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# Observed climate changes in the Toplica river valley - Trend analysis of temperature, precipitation and river discharge

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**Abstract**— Changes in air temperature, precipitation, and the Toplica river discharge were investigated. Annual and seasonal climatic data were collected at weather stations Kursumlija and Prokuplje, and discharge data on hydrological gauges Pepeljevac and Doljevac. The data covered a period of 62 years (1957–2018). Mann-Kendall and Pettitt's tests have been applied for the periods 1957–2018, 1957–1987, 1988–2018, and 1975–1994, which we find as very important period when atmospheric circulation was altered. Mean annual temperature and precipitation were greater in the second half-period, while the discharge was smaller, even all the signals had growth trend. Mean seasonal temperature increased for all seasons, as well as precipitation, except for summer (JJA). The discharge is lower in the second half-period for almost all seasons, with signs of recovery for all seasons except summer.

*Key-words*: climate change, the Toplica river, temperature, precipitation, discharge, linear trend, change point

## *1. Introduction*

Climate change is accepted to be one of the prevalent difficulties for humankind in this century. Large number of various fields are impacted by climate change. Rising temperatures increase extinction risk for numerous animal and plant species, droughts lead to decline of agriculture production and to problem with drinking water, severe floods cause destruction and loss of lives.

The idea for this research came during the study of the village of Plocnik, located in the middle of the Toplica basin (*Martić Bursać,* 2017). Local people said that the level of the Toplica river was significantly higher during their youth (mostly early 70s of the 20th century), and the winters were colder and longer, with more snow. Guided by these stories, we wanted to determine what has happened with the climate and the river flow over the time. According to latest advances in climate science, we assumed that global climate change, especially global warming, is the primary cause of these changes. We have examined changes in temperature, precipitation in the Toplica river valley and discharge of the Toplica river in the period from 1957 to 2018.

The climate system is very complex, and so is the climate. Complex systems can respond unexpectedly and abruptly to changes within the system, and these changes can be highly nonlinear. Nonlinear interactions among atmosphere, hydrosphere, and biosphere cause climate variables to exhibit highly nonlinear characteristics. The complexity of rainfall and temperature dynamics has been widely used to indicate the extent of the complexity of climate systems (*Kyoung et al.,* 2011). A variety of sophisticated techniques have been developed in order to quantify system complexity (*Di et al.,* 2018). The major factor of climate change is the increasing temperature. Mean air surface temperature increased globally by 0.85 °C over the 1880–2012 period (*IPCC*, 2013). Another important factor is the variability of precipitation. One of the reasons for the change in hydrological cycle is the increased energy for evapotranspiration, whereas increased temperature changes water holding capacity of the atmosphere (*Trenberth*, 2011). Exact impacts of climate change on water cycle are hard to predict. There is a general consensus among scientists that it will result in more frequent and more severe hydrologic extremes (*IPCC*, 2013). Precipitation is the primary input of water in a river basin, and while it plays dominant role in year-to-year streamflow variability, the effect of temperature on total annual discharge may become more important during multiyear droughts. In both wet and dry years, when the flow is substantially different than expected, given precipitation, air temperature, and soil moisture can modulate the dominant precipitation influence on streamflow (*Woodhouse et al.,* 2016). Different initial soil conditions are primary cause of runoff nonlinear response to rainfall. In general, the wetter the catchment prior to an input of rainfall is, the greater the volume of runoff that will be generated, and faster response will be, and vice versa. This general role drops after high intensity, low frequency storms. In that case, hydrological response is independent of the initial soil water content (*Castillo et al.,* 2003). In semiarid areas, as the Toplica valley, medium and low intensity precipitation is most frequent, and the antecedent soil water content is an important factor controlling runoff. Various infiltration models are specifically derived to eliminate the errors caused by the complex initial soil conditions in rainfall-runoff models (*Wang et al.,* 2017). Temperature can modulate the streamflow in various ways. Increase of temperature during winter changes the rate of accumulation, duration, density, and melting of snow cover. During the warmer part of the year, increased temperature changes soil conditions through evaporation, and reduces the amount of precipitation available for streamflow and groundwater recharge. It is not a one way relation, soil moisture-temperature coupling could be strong, especially during heatwaves (*Castillo et al.,* 2003).

Numerous studies of climate change in Serbia were conducted, focused on mean temperature change (*Vukovic et al.,* 2018; *JCERNI*, 2014; *Gavrilov et al.,* 2015), extreme temperature and precipitation indices (*Ruml et al.,* 2017; *Djordjevic S.,* 2008; *Unkasevic* and *Tosic*, 2013), increase in frequency and intensity of heat waves (*Unkaševic* and *Tošic,* 2015), accelerated temperature increase (*Unkasevic* and *Tosic*, 2013), prediction of intensification and acceleration of floods, forest fires, disturbance in agriculture, and health of ecosystem (*Vukovic, et al.,* 2018; *JCERNI*, 2017).

Projections of regional climate models predict that by the end of this century, the annual average temperatures will increase from 2.4 °C to 2.8 °C according to an optimistic scenario (A1B1), respectively from 3.4 °C to 3.8 °C according to a pessimistic scenario (A2). Situation with rainfall is more complex, under the A1B1, a reduction of precipitation is expected throughout Serbia, while according to the A2 scenario, the precipitation will increase in Vojvodina, while it will remain the same or decrease in the other parts of Serbia, with an increased number of floods and droughts (*Sekulić et al.*, 2012)

The impact of climate change on river discharge has been observed by many researchers: globally - change in stream flow extremes (*Asadieh* and *Krakauer*, 2017); in Europe - frequency of river floods (*Alfieri et al.*, 2015) modifying river flow regimes (*Schneider et al.*, 2013); in the region - impact on rivers discharge in Eastern Romania (*Croitoru* and *Minea*, 2015), impact on the Vrbas river discharge (Bosnia and Herzegovina) (*Gnjato et al.*, 2019), etc.

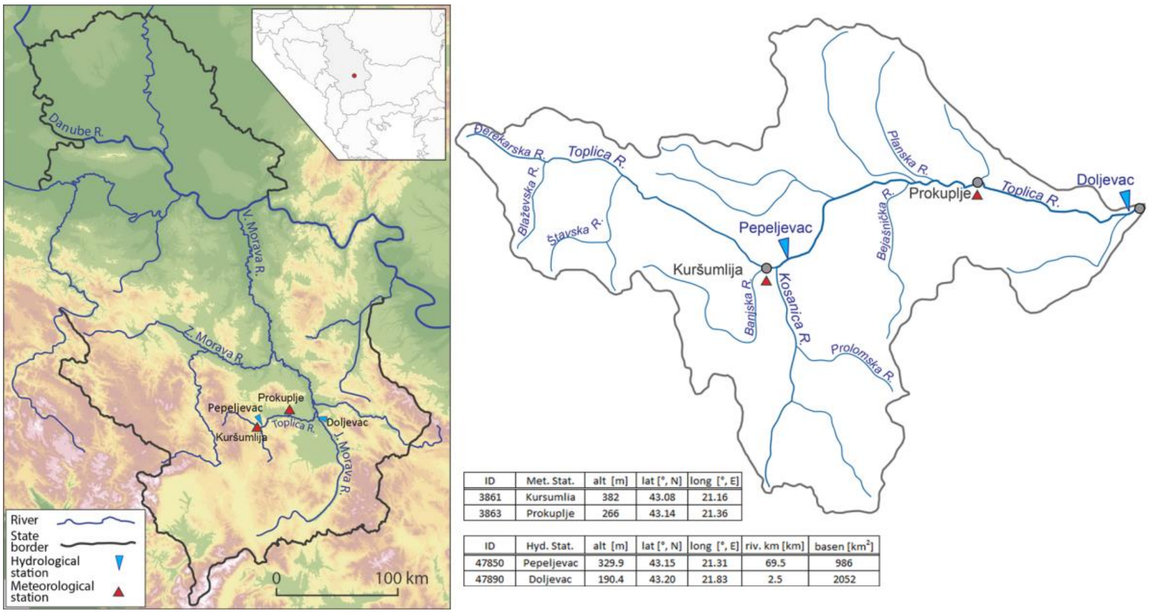
## *2. Data and methodology*

### *2.1. Study Area*

The basin of the Toplica river is located in southern Serbia, in the central part of the Balkan Peninsula (*Fig. 1*). Relief of the basin was formed in Oligo-Miocene, and is one of the oldest landmasses of the Balkan Peninsula. During the Neogene, the basin was filled with water of the Pannonian Sea, reaching 760 meters above sea level. After withdrawal of the lake, the Toplica river with the network of its tributaries was formed in a shallow and wide valley. The valley is elongated in the direction east-west, with the longer axis of about 30 km and shorter axis of about 10 km. The relief is hilly and gradually decreases from north to south (*Martić Bursać,* 2017; *Martić Bursać et al*., 2016b). The height of the basin is 633 m above sea level on average, the maximum height being 2016 m, and the minimum 187 m.

Climate of the Toplica basin is highly determined by its geographical position and relief. To the east, the basin is open to the South Morava river valley, where the continental air mass freely penetrates. From the north it is enclosed by the ranges of the mountains Veliki and Mali Jastrebac, from the south by the mountains of Radan, Sokolovica, Vidojevica, and Pasjaca, while the west is fenced by the massif of the mountain of Kopaonik. With their height and direction, these mountains represent barriers for the entry of somewhat milder air from the southwest, as well as colder continental air from the north and northeast (*Martić Bursać et al*., 2016a; *Rudić*, 1978). The basin of the Toplica has a moderate continental climate with a strong continental character. In addition to the very dominant continental influences, there are also influences of the Aegean and the steppe climate, which occur locally (*Ducić* and *Radovanović,* 2005; *Martic Bursac* and *Stricevic,* 2018). According to the Köppen climate classification, most of the basin belongs to group C, with an exception of the mountainous area, which belongs to group D (*Dukić,* 1999).

The river Toplica was formed by merging the rivers Djerekarusa and Lukovska near the village of Mercez, on the eastern slopes of the mountain of Kopaonik. The source of the river Djerekusa is a main source (1650 m above sea), with the total length of 130 km and the catchment area of 2180 km². The Toplica river is the largest left tributary of the South Morava, considering both the surface of the basin and water quantity. In the total area of the South Morava basin, the Toplica basin share is 14.9%, whereas in the total discharge its share is 10.9% (*Gavrilović,* 2011; *Martic Bursac et al*., 2016a).




| ID | Met. Stat. | alt [m] | lat [°, N] | long [°, E] |
|---|---|---|---|---|
| 3861 | Kursumlia | 382 | 43.08 | 21.16 |
| 3863 | Prokuplje | 266 | 43.14 | 21.36 |

| ID | Hyd. Stat. | alt [m] | lat [°, N] | long [°, E] | riv. km [km] | basen [$km^2$] |
|---|---|---|---|---|---|---|
| 47850 | Pepeljevac | 329.9 | 43.15 | 21.31 | 69.5 | 986 |
| 47890 | Doljevac | 190.4 | 43.20 | 21.83 | 2.5 | 2052 |

*Fig. 1.* Geographical position of Toplica Valley.

The Toplica basin is symmetrical, right and left tributaries are approximately equally long. The Toplica river has a very unstable river regime. The highest flow rate is in March and April, when the discharge is more than doubled due to the melting snow from the surrounding mountains, while the lowest flow rate is in August and September, when the discharge often drops below 1 $m^3$/s, and some of the tributaries dry up (*Rudić,* 1978).

In order to regulate the river regime and provide additional water supply to the towns of Kursumlija, Prokuplje, and Nis, an accumulation was built on the Toplica river. Dam construction in the village of Selova lasted from 1986 to 2006. Due to large erosion in the upper course, it was necessary to apply anti-erosion measures, which are still in progress. At the moment, the accumulation is not functional and does not affect the flow of the river (*Kostadinov*, 2008; *Martić Bursać*, 2016a).

## *2.2. Data*

Seasonal and annual climate data were examined, temperatures and precipitation in the towns of Kursumlija and Prokuplje, as well as discharge data from the two gauges on the Toplica river, in the villages of Pepeljevac and Doljevac. Monthly and annual temperature and discharge means, as well as monthly and annual sums of precipitation for all the stations in the period of 62 years (1957–2018), were provided by the Republic Hydrometeorological Service of Serbia (RHMZ).

Seasons are defined as three-month temperature and discharge averages, and three month total sums for precipitation. Winter season (DJF) corresponds to December of the previous year, and January-February of the calendar year, while all the other seasons, spring (MAM), summer (JJA), autumn (SON) correspond to the calendar year.

The time series of the observed signals is 62 years long, between 1957 and 2018, and that period will be referred to as "the entire period". We divided it into two equal 31-year-long half-periods, in order to find out if there are changes in signals, if the series is homogenous, if it is a trend, and what the possible cause of the changes is. The term "the first period" will hereinafter be used for the period between 1957 and 1987, "the second period" will be used for the period between 1988 and 2018. We also define the third, 20-year-long period between 1975 and 1994, where we found some important changes in the observed signals.

### *2.3. Method used*

#### *2.3.1. Pettitt's homogeneity test*

We used Pettitt's test for homogeneity of series and change points (*Pettitt*, 1979). The change point detection is an important aspect to assess the period from which significant change occurred in a time series. The Pettitt's test for change detection is a nonparametric test useful for evaluating the occurrence of abrupt changes in climatic records. According to Pettitt's test, if there is a change point in a series of $n$ observed data, then the distribution function of the first $t$ samples $F_1$ would be different from the distribution function of the second part of the series $F_2$. The null hypothesis $H_0$ implies that the data are homogeneous throughout the period of observation, and the alternative hypothesis $H_1$ implies the presence of a non-accidental component among data causing a shift of the location parameter at a particular moment. The test statistic $U_{t,n}$, $K_t$, and the associated confidence level $\rho$ for the sample length $n$ for this test are given in the following equations:

$$U_{t,n} = \sum_{i=1}^{t} \sum_{j=i+1}^{n} sgn(x_i - x_j), \tag{1}$$

$$; \quad K_t = \max_{1 \le t < n} |U_{t,n}|, \tag{2}$$

$$\rho = e^{-K/(n^2+n^3)}. \tag{3}$$

When $\rho$ is smaller than the specified confidence level, the null hypothesis is rejected. The approximate significance probability $p$ for a change-point is defined as $p = 1 - \rho$.

Quality control of datasets was made by RHMZ, and we assumed that any detected step changes are due to climate variability.

#### *2.3.2. Mann – Kendall trend test*

The Mann-Kendall (MK) trend test is a nonparametric approach, and it was used in this study to detect trends in temperature, precipitation, and discharge. The magnitudes of the trend in a time series have been estimated by the Sen's estimator method (*Kendall*, 1948). The test analyzes the difference in signs between earlier and later data points. The idea is that if a trend is present, the sign values will tend to either increase or decrease constantly. The hypothesis $H_0$- is that there is no trend in the series; alternatively, in hypothesis $H_1$, monotonic trend is present. First we calculated sign difference *S*, after that variance *VAR(S)*, and in the end MK test statistic $Z_{MK}$.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_i - x_j) \tag{4}$$

where

$$sgn(x) = \begin{cases} 1 & if\ x > x_i \\ 0 & if\ x = x_i \\ -1 & if\ x < x_i \end{cases} . \tag{5}$$

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p(t_p - 1)(2t_p + 5)\right] . \tag{6}$$

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ \ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ \ S < 0 \end{cases} , \tag{7}$$

where $x_i$ and $x_j$ are sequential values in the series, *n* is the sample size, *g* is the number of tied groups, and $t_p$ is the number of observations in the *p*th group.

A positive (negative) value of $Z_{MK}$ indicates that the data tend to increase (decrease) with time. If $\alpha$ is the Type I error rate, where $0 < \alpha < 0.5$, and $Z_{1-\alpha}$ is the 100(1-α)th percentile of the standard normal distribution (provided in statistics books or statistical software packages), then $H_0$ will be rejected, and replaced with the alternative $H_1$ if $Z_{MK} \geq Z_{1-\alpha}$ for the upward, or $Z_{MK} \leq -Z_{1-\alpha}$ for the downward trend.

### *2.3.3. Polynomial approximation*

We have used higher order polynomial functions for the least square approximation of signals in order to gain a better insight of their tendencies. Using MatLab Curve Fitting tool, all approximate polynomials of degree 2 to 10 have been examined. We have found that all the polynomials of degree 6 and greater have the same shape of the curve in general, so we have chosen polynomial to be of minimal 6th order to avoid polynomial wiggle as much as possible. Due to this effect, the shape of the curve at the ends of the time series should be taken with caution (*Cheney* and *Light.*, 2000). These polynomials are conditioned very badly, and cannot be used for quantitative calculations, but they can give us a good qualitative insight of changing signal in time. They are given as purple lines in *Figs. 2, 3,* and *4*.

## *3. Results and discussion*

### *3.1. Temperature*

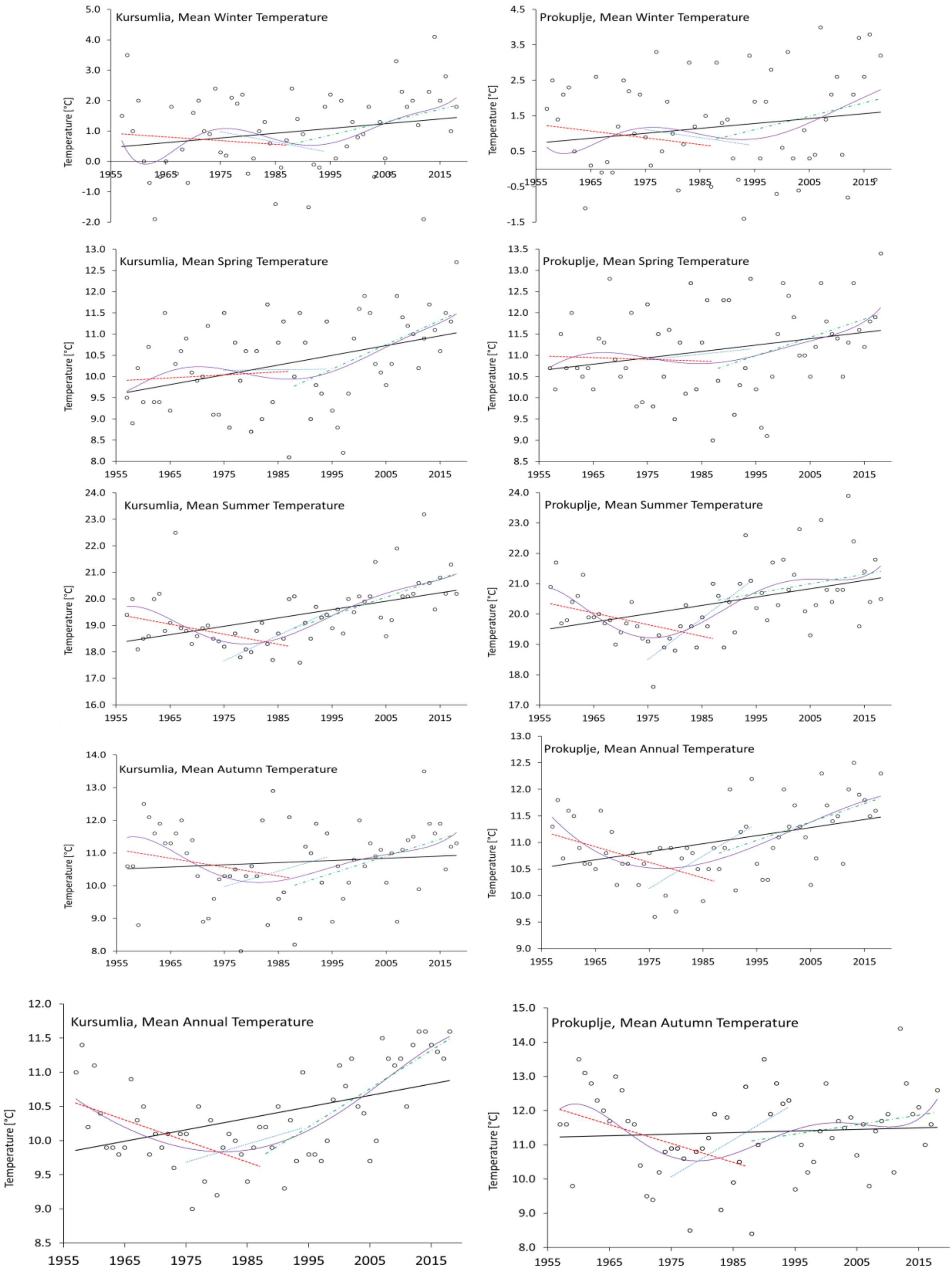
Average temperature for the period 1957–2018 is 10.4 °C and 11 °C in Kursumlija and Prokuplje (*Table 1*), respectively. Average temperatures increased by 0.5 °C in Kursumlija and 0.6 °C in Prokuplje in the second period. In 1998, a change point in mean annual temperatures was detected at both stations during the entire period. In the first period, the change point was found in Prokuplje in 1968, and in the second period, it was found at both stations in 2006. Linear trend of average annual temperatures increased in the entire period at both stations; in Kursumlija increasing is statistically significant. At both stations, there is a statistically significant decreasing temperature trend in the first period, and increasing in the second period. Besides the opposite trend in the first and the second half of the period, our attention is drawn to the fact that there is a significant discontinuity of mean temperature, precipitation, and discharge in the Toplica river between the periods. This discontinuity shows us that there is probably a period in between these two half-periods when something happened with climate signals. For this reason, the curves of polynomial approximations were used, and we clearly identified period 1975–1994 as a period where some dramatic changes happened. The curves of polynomial approximations (*Fig. 1*) at the beginning show temperature decrease at both stations, where the minimum is in the early eighties in Kursumlija, and a little earlier, in the late seventies, in Prokuplje. After that, the temperature increases, and the increase is more emphasized in Kursumlija than in Prokuplje. The trend of mean annual temperatures in the period 1975–1994 at both stations is increasing, but not statistically significant. In this case, nothing dramatic happened with temperature, but that is not the case with some other parameters.

The mean winter (DJF) temperature in Kuršumlija and Prokuplje increased by 0.5 °C in the second period (*Table 1*). The Pettitt test detects data inhomogeneity in Kuršumlija in the second period with a change point in 2006, while the significance probability $p$ in Prokuplje is above the threshold. The trend of DJF temperature (*Fig. 2*) is decreasing in the first period and in the period 1975–1994, and increasing throughout the second, but in all cases, it is statistically insignificant.

*Table 1.* Parameters of seasonal and annual temperatures in Kursumlija and Prokuplje

| | Period | Kursumlija | | | | | | Prokuplje | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean [°C]** | **σ** | **p** | **C.p.** | **m1/m2 [°C]** | **L.t. [°C/dec]** | **Mean [°C]** | **σ** | **p** | **C.p.** | **m1/m2 [°C]** | **L.t. [°C/dec]** |
| | 57-18 | 1.0 | 1.29 | 0.09 | 2006 | | 0.16 | 1.2 | 1.49 | 0.37 | 2006 | | 0.14 |
| **DJF** | 57-87 | 0.7 | 1.23 | 0.52 | 1960 | | -0.12 | 0.9 | 1.44 | 0.47 | 1961 | | -0.19 |
| **Winter** | 88-18 | 1.2 | 1.32 | 0.03 | 2006 | 0.8/1.9 | 0.43 | 1.4 | 1.53 | 0.25 | 2006 | | 0.38 |
| | 75-94 | | | | | | -0.34 | | | | | | -0.23 |
| | 57-18 | 10.3 | 1.04 | 0.00 | 1998 | 10/11.1 | 0.23 ** | 11.1 | 1.02 | 0.02 | 1998 | 10.9/11.7 | 0.15 ** |
| **MAM** | 57-87 | 10.0 | 0.95 | 0.95 | 1963 | | 0.07 | 10.9 | 0.94 | 0.93 | 1972 | | -0.04 |
| **Spring** | 88-18 | 10.6 | 1.05 | 0.01 | 1998 | 9.8/11.1 | 0.58 * | 11.3 | 1.07 | 0.08 | 1998 | | 0.43 * |
| | 75-94 | | | | | | 0.02 | | | | | | 0.14 |
| | 57-18 | 19.4 | 1.21 | 0.00 | 1991 | 18.8/20.1 | 0.32 *** | 20.4 | 1.15 | 0.00 | 1991 | 19.8/21.1 | 0.27 *** |
| **JJA** | 57-87 | 18.8 | 1.07 | 0.02 | 1972 | 19.2/18.3 | -0.38 * | 19.8 | 0.82 | 0.00 | 1968 | 20.3/19.4 | -0.38 * |
| **Summer** | 88-18 | 19.9 | 1.08 | 0.00 | 2006 | 19.4/20.7 | 0.69 *** | 20.9 | 1.16 | 0.55 | 1991 | | 0.32 *** |
| | 75-94 | | | | | | 0.96 * | | | | | | 1.36 * |
| | 57-18 | 10.7 | 1.15 | 0.25 | 1969 | | 0.07 | 11.4 | 1.22 | 0.16 | 1968 | | 0.05 |
| **SON** | 57-87 | 10.7 | 1.21 | 0.03 | 1968 | 11.3/10.2 | -0.27 | 11.2 | 1.25 | 0.00 | 1968 | 12.1/10.6 | -0.55 |
| **Autumn** | 88-18 | 10.8 | 1.1 | 0.08 | 2007 | | 0.52 * | 11.5 | 1.18 | 0.39 | 2011 | | 0.28 * |
| | 75-94 | | | | | | 0.47 * | | | | | | 1.08 * |
| | 57-18 | 10.4 | 0.68 | 0.00 | 1998 | 10.1/11 | 0.17 ** | 11.0 | 0.67 | 0.00 | 1998 | 10.8/11.5 | 0.15 |
| **Annual** | 57-87 | 10.1 | 0.53 | 0.63 | 1968 | | -0.31 * | 10.7 | 0.53 | 0.02 | 1968 | 11.1/10.5 | -0.3 * |
| | 88-18 | 10.6 | 0.7 | 0.00 | 2006 | 10.2/11.3 | 0.56 *** | 11.3 | 0.68 | 0.00 | 2006 | 11/11.8 | 0.35 *** |
| | 75-94 | | | | | | 0.26 | | | | | | 0.26 |

*Note:* Mean [°C] – mean temperature for period; σ – standard deviation; p – significance probability (Pettitt);C.p.– changing point (Pettitt) [year]; m1/m2 [°C] – mean value before and after change point, for p<α=0.05 (Pettitt); L.t.[°C/dec] – slope of linear trend (no star – no statistical significance,
* – α=0.05, ** – α=0.01, *** – α=0.001, Mann-Kendall)




*Note:* black dots – mean temperatures; lines – temperature trends for different periods: black (1957–2018); red (1957-1987); green (1988-2018); blue (1974-1995); purple –polinomial approximation

*Fig. 2.* Annual and seasonal temperature in Kursumlija and Prokuplje.

The mean spring (MAM) temperature is higher in the second period by 0.6 °C in Kuršumlija, and 0.4 °C in Prokuplje. A change point in the data was detected in 1998 in the entire and the second period at both stations, but in the second period the probability significance in Prokuplje was above the set value ($p = 0.05$), so the initial hypothesis of data homogeneity could not be discarded. The temperature trend (*Fig. 2*) in the MAM season generally increased at both stations. In the first period we do not detect any trend, while in the second period there is a significant increasing temperature trend at both stations.

The mean summer (JJA) temperature is 1.1 °C higher in the second than in the first period at both stations, which is the largest absolute increase in temperature compared to other seasons. In 1991, a change point was detected at both stations during the entire period. In the first period, change points were also detected at both stations, in Kursumlija in 1972, and in Prokuplje in 1968, while in the second period, change points were detected only in Kursumlija in 2006. A statistically significant trend of temperature exists in all the examined periods. In the first period, there is a negative trend of air temperature at both stations, while in the second period it is increasing. In the period 1975–1994, at both stations we recorded an extremely high temperature growth trend of 0.96 °C/dec in Kursumlija and 1.36 °C/dec in Prokuplje.

In the autumn season (SON), the smallest increase in temperature was recorded between the two periods, 0.1 °C in Kursumlija and 0.3 °C in Prokuplje. A change point was detected at both stations in the first period in 1968. A trend of statistically significant increase in air temperature exists at both stations in the second period, where we have almost twice as much growth in Kursumlija than in Prokuplje. There is a significant growth trend in the period 1975–94 at both stations, in Prokuplje it is extreme, 1.08 °C/dec, while in Kursumlija it is twice smaller, but still very large.

### *3.2. Precipitation*

Unlike in temperatures, where the situation is quite clear and we have a more or less pronounced increase in all cases, the situation with precipitation is more complicated. This situation is ultimately predicted by climate models (*Sekulić*, 2012).

Average precipitation for the entire period is 651.9 mm in Kursumlija and 563.8 mm in Prokuplje (*Table 2*). A change point in 1994 was detected in Prokuplje. The increase in the average precipitation in the second period is 2.5% in Kursumlija and 8.6% in Prokuplje.

The Mann-Kendal test reveals that the linear trend of total annual precipitation in the entire period is increasing and statistically significant at both stations, with a rate of 15.5 mm/dec in Kursumlija and 19.2 mm/dec in Prokuplje. In the first period, change point was not detected at the stations, and the precipitation trend has a different sign. In Kursumlija the trend is increasing, while in Prokuplje it is decreasing, in both cases without statistical significance. In the second period, a change point was detected at both stations in 2003, and in both cases there is an abrupt jump of mean value of over 100 mm. The linear trend of precipitation in the second period is positive and statistically significant at both stations. The situation in the period 1975–1994 is especially interesting, where at both stations precipitation trend is highly decreasing by about 90 mm/dec.

*Table 2.* Parameters of seasonal and annual precipitations in Kuršumlija and Prokuplje

| | Period | Kursumlia Mean [mm] | Cv | p | C.p. | m1/m2 | L.t. [mm/dec] | Prokuplje Mean [mm] | Cv | α | C.p. | m1/m2 | L.t. [mm/dec] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DJF Winter** | 57-18 | 143.8 | 0.36 | 0.38 | 1993 | | 3.11 | 124.9 | 0.39 | 0.02 | 1993 | 109/149 | 8.75 * |
| | 57-87 | 144.8 | 0.3 | 0.36 | 1977 | | 5.85 | 112.4 | 0.32 | 0.62 | 1976 | | 4.04 |
| | 88-18 | 142.9 | 0.42 | 0.15 | 1993 | | 22.83 | 137.3 | 0.42 | 0.30 | 2002 | | 21.24 |
| | 75-94 | | | | | | -8.96 | | | | | | -1.6 |
| **MAM Spring** | 57-18 | 175.4 | 0.3 | 0.09 | 2005 | | 4.92 | 152.7 | 0.36 | 0.02 | 2000 | 138/189 | 7.72 |
| | 57-87 | 169.6 | 0.27 | 0.13 | 1962 | | -15.15 | 141.9 | 0.31 | 0.38 | 1964 | | -13.88 |
| | 88-18 | 181.1 | 0.32 | 0.02 | 2005 | 156/215 | 32.36 * | 163.4 | 0.38 | 0.01 | 2004 | 134/199 | 36.57 ** |
| | 75-94 | | | | | | -12.18 | | | | | | -16.65 |
| **JJA Summer** | 57-18 | 169.1 | 0.46 | 0.25 | 1971 | | 3.68 | 149.7 | 0.44 | 0.00 | 1983 | | -2.9 |
| | 57-87 | 170.2 | 0.46 | 0.01 | 1971 | 133/205 | 25.65 | 159.3 | 0.41 | 0.35 | 1971 | | 7.79 |
| | 88-18 | 168.1 | 0.47 | 0.93 | 2013 | | 7.8 | 140.1 | 0.46 | 0.96 | 2010 | | 4.73 |
| | 75-94 | | | | | | -29.35 * | | | | | | -56.19 * |
| **SON Autumn** | 57-18 | 162.5 | 0.41 | 0.62 | 1995 | | 4.73 | 137.8 | 0.43 | 0.49 | 1991 | | 5.4 |
| | 57-87 | 156.6 | 0.44 | 0.37 | 1969 | | 4.01 | 126.8 | 0.41 | 0.91 | 1964 | | 5.3 |
| | 88-18 | 168.3 | | 0.62 | 1995 | | 11.27 | 148.8 | 0.43 | 0.93 | 2013 | | 6.45 |
| | 75-94 | | | | | | -36.24 * | | | | | | -14.61 |
| **Annual** | 57-18 | 651.9 | 0.19 | 0.07 | 2000 | | 15.54 * | 563.8 | 0.2 | 0.00 | 1994 | 528/621 | 19.18 * |
| | 57-87 | 643.8 | 0.16 | 0.12 | 1971 | | 19.72 | 540.6 | 0.16 | 0.63 | 1971 | | -5.47 |
| | 88-18 | 660.0 | 0.21 | 0.00 | 2003 | 598/726 | 73.31 ** | 587.0 | 0.23 | 0.00 | 2003 | 535/636 | 69.19 * |
| | 75-94 | | | | | | -91.55 * | | | | | | -89.49 * |

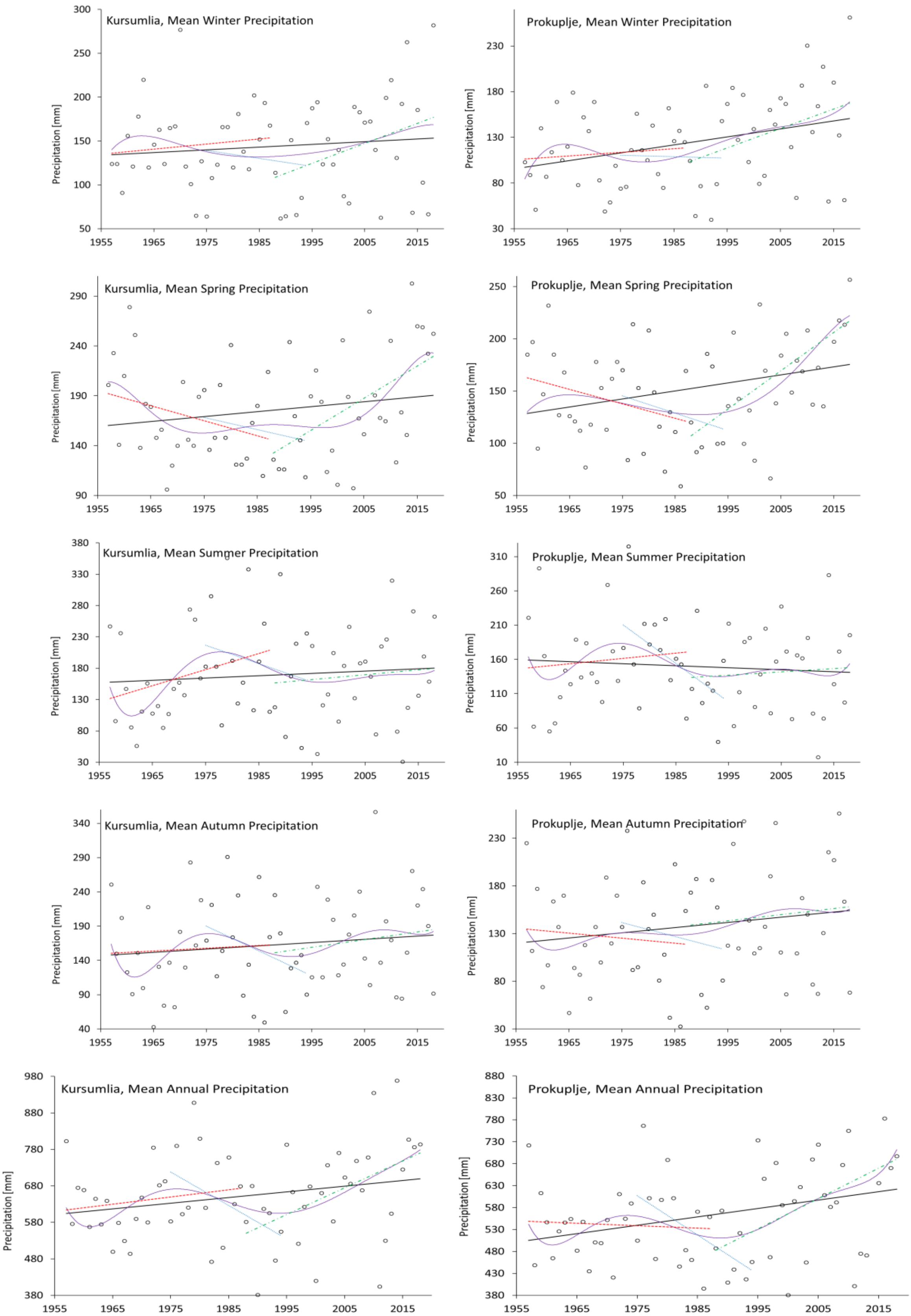
*Note:* Mean [mm] – mean precipitation for period; Cv – coefficient of variation; p – significance probability (Pettitt) ; C.p. – changing point (Pettitt) [year]; m1/m2 [mm] – mean value before and after change point, for p<α=0.05 (Pettitt); L.t.[mm/dec] – slope of linear trend (no star – no statistical significance,
* – α=0.05, ** – α=0.01, *** – α=0.001, Mann-Kendall)

The winter season (DJF) in Kursumlija is quite stable, and there are no significant differences between the periods. The average is slightly lower in the second period, in all the cases without change points and a significant linear trend. In Prokuplje, the situation is different, there is a change point detected in 1993, in the entire period, linear trend is positive and statistically significant. There is also a significant increase in the average value of 22% in the second period. In the period 1975–1994, there is a slight negative trend at both stations, somewhat higher in Kursumlija, in both cases without statistical significance.

In the spring season (MAM) both stations recorded increasing trend in the entire period, with a change point in Prokuplje in 1993. In *Fig. 3* it is clear, that there is a declining trend in the entire first period, not only in the period 1975–1994, although without statistical significance. In the second period, the change point was found in 2004 in Prokuplje, and in 2005 in Kursumlija. In both cases there is a sudden jump in the mean value. At both stations in the second period, a statistically significant growing precipitation trend was found, with the rate of over 30 mm/dec.

In the summer season (JJA) there is a decrease in the mean value between the first and second period at both stations, despite the fact that in both half-periods there are positive precipitation trends. The positive trend in the first period is much more pronounced in Kursumlija, with a change point in 1971 (*Fig. 3*). The cause of lower mean precipitation in the second period, and the negative trend in the whole period in Prokuplje, despite the positive precipitation trend in both half-periods is in a very pronounced decline in 1975–1994. At both stations in this period there is a statistically significant decrease in precipitation and a simultaneous increase in temperature. In *Figs. 2* and *3*, for JJA we see that the polynomial approximation of precipitation almost mirrors the temperature polynomial. The decrease in precipitation in this season is more pronounced in Prokuplje than in Kursumlija.

In the autumn season (SON), similarly to summer, we found a significant decrease in the precipitation amount in the period 1975–1994, but in this case the decrease is higher in Kursumlija than in Prokuplje. However, the precipitation increase in the second period of the SON season is greater than the increase in the JJA season, so this decrease is compensated for. Therefore, there is an increase in mean precipitation in the second period at both stations. There are no change points in any period, while the trend is slightly positive without statistical significance.




*Note*: black dots – precipitation; lines – precipitation trends for the periods: black (1957–2018); red (1957–1987); green (1988-2018); blue (1974–1995); purple –polinomial approximation.

*Fig. 3.* Annual and seasonal precipitation in Kuršumlija and Prokuplje.

### *3.3. Discharge*

The average discharge of the Toplica in the entire period in Pepeljevac is 7 $m^3/s$ with a slight positive trend; in Doljevac it is 9.9 $m^3/s$ with a slight negative trend (*Table 3*). There is a change point in Doljevac in 1982, where the mean value of the discharge dropped. The mean value of the discharge is higher in the first period at both stations, although in both half-periods there is a slight trend of increasing discharge. In the period 1975–1994, there is a very pronounced, statistically significant decreasing trend in discharge at both stations (*Fig. 4*). This is certainly to be expected, considering that there is a significant drop in precipitation in that period. However, total precipitation at both stations increases significantly in the entire period, so decrease is not to be expected in the discharge in Doljevac in the same period. Therefore, the cause of this decline and the appearance of the change point cannot be fully explained by the changes of precipitation in 1975–1994. Apparently, a significant increase in temperature, especially during the summer period, led to an increase in evaporation in the basin, and therefore, there was an additional decrease in discharge. Additional decrease in summer discharge is probably of anthropogenic nature, since intensive agricultural production of the remaining rural households has led to increased use of water, both from the river stream and groundwater near the river.

In the DJF season, there was a decrease in the mean annual discharge at both stations in the second period. In Doljevac, the average discharge was 21.1% lower in the second period, while precipitation was higher by 22.2%. The answer to this anomaly could again be found in the period 1975–1994. In this period, there was a decrease in precipitation at both measuring stations, but this decrease is the lowest of all the seasons, so it could not cause such a reduction in discharge. At the same time, in this period, the temperature dropped at both stations, which apparently significantly slowed down the melting of snow from the mountains, primarily from Kopaonik as the largest massif in the basin, which practically led to such a reduction in discharge.

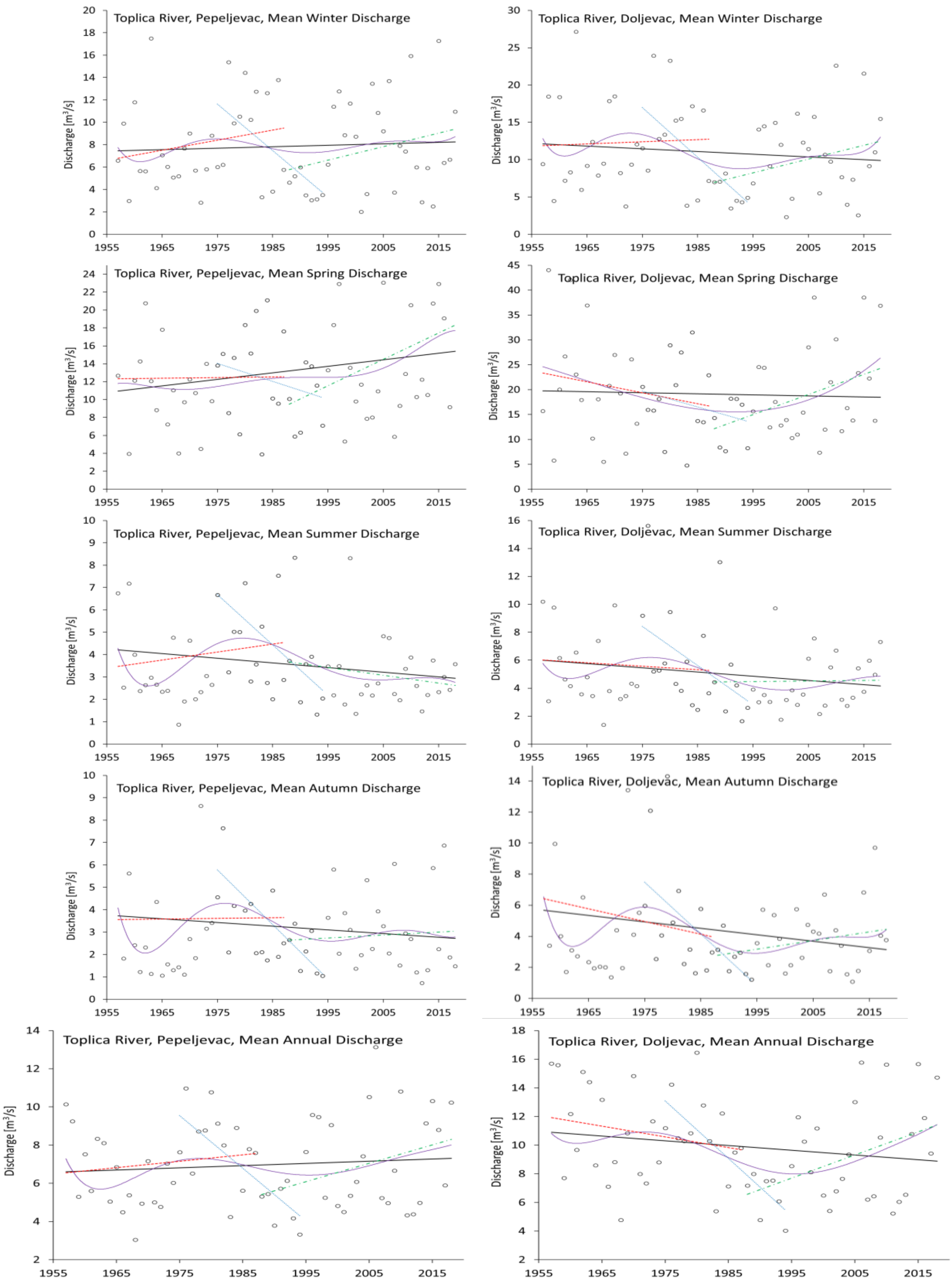
In the MAM season, there is a trend of increasing discharges in the entire period in the upper course of the river and a declining trend in the lower, without statistical significance. In Pepeljevac, the average discharge increased by 12.1% in the second period, while at the same time, the increase in precipitation in Kursumlija was 6.8%. As there is also a positive trend of average temperature in Kursumlija, the most probable cause of additional discharge during this season comes from the melting of snow accumulated during the DJF season, primarily on Kopaonik. During the entire second period, there is a positive, statistically significant trend of increase in precipitation and temperature in Prokuplje, which lead to a positive trend in the mean discharge in Doljevac. Even so, meane discharge in Doljevac dropped 9% in the second period.

*Table 3*. Parameters of seasonal and annual discharges on Toplica river in Pepeljevac and Doljevac

| | Period | Pepeljevac | | | | | | Doljevac | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean [m³/s]** | **Cv** | **p** | **C.p.** | **m1/m2** | **L.t. [m³/s/dec]** | **Mean [m³/s]** | **Cv** | **p** | **C.p.** | **m1/m2** | **L.t. [m³/s/dec]** |
| **DJF Winter** | 57-18 | 7.9 | 0.51 | 0.69 | 1995 | | 0.13 | 11.0 | 0.53 | 0.17 | 1982 | | -0.37 |
| | 57-87 | 8.1 | 0.48 | 0.16 | 1976 | | 0.9 | 12.3 | 0.5 | 0.91 | 1976 | | 0.29 |
| | 88-18 | 7.6 | 0.56 | 0.08 | 1995 | | 1.21 | 9.7 | 0.55 | 0.08 | 1995 | | 1.84 |
| | 75-94 | | | | | | -4.15 ** | | | | | | -6.67 * |
| **MAM Spring** | 57-18 | 13.2 | 0.49 | 0.45 | 2004 | | 0.73 | 19.1 | 0.49 | 0.70 | 1965 | | -0.21 |
| | 57-87 | 12.4 | 0.44 | 0.79 | 1979 | | 0.08 | 20.0 | 0.5 | 0.56 | 1965 | | -2.2 |
| | 88-18 | 13.9 | 0.52 | 0.23 | 2004 | | 2.94 | 18.2 | 0.48 | 0.26 | 2004 | | 4.05 |
| | 75-94 | | | | | | -2.01 | | | | | | -3.19 |
| **JJA Summer** | 57-18 | 3.6 | 0.58 | 0.00 | 1989 | | -0.21 | 5.1 | 0.55 | 0.09 | 1989 | | -0.3 |
| | 57-87 | 4.0 | 0.59 | 0.05 | 1974 | 3.2/5.1 | 0.36 | 5.7 | 0.54 | 0.84 | 1980 | | -0.25 |
| | 88-18 | 3.2 | 0.53 | 0.77 | 1992 | | -0.35 | 4.5 | 0.55 | 0.60 | 2004 | | 0.04 |
| | 75-94 | | | | | | -2.25 * | | | | | | -2.81 * |
| **SON Autumn** | 57-18 | 3.2 | 0.75 | 0.46 | 1981 | | -0.17 | 4.4 | 0.83 | 0.41 | 1981 | | -0.42 |
| | 57-87 | 3.6 | 0.83 | 0.05 | 1971 | 2.8/4.4 | 0.03 | 5.2 | 0.9 | 0.46 | 1971 | | -0.82 |
| | 88-18 | 2.8 | 0.58 | 0.79 | 1994 | | 0.13 | 3.6 | 0.54 | 0.56 | 1994 | | 0.55 |
| | 75-94 | | | | | | -2.44 ** | | | | | | -3.34 ** |
| **Annual** | 57-18 | 7.0 | 0.33 | 0.00 | 2013 | | 0.11 | 9.9 | 0.34 | 0.03 | 1982 | 11.2/9 | -0.33 |
| | 57-87 | 7.1 | 0.29 | 0.07 | 1974 | | 0.33 | 10.8 | 0.29 | 0.41 | 1963 | | -0.75 |
| | 88-18 | 6.9 | 0.37 | 0.00 | 1994 | | 0.96 | 9.0 | 0.38 | 0.22 | 1994 | | 1.62 |
| | 75-94 | | | | | | -2.76 ** | | | | | | -4.01 *** |

*Note:* Mean [m³/s] – mean discharge for period; Cv – coefficient of variation; p – significance probability (Pettitt) ; C.p. – changing point (Pettitt) [year]; m1/m2 [m³/s] – mean value before and after change point, for $p<\alpha=0.05$ (Pettitt); L.t.[m³/s/dec] – slope of linear trend (no star – no statistical significance,

* – $\alpha$=0.05, ** – $\alpha$=0.01, *** – $\alpha$=0.001, Mann-Kendall)




*Note:* black dots – discharge; lines – discharge trends for different periods: black (1957–2018); red (1957–1987); green (1988–2018); blue (1974–1995); purple –polynomial approximation

*Fig. 4*. Seasonal and annual discharge on Toplica river in Pepeljevac and Doljevac.

The discharge trend throughout the summer season declined at both stations. The mean discharge in the second period is lower by 20% in Pepeljevac and 14% in Doljevac. This decline was mostly affected by a strong negative trend in the period 1975-1994, which is statistically significant at both stations. In Pepeljevac, the discharge trend in the second period is negative, despite the positive precipitation trend in Kursumlija. The answer is probably in the very pronounced positive trend of temperature in Kursumlija and the increased evaporation in the upper course of the Toplica river. In Doljevac, the trend in the second period is neutral, despite the positive precipitation trend in the second period in Prokuplje.

In the summer and autumn seasons, the trend of decreasing discharge is most strongly expressed at both stations in the period 1975–1994. with great statistical reliability. The decline in the mean discharge between the two observed periods is most pronounced in the SON season. In Pepeljevac, the discharge was 22% lower in the second period, while in Doljevac it was lower by 34.6%. At the same time, we found that the average precipitation is higher by 7.5% in Kursumlija and 17.4% in Prokuplje compared to the first period. This imbalance is again a consequence of a strong drop in precipitation and discharge during 1975–1994, and of a simultaneous increase in temperature.

## *4. Summary*

The paper studies annual and seasonal changes in temperature and precipitation at two meteorological stations in the Toplica valley, Kursumlija and Prokuplje, and the discharge of the Toplica river at two hydrological stations, Pepeljevac and Doljevac.

The trend of the parameters was examined by the Mann-Kendall test, and the homogeneity of data by the Pettitt's test, in the period of 62 years, from 1957–2018. This period was divided into two equal half-periods of 31 years: 1957–1987 and 1988–2018, in order to examine the changes between the two periods. The period 1975–1994 was identified as the period in which the change in atmospheric circulation most likely occurred, which strongly influenced all the observed parameters. The changes in this period are easily noticeable on the graphs of the polynomial approximation.

In the entire period, the mean temperature and precipitation increased at both examined stations. In the first period, temperature trends decreased with statistical significance at both stations, the precipitation trend in Kursumlija increased, whereas in Prokuplje it decreased, without statistical significance in both cases. In the second period at both stations, temperature and precipitation trends strongly increased, with statistical significance. The period 1975–1994 is characterized by an increase in temperature, without statistical significance and, at the same time, an extremely strong drop in precipitation of about 90 mm/dec at both stations. This period had a large impact on the river Toplica discharge.

Average values of temperature and precipitation in the second period at both stations are higher than in the first, while the discharge is reversed, in the second period the mean value is lower than in the first. This is certainly a consequence of a strong drop in precipitation, and thus in discharge in the period 1975–1994. During this period, the flow decreased so much (about 2.8 $m^3$/s /dec in Pepeljevac and 4 $m^3$/s /dec in Doljevac) that the mean value of the discharge did not recover, despite the strong increasing precipitation trend in the second period.

Mean seasonal values of discharge at both stations are in all cases lower in the second period, except in the MAM season in Pepeljevac. In the DJF season, at both meteorological stations there is an increase in the mean precipitation and temperature in the second season, and a simultaneous decrease in discharge. In this season, in the period 1975–1994, both precipitation and temperature dropped, which additionally slowed down the melting of the accumulated snow and thus negatively affected the discharge. In Pepeljevac, in MAM season, there is an increase in the average discharge, which is expected considering that in the second period there was an increase in precipitation and temperature at both stations, so that the melting of snow from the mountains left behind in the DJF season increased the mean. The anomalous situation is found at the station in Doljevac, where an even larger increase in the average discharge is expected than in Pepeljevac, but the discharge has decreased. In the period 1975–1994, there were no drastic changes in either temperature or precipitation, and the research conducted in this study is not sufficient to explain this change. In the summer season, the mean discharge of the Toplica river declined at both stations. At the Pepeljevac station, we also recorded a drop in the discharge in the second period, while in Doljevac it stagnated. At both stations, the average is 20% lower in the second period. Increased evaporation due to the increase in temperature is probably to blame for this decline. The situation is similar in the autumn season, but there is a positive trend in the second period at both stations.

In conclusion, we can say that the changes in temperatures in the Toplica valley due to climate change are quite expected and in line with all the previous research (*Vukovic et al.* 2018; *Gavrilov,* 2015; *Ruml et al.,* 2017; *Unkasevic, Tosic*, 2013). Precipitation changes are more complicated, which is also known, and for now they do not fit into the predictions of either the A1B1 or A2 models (*Sekulić*, 2012), but are likely to rise in all seasons.

Changes in discharge vary considerably from river to river, and thus, need to be investigated at a local scale, for each individual basin. For example, negative discharge trends were detected in the Vrbas river (Bosnia and Herzegovina) during all seasons, and the observed changes in river discharges were strongly related to the large-scale atmospheric circulation patterns over the Northern Hemisphere (*Gnjato,* 2019). On the other hand, upward trends for annual, summer, and autumn discharges were detected in East Romania (*Croitoru*, 2015).

The strongest increase is in the MAM season, which has led to large floods in the last decade, in the middle and lower course of the Toplica river, as the catastrophic flood in 2014. The discharge of the Toplica river dropped dramatically in the period 1975–1994, and since that it has been recovering. However, it seems that the already poor discharge distribution is getting worse over time, floods are becoming more frequent in spring,0 and the water level is getting lower in summer. The increase in temperature in the Toplica basin has hit the summer season discharge the hardest, when the water is most needed, both directly through increased evaporation and indirectly through anthropogenic factors, increased consumption of water for agriculture and irrigation.

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