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Assessment of hydroclimatic trends in Southeast Europe – Examples from two adjacent countries (Bosnia & Herzegovina and Serbia)

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Abstract— Water quantity is often analyzed throughout mean annual and seasonal discharges in various studies worldwide. This paper aims to present water discharge trends in the lower parts of the Una, Sana, and Vrbanja rivers in Bosnia and Herzegovina and the largest Serbian national river Velika Morava and its tributaries Jasenica and Resava rivers in Serbia for the period 1961–2020. Also, the paper examines air temperature and precipitation trends and their connection with discharge trends. Mann-Kendall test was applied for the determination of trends in air temperature, precipitation, and discharges; the Sen's nonparametric estimator was utilized for establishing the magnitude of the trend, while the t-test was used for determining the statistical significance of the trend. In order to determine possible changes, two periods were observed: 1961–1990 and 1991–2020. Results showed statistically insignificant changes in discharges and precipitation trends on annual and seasonal levels. On the other hand, a significant air temperature increase was recorded in the period 1991–2020, with the highest increase during the summer. The most significant increase was observed in Banja Luka due to urban heat island effect in this city.

Key-words: air temperature, discharge, precipitation, trends, Bosnia and Herzegovina, Serbia

1. *Introduction*

Water resources, including their quality, quantity, and availability, are vital in all aspects of life, human activities, and development. Considering their significance, knowledge of water resources, as well as water-related disasters, such as floods and droughts, is important for adequate water resources management.

Water quantity is often analyzed throughout mean annual and seasonal discharges. Discharges are usually studied regarding their dependence on recent climate change and variability. Opinions about their possible impacts are divided. While some studies found changes in climate elements (precipitation and air temperature) in recent years and their impacts on water quantity (*Zhong et al.,* 2021; *Rajčević* and *Mislicki-Tomić*, 2021), the other ones considered climate variability as an influence of cyclicity (*Arrieta-Pastrana et al.,* 2022), with no or insignificant changes in long-term period (*Balistrocchi et al.,* 2021).

Discharges are directly dependent on climatic elements, especially precipitation and air temperature. Previous studies researched trends of precipitation, air temperatures, and discharges, as well as their correlation. Researches have been done around the world: *Shrestha et al.* (2021) in Canada; *Xu et al.* (2021) in the Amu Darya River Basin in Central Asia; *Dissanayaka* and *Rajapakse* (2019) in the Kelani River basin in Sri Lanka; *Orkodjo et al.* (2022) in the Omo-Gibe basin in Ethiopia.

Many studies analyzed the connection between precipitation and discharge trends: *Zhong et al.* (2021) in the Yellow River basin in China; *Swain et al.* (2021) in the Brahmani and Baitarani River basins in India; *Manzano* and *Barkdoll* (2022) in Michigan; *Mallakpour et al.* (2018) in California; *Silva et al.* (2019) in Brazil; *Cuevas et al.* (2019) in Chile; *Talchabhadel et al.* (2021) in the west Rapti River basin in Nepal; *Malede et al.* (2022) in the Birr River watershed in Ethiopia; *Balistrocchi et al.* (2021) in the Central Italian Alps.

Air temperature and discharge trends have also been the subject of various studies: *Ouyang et al.* (2017) in the Lower Mississippi River Alluvial Valley; *Jiang et al.* (2007) in the Tarim River basin in China; *Shahgedanova et al.* (2018) in the northern Tien Shan in Kazakhstan; *Singh et al.* (2010) in the Gangotri Glacier basin in Western Himalayas in India.

Climate change significantly influences the river regime in Bosnia and Herzegovina. The consequences are increase in occurrence of extremely dry periods and heavy rains, which cause floods (*Crnogorac* and *Rajcevic,* 2019). However, a few researchers studied the impact of climate change on discharges in Bosnia and Herzegovina. In recent periods, annual and seasonal trends were analyzed in the lower parts of the Vrbas River from 1961–2016 (*Gnjato et al.,* 2019) and in the Sana River from 1961–2014 (*Gnjato,* 2018). Results showed a negative correlation between annual discharges and air temperature, while the connection between discharges and precipitation was positive. According to *Gnjato et al.* (2021), an analysis of annual and seasonal trends of climatic and hydrological elements in the Sava River basin in Bosnia and Herzegovina shows a warming tendency in all seasons, while the precipitation trends are insignificant. *Rajčević* and *Mislicki-Tomić* (2021) emphasised air temperature increase in the Vrbanja River basin in the period 1961–2015, while the precipitation trends are negative. A statistically significant positive correlation is recorded between discharges and precipitation and a negative and insignificant correlation between discharges and air temperature. According to *Imamović* and *Trožić-Borovac* (2013), a negative discharge trend is obtained for eight hydrological stations on the Bosnia River in the period 1961–1990.

In Serbia, mean annual and seasonal discharges were analyzed on 94 hydrological stations in the period 1961–2010 (*Kovačević-Majkić* and *Urošev,* 2014). *Dimkić* (2018) found a correlation between precipitation and discharge trends in the following periods: 1946–2006, 1946–2016, and 2007–2016. *Đorđević et al.* (2020) forecasted negative impacts of a decrease in precipitation and increased air temperatures on the discharge regime for the periods 2011–2040, 2041–2070, and 2071–2100, comparing with the control period 1971–2000. Annual discharge trends were also analyzed for Jablanica and Toplica rivers from 1950 to 2012 (*Gocić et al,* 2016), Zapadna Morava River basin in the period 1965–2014 (*Langović et al.,* 2017), Velika Morava River (*Manojlović et al.,* 2016) in the period 1967–2007. Air temperature trends were examined for Šumadija region in the period 1961–2010 (*Milanović Pešić* and *Milovanović,* 2016). *Milentijević et al.* (2020) analyzed air temperature and precipitation trends for Mačva region in the period 1945–2015. *Plavšić et al.* (2016) examined precipitation changes for Belgrade station (1923–2014), Loznica station (1952–2014), and Valjevo station (1949–2014). *Milanović Pešić* (2015) found that maximum values in precipitation in May and June in the Šumadija region are not in line with maximum discharges which occur in February and March due to increased evapotranspiration in May and June. During the period 1961–2015, the lowest discharges of the Šumadija rivers were recorded in August and September (*Milanović Pešić,* 2019). *Leščešen et al.* (2022) found decreasing discharges of Sava River on Sremska Mitrovica station for the period 1928–2017 as the consequence of decreasing precipitation and increasing temperature. *Haddeland et al.* (2013) projected the effects of changes in air temperature and precipitation on discharges in the Kolubara River basin and the Toplica River basin for the periods 2001–2030 and 2071–2100, compared with the control period 1961–1990. *Martić Bursać et al.* (2022) analyzed changes in air temperatures, precipitation, and discharges in Toplica River valley in the following periods: 1957–2018, 1957–1987, and 1988–2018. *Langović et al.* (2023) found significant cyclicity of mean annual discharges in the South (Južna) Morava River, from 1924 to 2021, which was mainly influenced by variation in the precipitation.

This paper aims to present a trend analysis of mean annual and seasonal discharges for selected rivers in Bosnia and Herzegovina and Serbia for the period 1961–2020. It examined whether the changes in discharges exist, whether they occur on the annual or seasonal level, whether the changes are significant, and on what level of confidence. As discharges directly depend on climatic elements, the correlation between discharge trends in rivers with a natural regime and trends in precipitation and air temperatures in their basins was analyzed. This paper's primary objective is to explore the impact of recent climate change and variability on discharge trends in this region of Europe. One of the goals of this study is to determine whether river basins with significant changes exist in the study area, which is important for sustainable water resources management establishing.

2. *Study area*

The study area covers three rivers in central Serbia and Bosnia and Herzegovina, in the Republika Srpska (*Fig. 1, Table 1*). On the territory of Serbia, the largest national river Velika Morava and its tributaries, Jasenica River and Resava River, while in Bosnia and Herzegovina, the lower parts of the Una River, Sana River, and Vrbanja River were analyzed (*Table 1*).

Rivers with a natural regime with no or minor hydromorphological alteration were chosen in this study, making them more suitable for studying the connection between climate variables and discharges. There are no built dams on the selected rivers, and existing meanders were cut only on the Velika Morava in the 60s and 70s of the 20th century, in order to straighten the riverbed and minimize floods caused by the formation of ice barriers (*Gavrilović* and *Dukić,* 2014).

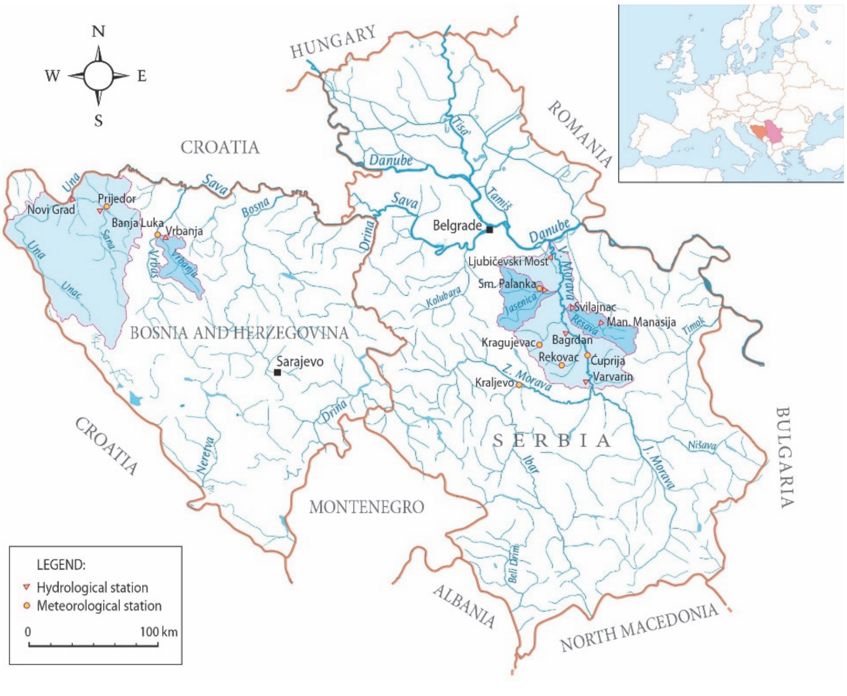

Fig. 1. The study area.

Table 1. Morphometric data of rivers. L: length of the river, F: surface of the river basin, I: total fall of the river, It: mean fall of the river.

	River	**River Basin**	**L (km)**	**F (km^2)**	**Elevation of the source (m a.s.l.)**	**Elevation of the mouth (m a.s.l.)**	**I (m)**	**It (‰)**
Bosnia and Herzegovina	Una	Sava	212	9980	376	94	2812	1.32
	Sana	Una	146	3782	440	116	324	2.21
	Vrbanja	Vrbas	96	804	1515	147	1368	14.24
Serbia	Velika Morava	Danube	175	6814	130.3	71	60	0.34
	Jasenica	Velika Morava	73	1417	705	92	613	8.43
	Resava	Velika Morava	66	681	668	93	575	8.78

The prevailing climate of the study area is moderate continental climate. According to the Köppen climate classification, this region belongs to the following types: Cfa – moderately warm and humid climate with hot summer, Cfb – moderately warm and humid climate with warm summer, and Dfb – moderately cold and humid climate with warm summer (*Milovanović et al.,* 2017). The region is influenced by the North Atlantic circulation and continental polar masses from northern Europe and western Siberia. The river basins are located in the middle of the temperate zone, in the area of frequent and intensive exchanges of tropical and polar air masses. According to *Bajić* and *Trbić* (2016), two action centers of atmospheric circulation impact climate features: the Azores anticyclone, which causes stable weather conditions and hot weather during the summer and the Icelandic cyclone, which brings precipitation. Precipitation increase is in correlation with high altitudes (*Rajčević* and *Crnogorac,* 2011).

In this study, data from 3 hydrological stations in Bosnia and Herzegovina and 6 hydrological stations in Serbia were used for hydrological analyses, and data from 2 meteoroological stations in Bosnia and Herzegovina and 5 meteorological stations in Serbia were used for the analysis of air temperature and precipitation (*Fig. 1*).

3. *Data and methods*

For the rivers in Bosnia and Herzegovina, annual and seasonal discharges in the period 1961–2020 were calculated by using the data on mean monthly discharges from Novi Grad, Prijedor, and Vrbanja hydrological stations, located in the lower parts of the Una River, Sana River, and Vrbanja River, respectively. The selection of these three hydrological stations is a result of the non-existence of continuous long-term measurements at most rivers of Bosnia and Herzegovina. The analysis of annual and seasonal discharges on the rivers in Serbia for the same observation period was made based on data on mean monthly discharges from hydrological stations Varvarin, Bagrdan, and Ljubičevski Most on the Velika Morava River, Smederevska Palanka on the Jasenica River, and Manasija and Svilajnac on the Resava River.

Analysis of the climatological dataset in the period 1961–2020 was performed based on mean monthly values of air temperatures and precipitation retrieved from two meteorological stations (Prijedor and Banja Luka) in Bosnia and Herzegovina and five meteorological stations (Ćuprija, Kragujevac, Kraljevo, Rekovac, and Smederevska Palanka) in Serbia. All hydrological and climatological data were acquired from the Republic Hydrometeorological Institute – Republic of Srpska (https://rhmzrs.com/) and the Republic Hydrometeorological Service of Serbia (https://www.hidmet.gov.rs/).

For determining monotonic positive/negative hydroclimatic trends in this study, a sixty-year time series of annual and seasonal values were submitted to the nonparametric Mann-Kendall (MK) test and the nonparametric Sen's estimator of the slope. The Mann-Kendall test is often used to examine trends in a data series. This test was proposed by *Mann* (1945) and further developed by *Kendall*. It is related to the Kendall's correlation coefficient (*Kendall,* 1975). It was further improved by *Hirsch et al.* (1982, 1984), who included seasonality. In addition, *Gilbert* (1987), *Helsel* and *Hirsch* (1992), and *Helsel et al.* (2020) later studied and improved this test. This test is used to statistically assess whether or not there is a linear monotonic upward or downward trend in the given time series data. There are three alternative hypotheses: there is no trend in the series, there is a negative trend, or there is a positive trend. The Mann-Kendall test analyses the differences between later-measured data and earlier-measured data. Each later measured value is compared with all values measured earlier, resulting in a total of $n(n\text{-}1)/2$ possible data pairs, where n is the total number of observations (*Helsel et al.,* 2020). The advantages of using the MK test are that it does not require the normal distribution of the data, not affected by missing data, irregular spacing of time points of measurements, and length of the time series. The limitation of the MK test is the tendency to give more negative results for shorter data series (*Helsel* and *Hirsch,* 1992).

If a significant trend for data series is found, the rate of change can be calculated using the Sen's slope estimator (*Helsel* and *Hirsch,* 1992). According to *Salmi et al.* (2002), this test is very convenient when a monotonic trend (without seasonal or cyclic variations) exists in the data. The Sen's method is very useful in slope estimation and shows changes in units per time. Also, it is not sensitive to errors and outliers.

The t-test is a widely used statistical test for comparing data of two groups. It is often used to examine whether the difference between the two groups is statistically significant or not. This test is usually applied when data sets follow a normal distribution. This test is called Student's t-test, after William Sealy Gosset, who first published it in English in 1908 in the scientific journal Biometrika under the pseudonym "Student" (*Student,* 1908).

In this study, the MK test is used to identify a trend in the time series. At the same time, the Sen's nonparametric estimator is utilized to establish the trend's magnitude. The statistical significance of the identified trends was determined at the 99% ($p \leq 0.01$) and 95% ($0.01 < p \leq 0.05$) levels. Furthermore, to verify hydroclimatic trends in the studied river basins, mean annual and seasonal climatic and discharge values in two 30-year periods (1961−1990 and 1991–2020) were analyzed and compared. The t-test was applied to estimate the significance of distribution differences between the two periods.

For the calculations in this study, the Mann-Kendall test and the Sen slope incorporated in Excel 2010 software were used, as well as the t-test within the SPSS Statistics 20 software.

4. ***Results and discussion***

4.1. Discharges

Rivers of various sizes and mean annual discharges are selected for this study, including two rivers with mean annual discharges above 200 m^3/s, two rivers with mean annual discharges above 10 m^3/s and three rivers with mean annual discharges below 10 m^3/s (*Table 2*). The mean annual and monthly values of discharge and their MK trend values at the selected stations in the period 1961–2020 are presented in *Tables 2* and *3*, respectively. The lowest discharge was observed in the summer season in all three rivers in Bosnia and Herzegovina and at the most upstream station in Velika Morava River (Varvarin), while it was observed in the autumn season at the other two stations on the Velika Morava, as well as on the other analyzed rivers. The highest discharges were registered in the spring season at all rivers (*Table 2*). It could be addressed that the same values of multi-annual discharges are recorded during the winter and spring seasons on the Resava River (Manasija).

In the period 1961–2020, mean annual discharges showed a weak and negative trend change that has low significance or is not statistically significant on all rivers (*Table 3*). A moderate significant negative trend ($p \leq 0.05$) is recorded only at Varvarin (-0.94 $m^3/s/year$). Similar results have been obtained for the same stations in Serbia in the previous studies. *Manojlović et al.* (2016) confirmed no statistically significant trend at Ljubičevski Most in the period 1967–2007. *Milanović Pešić* (2019) found low significant negative trends for the Ljubičevski Most and Bagrdan and trends with no statistical significance for other stations in the period 1961–2015. *Kovačević-Majkić* and *Urošev* (2014) also obtained the trends with no statistical significance in the period 1961–2010. *Gnjato et al.* (2021) found that negative discharge trends are recorded on the Sana and Vrbanja rivers.

Table 2 Annual and seasonal mean discharges at the selected hydrological stations in 1961–2020, 1991–2020, and 1961–1990 and differences between 1991–2020 and 1961–1990 (m^3/s)

	Period	**Year**	**Winter**	**Spring**	**Summer**	**Autumn**
Bosnia and Herzegovina	Novi Grad – Una					
	1961–2020	217.7	266.8	311.7	121.0	171.1
	1961–1990	219.7	269.4	315.2	131.4	161.3
	1991–2020	215.7	264.0	308.1	110.6	180.8
	difference	-4.0	-5.4	-7.1	-20.8	19.5
	Prijedor – Sana					
	1961–2020	79.0	97.0	119.3	41.3	58.1
	1961–1990	81.6	98.2	122.5	47.7	57.5
	1991–2020	76.4	95.7	116.0	35.0	58.7
	difference	-5.2	-2.5	-6.5	*-12.7*	1.2
	Vrbanja – Vrbanja					
	1961–2020	15.6	19.1	23.8	10.3	9.1
	1961–1990	16.4	21.0	24.2	11.1	9.4
	1991–2020	14.7	17.2	23.4	9.5	8.8
	difference	-1.7	-3.8	-0.8	-1.6	-0.6
Serbia	Varvarin – Velika Morava					
	1961–2020	198.3	221.91	343.24	131.30	96.64
	1961–1990	212.29	243.60	360.82	143.87	100.84
	1991–2020	184.26	200.22	325.66	118.72	92.44
	difference	*-28.03*	-43.38	-35.16	-25.15	-8.4
	Bagrdan – Velika Morava					
	1961–2020	211.7	234.19	368.94	142.42	101.87
	1961–1990	223.29	256.90	381.05	154.91	107.07
	1991–2020	200.43	215.65	356.34	130.90	98.82
	difference	-22.86	-41.25	-24.71	-24.01	-8.25
	Ljubičevski Most – Velika Morava					
	1961–2020	229.0	252.26	396.18	159.85	109.21
	1961–1990	237.47	267.58	403.55	169.81	108.96
	1991–2020	221.28	236.94	388.82	149.90	109.47
	difference	-16.19	-30.64	-14.73	-19.91	0.51
	Manasija – Resava					
	1961–2020	3.56	6.43	6.43	2.79	1.48
	1961–1990	3.88	3.67	7.05	3.31	1.50
	1991–2020	3.24	3.42	5.81	2.28	1.46
	difference	-0.64	-0.25	-1.24	-1.03	-0.04
	Svilajnac – Resava					
	1961–2020	4.73	4.89	8.46	3.68	1.85
	1961–1990	5.05	4.92	8.93	4.32	1.98
	1991–2020	4.40	4.86	7.98	3.04	1.72
	difference	*-0.65*	-0.06	-0.95	-1.28	-0.26
	Smederevska Palanka – Jasenica					
	1961–2020	1.80	2.00	3.23	1.42	0.65
	1961–1990	1.72	2.16	3.35	1.52	0.64
	1991–2020	1.65	1.85	3.11	1.22	0.59
	difference	-0.07	-0.31	-0.24	-0.3	-0.05

Table 3. Trends in annual and seasonal mean discharges at the selected hydrological stations in 1961–2020

	Station	**River**	**Year**	**Winter**	**Spring**	**Summer**	**Autumn**
Bosnia and Herzegovina	Novi Grad	Una	-0.48	-0.86	-0.03	-0.65	-0.14
	Prijedor	Sana	-0.27	-0.30	-0.05	**-0.38**	-0.14
	Vrbanja	Vrbanja	-0.07	**-0.21**	-0.02	*-0.09*	-0.07
Serbia	Varvarin	Velika Morava	*-0.938*	-1.051	-1.529	-0.259	-0.068
	Bagrdan	Velika Morava	-0.728	-0.851	-1.003	-0.026	0.042
	Ljubičevski Most	Velika Morava	-0.494	-0.564	-0.668	-0.060	0.248
	Manasija	Resava	-0.015	-0.003	-0.028	-0.014	0.003
	Svilajnac	Resava	-0.010	-0.004	-0.012	-0.020	0.000
	Smed. Palanka	Jasenica	-0.009	-0.013	0.002	-0.008	-0.005

Statistical significance: **p ≤ 0.01** and *p ≤ 0.05*

The comparative analyses of mean annual discharges between two 30-year periods displayed an insignificant decrease in 1991–2020 compared to the period 1961–1990 at all analyzed hydrological stations in Bosnia and Herzegovina and Serbia (*Table 2*). Mean discharges also changed towards lower values in winter, spring, and summer in the period 1991–2020, while the highest decrease was observed in the summer and winter seasons. An insignificant increase in the period 1991–2020 compared to the period 1961–1990 was observed in the autumn season at Novi Grad, Prijedor, and Ljubičevski Most (*Table 2*).

At the seasonal level, mainly decreasing trends were detected throughout the year in the period 1961–2020. The highest negative tendency was primarily observed in winter in the rivers of Bosnia and Herzegovina and in spring and winter in the rivers of Serbia. The exceptions are Prijedor and Svilajnac, with the highest negative trend in summer. A significant negative trend ($p \leq 0.01$) is recorded on Prijedor (-0.38 m^3/s/year) during the summer and at Vrbanja (- 0.21 m^3/s/year) in winter; a moderate significant negative trend ($p \leq 0.05$) is recorded at Vrbanja (-0.09 m^3/s/year) in summer. Negative discharge trends in all seasons on Sana River in the period 1961–2014 are also confirmed by *Gnjato* (2018), while on Vrbas River, the most expressed ones were in winter and spring for the period 1961–2016 (*Gnjato et al.,* 2019). On other stations, negative trends are low significant or not statistically significant. A positive trend, which is not statistically significant, is obtained on some rivers in Serbia in spring or autumn (*Table 3*).

Applying the t-test, it was determined that the changes in discharges between two 30-year periods generally are not statistically significant. The moderate significance decrease ($p \leq 0.05$) in discharge was determined at Prijedor

(- 12.8 m^3/s) in the summer period (1991–2020), as well as at Varvarin (-28.8 m^3/s) and Svilajnac (-0.65 m^3/s) in the same period on annual level.

4.2. Climatic variables

Mean seasonal and annual air temperatures and precipitation at the meteorological stations in selected river basins during the period 1961–2020 are presented in *Table 4,* while their seasonal and annual trend values are given in *Table 5*. It is calculated that the mean annual air temperatures are about 11°C at all stations.

Table 4. Annual and seasonal mean temperatures (°C) at the selected meteorological stations in 1961–2020, 1991–2020, and 1961–1990 and differences between 1991–2020 and 1961–1990

	Period	**Year**	**Winter**	**Spring**	**Summer**	**Autumn**
Bosnia and Herzegovina	Prijedor					
	1961–2020	11.2	1.1	11.5	20.8	11.4
	1961–1990	10.7	0.5	11.0	20.0	11.1
	1991–2020	11.7	1.7	12.0	21.6	11.6
	difference	**1**	*1.2*	**1.0**	**1.6**	0.5
	Banja Luka					
	1961–2020	11.3	1.5	11.5	20.7	11.4
	1961–1990	10.6	0.8	10.9	19.7	10.9
	1991–2020	12	2.2	12.1	21.8	11.9
	difference	**1.4**	**1.4**	**1.2**	**2.1**	**1.0**
Serbia	Ćuprija					
	1961–2020	11.3	1.1	11.5	20.8	11.5
	1961–1990	10.8	0.7	11.2	19.9	11.1
	1991–2020	11.7	1.5	11.8	21.6	11.8
	difference	**0.9**	*0.8*	*0.6*	**1.7**	*0.7*
	Kragujevac					
	1961–2020	11.6	1.7	11.6	20.9	11.9
	1961–1990	11	1.3	11.2	19.9	11.5
	1991–2020	12.1	2.2	12.0	21.9	12.3
	difference	**1.1**	**0.9**	*0.8*	**2.0**	*0.8*
	Kraljevo					
	1961–2020	11.5	1.4	11.7	20.9	11.8
	1961–1990	11.1	1.1	11.5	20.1	11.6
	1991–2020	11.9	1.8	12	21.7	12.1
	difference	**0.8**	*0.7*	0.5	**1.6**	0.5
	Rekovac					
	1961–2020	10.8	0	11.0	20.0	11.0
	1961–1990	10.3	0.6	10.6	19.3	10.6
	1991–2020	11.3	1.4	11.4	20.8	11.4
	difference	**1.0**	*0.8*	*0.8*	**1.5**	*0.8*
	Smederevska Palanka					
	1961–2020	11.6	1.5	11.7	21.1	11.7
	1961–1990	11.0	1.1	11.4	20.2	11.3
	1991–2020	12.1	2.0	12.1	22.0	12.1
	difference	**1.1**	**0.9**	*0.7*	**1.8**	*0.8*

Statistical significance: **$p \le 0.01$** and *$p \le 0.05$*

The comparative analyses of mean annual and seasonal air temperature between two 30-year periods showed a significant increase in the period 1991–2020 (*Table 4*), confirming the warming tendency. Mean air temperature has the lowest increase in Kraljevo (0.8 °C) and the highest one in Banja Luka (1.4 °C). The highest increase is obtained for mean summer temperatures at all stations and ranges from 1.5 °C in Rekovac to 2.1 °C in Banja Luka. This could be explained by the fact that Rekovac is a small settlement surrounded by forest, which causes a slight increase in temperature. The lowest increase in mean seasonal temperatures is obtained for autumn at most stations ranging from 0.5 °C (Prijedor and Kraljevo) to 1 °C (Banja Luka). The highest increase in mean annual and seasonal temperatures in Banja Luka could be explained by the fact that it is a town with a lot of urban surfaces, which contributes to an increase in air temperature and to the effect of an urban heat island, typical for cities (*Milovanović et al.,* 2020).

Obtained results calculated by the MK test have shown a significant increase in air temperature at all analyzed meteorological stations in the 1991–2020 period (*Table 5*). Very significant ($p \le 0.001$) air temperature increase was obtained on the annual level for all stations, from 0.03 °C/year in Kraljevo (Serbia) to 0.05 ºC/year in Prijedor and Banja Luka (Bosna and Herzegovina). The highest air temperature increases were obtained for the summer period at all stations (0.04 to 0.06 °C/year), while significant, moderate, and very significant increases were obtained in other seasons with the lowest rates in autumn (0.015 to 0.04 ºC/year). Seasonally, the highest temperature increase was determined at Banja Luka, Prijedor, and Kragujevac in summer. An increase in air temperature that is not statistically significant was obtained only at Kraljevo in spring and autumn. Obtained results are in line with the previous studies for the same stations in Serbia in the period 1961–2010 (*Milanović Pešić* and *Milovanović*, 2016; *Crnogorac* and *Rajcevic*, 2019; *Gnjato*, 2018, 2021; *Rajčević* and *Mislicki-Tomić*, 2021).

Table 5. Trends in annual and seasonal mean air temperature at the selected meteorological stations in 1961–2020

	Station	**Year**	**Winter**	**Spring**	**Summer**	**Autumn**
Bosnia and Herzegovina	Prijedor	**0.05**	**0.04**	**0.04**	**0.06**	*0.02*
	Banja Luka	**0.05**	**0.05**	**0.04**	**0.06**	**0.04**
Serbia	Ćuprija	**0.031**	**0.032**	**0.024**	**0.048**	0.018
	Kragujevac	**0.036**	**0.037**	**0.026**	**0.049**	*0.020*
	Kraljevo	**0.030**	**0.032**	*0.021*	**0.042**	0.015
	Rekovac	**0.034**	**0.032**	**0.028**	**0.044**	0.018
	Smed. Palanka	**0.033**	**0.036**	**0.026**	**0.048**	*0.019*

Statistical significance: **$p \le 0.001$**, **$p \le 0.01$**, and *$p \le 0.05$*

Mean annual precipitation (*Table 6*) ranges from 619.6 mm (Rekovac) to 1036 mm (Banja Luka). The highest precipitation is recorded in the summer due to heavy rains in the summer months, especially in June; the mean summer precipitation ranges from 182.1 mm (Rekovac) to 278 mm (Banja Luka).

Table 6. Annual and seasonal mean precipitation (p - mm) at the selected meteorological stations in 1961–2020, 1991–2020, and 1961–1990 and differences between 1991–2020 and 1961–1990

	Period	**Annual**	**Winter**	**Spring**	**Summer**	**Autumn**
Bosnia and Herzegovina	Prijedor					
	1961–2020	943	198	233	245	267
	1961–1990	928	194	234	261	239
	1991–2020	958	202	233	228	295
	difference	30	8	-1	-33	*56*
	Banja Luka					
	1961–2020	1036	227	267	278	264
	1961–1990	1028	221	262	299	246
	1991–2020	1043	234	271	257	282
	difference	15	13	9	-42	36
Serbia	Ćuprija					
	1961–2020	667.0	150.4	181.5	186.4	148.7
	1961–1990	648.3	144.0	175.5	191.4	137.4
	1991–2020	685.7	156.7	187.6	181.4	160.0
	difference	37.4	12.7	12.1	-10	22.6
	Kragujevac					
	1961–2020	642.2	128.3	169.7	202.5	141.7
	1961–1990	632.5	127.4	168.1	205.9	131.1
	1991–2020	651.9	129.3	171.2	199.0	152.4
	difference	19.4	1.9	3.1	-6.9	21.3
	Kraljevo					
	1961–2020	753.4	154.5	204.7	227.2	167.1
	1961–1990	754.8	163.8	201.0	228.0	162.0
	1991–2020	752.0	145.2	208.3	226.3	172.3
	difference	-2.8	-18.6	7.3	-1.7	10.3
	Rekovac					
	1961–2020	619.6	136.7	163.6	182.1	137.3
	1961–1990	654.1	142.1	173.4	199.3	139.4
	1991–2020	605.3	135.8	159.2	170.5	139.8
	difference	-48.8	-6.3	-14.2	-28.8	0.4
	Smederevska Palanka					
	1961–2020	652.0	136.8	166.8	198.8	149.6
	1961–1990	635.0	133.5	166.3	196.4	138.7
	1991–2020	669.1	140.0	167.3	201.2	160.5
	difference	34.1	6.5	1.0	4.8	21.8

Statistical significance: **$p \leq 0.01$** and *$p \leq 0.05$*

A mild increase in the precipitation amount is recorded at the five stations in the period 1991–2020 compared with the period 1961–1990 (*Table 6*). The decline in mean precipitation amount is recorded in Rekovac (-48.8 mm) and Kraljevo (-2.8 mm) stations. According to obtained results presented in *Table* 7, changes in seasonal precipitation amounts are negligible. In the period 1991–2020, mean seasonal precipitation amounts increased at most stations compared with the period 1961–1990 during the winter, spring, and autumn. During the summer, the decline in precipitation amount is recorded at all stations except Smederevska Palanka. It could be explained by the intense precipitation on the Rudnik Mountain and the lower part of the Jasenica River basin at the beginning of July 1999. For example, on July 10, 1999, meteorological station Smederevska Palanka recorded 66.5 mm of precipitation, while the mean July precipitation in 1961–1990 amounted to 58.7 mm (*Milanović Pešić,* 2015). This caused floods that covered all left and some right tributaries of Velika Morava, and the Šumadija region suffered the most severe damage (*Gavrilović et al.,* 2012). Results in the Vrbanja River basin show a negative mean annual precipitation trend with a decreasing tendency of -4.33 mm per decade for the period 1961–2015 (*Rajčević* and *Mislicki-Tomić,* 2021).

Opposite to air temperature, precipitation trends displayed negligible positive or negative tendencies on annual and seasonal levels. Observing the annual values, an increase in precipitation was obtained at five stations and a decrease at two stations. Statistically low significant increase in precipitation is obtained only in Smederevska Palanka (1.84 mm/year). During the spring and autumn seasons, negligible increase in precipitation is recorded at all stations except Rekovac. In winter, an increase is recorded in the precipitation at most stations, while in summer, an increase is recorded at three stations and a decline at four stations (*Table 7*). No one of those trends is statistically significant.

Table 7. Trends in annual and seasonal mean precipitations at the selected meteorological stations in 1961–2020

	Station	**Year**	**Winter**	**Spring**	**Summer**	**Autumn**
Bosnia and Herzegovina	Prijedor	0.7	0.1	0.2	-1.1	1.3
	Banja Luka	-1.2	0.03	0.2	-1.5	0.4
Serbia	Ćuprija	1.68	0.48	0.61	-0.07	0.62
	Kragujevac	1.19	0.16	0.14	0.06	0.56
	Kraljevo	0.34	-0.52	0.40	0.32	0.18
	Rekovac	-1.00	-0.23	-0.69	-0.81	-0.30
	Smed. Palanka	1.84	0.27	0.39	0.37	0.64

Statistical significance: **p ≤ 0.01** and *p ≤ 0.05*

Comparison of differences between mean annual and seasonal precipitations in two observation periods using the t-test confirmed insignificant changes. Only a significant ($p \leq 0.01$) increase relative to the period 1961–1990 was observed at Prijedor in autumn.

The obtained results indicate that in all analyzed rivers, there is a decrease in discharges on annual and seasonal levels (winter, spring, and summer). During autumn, a decrease is recorded at Novi Grad, Prijedor, Vrbanja, and Smederevska Palanka stations and an increase at Bagrdan, Ljubičevski Most, and Manasija stations (*Table 3*). However, these changes are mostly not statistically significant. At all stations, there is a significant increase in mean annual and summer temperatures, while statistically significant increases are obtained for other seasons. In the observed period, the annual precipitation increased at most stations, but it is not statistically significant. At the seasonal level, an increase in precipitation can be observed at all stations during autumn, at most during winter and spring. In contrast, a decrease in precipitation during summer is recorded at almost all stations. According to the results, the increase in annual and seasonal amounts of precipitation at certain stations did not cause an increase in discharges, so it seems that decreasing discharges are mainly the consequence of increasing air temperature (increasing evaporation), which is consistent with the results of other studies of the region.

These findings are in line with the findings for other rivers in this region. *Blöschl et al.* (2019) reported that decreasing discharges in the Balkan Region mainly result from decreasing precipitation and increasing evaporation (due to higher temperatures). *Dimkić* and *Despotović* (2012) found an inversely proportional correlation between mean annual air temperatures and mean annual discharges on selected hydrological stations in Serbia. They indicate that the changes in air temperature are crucial for precipitation and discharge changes. *Leščešen et al.* (2022) found a statistically insignificant decrease in discharges on the Sava River in the period 1928–2017, which was the consequence of insignificant decreasing precipitation and increasing temperatures. *Gnjato et al.* (2019) concluded that discharge in rivers of Bosnia and Herzegovina displayed a negative tendency in all seasons, but these changes were weak and statistically insignificant. The discharges showed a significant positive correlation with precipitation (especially in summer) and a primarily significant and negative connection with air temperature. *Martić Bursać et al.* (2022) indicated that although precipitation plays a dominant role in year-to-year discharge variability, the effect of air temperature on total annual discharge may become more critical during multiyear droughts. In addition, *Martić Bursać et al.* (2022) found a statistically significant decrease trend in discharges on the Toplica River in the period 1975–1994. In the same period, total precipitation in the river basin increases significantly, so the cause of this decline is a significant increase in air temperature, especially during the summer, that led to an increase in evaporation.

5. *Conclusion*

This study aimed to present annual and seasonal trends of the hydroclimatic elements (discharge, air temperature, and precipitation) in the lower parts of the Una, Sana, and Vrbanja River basins in Bosnia and Herzegovina and Velika Morava, Jasenica, and Resava River basins in Serbia for the period 1961–2020. In order to show possible changes in these trends, the period 1961–2020 is divided into two parts, 1961–1990 and 1991–2020, which are compared.

The following results have been obtained:

The highest discharges were recorded in spring at all stations. In contrast, the lowest ones were recorded in summer at the stations in Bosnia and Herzegovina and some stations in Serbia and in autumn at other ones in Serbia. With no statistical significance, a decline in mean annual discharges is recorded on all rivers. At the seasonal level, the highest negative tendency is recorded in winter in rivers in Bosnia and Herzegovina and in summer in rivers in Serbia. However, comparing two 30-year periods, as well as the entire period, these changes are not statistically significant.

The highest precipitation is recorded during the summer season as a consequence of heavy rains in the summer months at all stations. Precipitation trends displayed negligible positive or negative tendencies on annual and seasonal levels, with no statistical significance, which is in line with the discharge trends.

Significant increase in air temperature at annual and seasonal levels is recorded at all stations in the period 1991–2020, compared with the period 1961–1990. The highest increase is recorded during the summer season at all stations. The station with the most significant increase in air temperature, both on annual and seasonal levels, is Banja Luka, which could be explained by the presence of large urban surfaces in this town.

The obtained results showed increasing trends in air temperature throughout the year, whereas precipitation displayed mainly insignificant trends. In line with the observed climatic trends, discharges showed negative trends that were mainly insignificant.

The exact impacts of climate change on the water cycle are hard to predict. However, based on the results of this study, it can be concluded that the decrease in discharges on the analyzed rivers (although not statistically significant) is caused mainly by a significant increase in air temperature both at annual and seasonal levels. Increasing air temperature and precipitation variability can lead to water deficiency (especially in small river basins) and cause negative natural and economic implications.

This study represents an attempt to provide detailed hydroclimatic analysis for selected river basins in Bosnia and Herzegovina and Serbia as a base for future research. The obtained results confirm that climatic variable changes affect the discharge regimes over the study area. In addition, the link between trends in air temperature, precipitation, and discharges is very important in the further assessment of the water resources quantity. Despite the small number of hydrological and meteorological stations in these river basins, which is partly a limitation of this study, the obtained values and the observed changes can be helpful to decision-makers in the development of more efficient water management. We consider that the continuation of the research should be directed toward expanding the research on other rivers with the natural regimes in this region to contribute a complete picture of discharge, precipitation, and air temperature trends.

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