in precipitation found in these parts of Croatia (Gajić-Čapka *et al.* 2015). Similar results with a statistically non-significant decrease of precipitation during winter, spring, and summer in Slovenia were presented by Milošević *et al.* (2016). The same researchers reported a precipitation increase for autumn, but it was statistically non-significant.

Seasonal temperatures at the Sremska Mitrovica meteorological station showed a positive trend in all seasons during the period (1949–2017), but only during the warmer period of the year (spring and summer), was the increase in temperature statistically significant at the level $\alpha = 5\%$ ($p = 0.0001$).

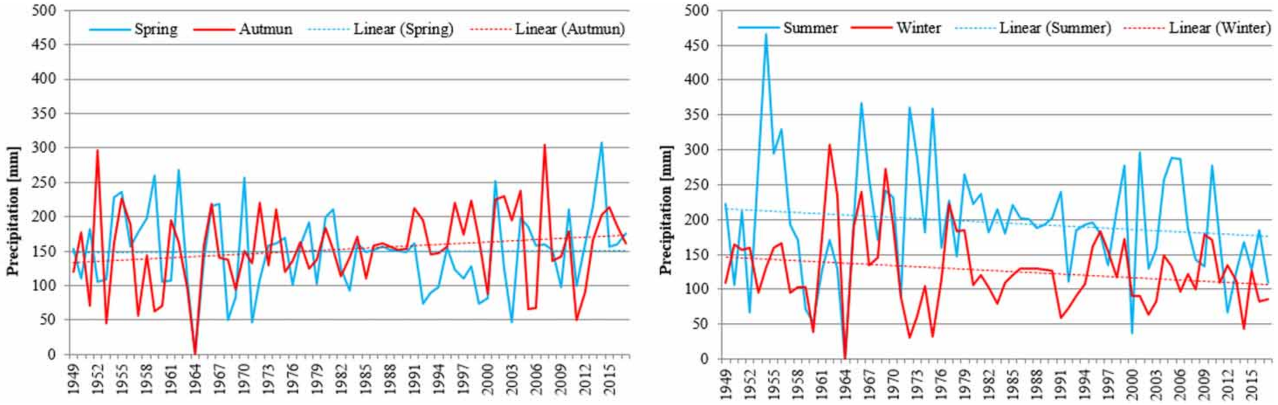

Figure 7 | Seasonal precipitation for spring, autumn, summer and winter at Sremska Mitrovica meteorological station.

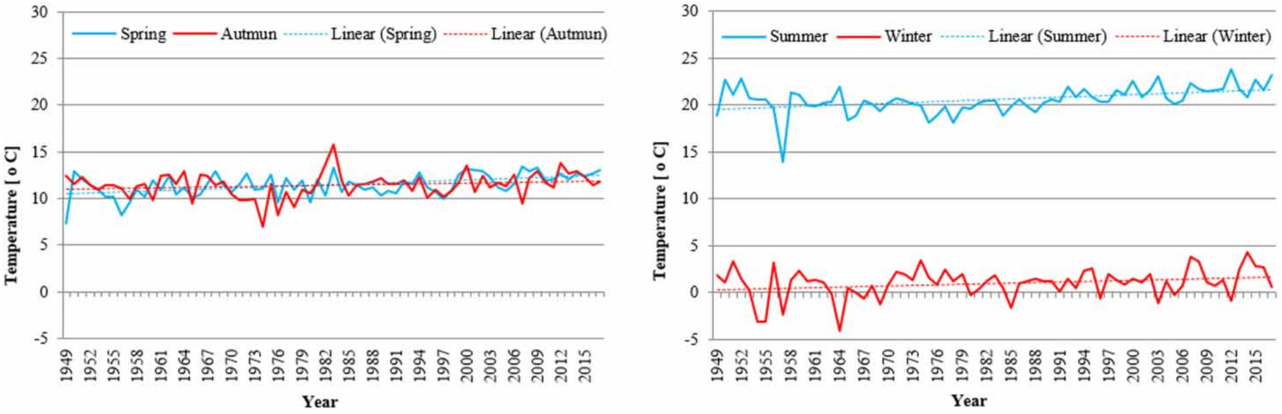

Figure 8 | Seasonal temperatures in spring, autumn, summer and winter at the Sremska Mitrovica meteorological station.

CONCLUSIONS

In this study, 90 years (1928–2017) of discharge data recorded at the Sremska Mitrovica gauging station on the Sava River were analyzed. Flood frequency analysis was performed based on annual maxima series. It was found that the three-parameter distributions (Pearson III, Log-Pearson III) are more suitable for modelling annual maxima at the Sremska Mitrovica station on the Sava River than distribution functions with only two parameters (Normal, Log-Normal and Gumbel). An investigation of the statistical trends and seasonality of discharges, precipitation and temperature were also conducted. The entire data set was divided into seven parts, each containing 30 years of annual maximum discharge values. The period 1958–1987 provided the highest estimated discharge values of the seven periods. Differences as high as 26.7% are obtained between the 100-year return period discharge for the period from 1958 to 1987 (highest) and the period from 1928 to 1957 (lowest).

Trend analysis results demonstrate fluctuations in both mean and maximum discharges over this period. However, the Mann–Kendall test statistic indicated that there is no statistically significant trend identified in annual maximum discharges or average annual discharges. A positive increasing trend was observed in average annual temperature over the period 1928–2017, while annual precipitation shows a decreasing trend that is non-significant.

The seasonality analysis found a statistically non-significant weak negative trend in discharge in spring, summer and autumn and a statistically non-significant weak positive trend in winter discharge. During winter, spring, and summer a non-significant negative trend in precipitation was observed, while autumn precipitation has experienced a statistically significant increasing trend. Temperatures show a positive trend in all seasons, but only temperatures during the warm period show a statistically significant increase over the period 1928–2017. The results demonstrate that decreasing discharges of the Sava River at the Sremska Mitrovica gauging station are mainly the consequence of decreasing precipitation and increasing temperature (increasing evaporation), which is consistent with the results of other studies of the region. Any new research, especially one based on measured data, is important for the advances in hydrology and the future. Moreover, none of the previous studies addressed all considered aspects in such detail. After all, such studies in this region are still very rare. This study is the first study that considers such a long set of data in Serbia. It provides a basis to better understand the Sava river discharge variability and can contribute to prevention of future floods such as were seen in May of 2014. Future studies should focus on the main tributaries of Sava River, Drina and Kolubara, for the purpose of further contributing to flood prevention in this part of Serbia.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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