RESEARCH PAPER

WATER REGIME VARIABILITY OF SELECTED RIVERS ON THE BALKAN PENINSULA: A COMPARATIVE STUDY OF CENTRAL SERBIA AND NORTHERN REGION OF MONTENEGRO

Ana Milanović Pešić[1]*, Dejana Jakovljević[1], Golub Ćulafić[2], Milovan Milivojević[1]
[1] Geographical Institute "Jovan Cvijić" Serbian Academy of Sciences and Arts, Djure Jakšića 9, 11000, Belgrade, Serbia
[2] Institute of Hydrometeorology and Seismology, IV Proleterske 19, 81000 Podgorica, Montenegro
*Corresponding author: a.milanovic@gi.sanu.ac.rs
Received: May 18th 2024 / Accepted: November 22nd 2024 / Published: December 31st 2024
https://doi.org/10.24057/2071-9388-2024-3404

ABSTRACT. River discharge and its variations are often the subject of research from different aspects. This study aims to examine the discharge variability of selected rivers in central Serbia and the northern part of Montenegro, which belong to the Danube River basin (Black Sea Drainage basin). In general, all these rivers have uneven water regimes, a large share of evaporation in the water balance during the year, and very low values in discharges in the summer. In this regard, an analysis of mean annual and monthly discharge changes in ten hydrological stations from nine rivers in the 1961–2020 period was made. By using the t-test, a comparison of two 30-year periods (1961–1990 and 1991–2020) was made to examine if there were significant changes in the discharges. The obtained results indicate that in all rivers, annual discharge decreased in the second period compared to the earlier one, and a statistically significant decrease is recorded in 3 rivers, Lepenica, Lugomir and Lim. Changes in monthly discharges between the two 30-year periods are statistically very significant in the summer period in the selected rivers of Montenegro. In contrast they are not statistically significant in selected rivers of Serbia, with several exceptions in spring and autumn. The obtained results indicate mainly a statistically significant discharge decreasing in the second period, which is primarily correlated with a significant increase in air temperature. As discharge changes influence water resource management, the results obtained in this study are important for decision-makers.

KEYWORDS: discharge variability, air temperature, precipitation, t-test, Serbia, Montenegro

CITATION: Milanović Pešić, A., Jakovljević D., Ćulafić G., Milivojević M. (2024). Water Regime Variability of Selected Rivers on The Balkan Peninsula: A Comparative Study of Central Serbia and Northern Region of Montenegro. Geography, Environment, Sustainability, 4(17), 35-43
https://doi.org/10.24057/2071-9388-2024-3404

ACKNOWLEDGEMENT: This study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-66/2024-03/200172).

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Water resources are the subject of various hydrological studies worldwide, mainly due to potential water scarcity. Water quantity is usually analysed throughout discharge changes and variability. Long-term changes in discharges are often estimated by comparing two periods (Georgiadi et al. 2023). Changes in discharges (both increase and decrease) cause many consequences. Temporal and spatial variations in discharges impact on river morphology (Miao et al. 2010). Discharge decrease affects water supply, reduces crop production, and causes problems in river transportation and hydroelectric production (Souza and Reis 2022; Balistrocchi et al. 2021), while its prolonged duration leads to hydrological drought (Leščešen et al. 2020; Urošev et al. 2016). On the other hand, discharge increase often contributes to river bank erosion (Kärkkäinen and Lotsari 2022; Moody 2022; Gao et al. 2021; Brown et al. 2020; Botero-Acosta et al. 2017; DiBiase and Whipple 2011; Larsen et al. 2006) and an augmented risk of flooding, especially in the regions where climate change induced increase in precipitation quantity is expected. According to Langović et al. (2021), variations of discharge values (extremely high or low discharges) are the most important natural factor of riverbank erosion intensity and soil loss. Increased discharges often lead to floods, which further cause infrastructure damage, transportation disruption, and loss of human lives and property (Souza and Reis 2022; Petrović 2015).

Mean annual and seasonal discharge trends were analysed on 94 hydrological stations in Serbia from 1961 to 2010. Results of this study show negative annual, spring, winter and summer trends and positive trends on most stations in autumn and at a small number of stations in winter (Kovačević-Majkić and Urošev 2014). Đorđević et al. (2020) forecasted decreasing average annual discharges in the river basins of Velika, Zapadna and Južna Morava, Ibar, Timok and Drina with especially negative distribution of seasonal discharges in the vegetative period, from July to October for the following three periods: 2011–2040, 2041–2070, and 2071–2100, comparing with the reference period 1971–2000. Haddeland et al. (2013) projected increased maximum values of discharges in the Kolubara River basin and no increase in the peak annual discharges in the Toplica River basin for the periods 2001–2030 and 2071–2100, compared with the reference period 1961–1990. Also, this study forecasted an increase in drought events in both the Kolubara and Toplica river basins at the end of the 21st century (Haddeland et al. 2013). Dragićević et al. (2013) determined the maximum discharge probability for the Kolubara River and its tributaries in order to assess future flood impacts on bank erosion. Kolubara River has the highest coefficient of discharge variation among the Serbian rivers, which causes a significant impact on river bank erosion (Dragićević et al. 2017). Radulović et al. (2014) analysed the river regime of the Temštica River basin in south-east Serbia for the period 1980–2012. Results of this study showed that maximum discharges occurred in April, while the minimum discharges were recorded in September (Radulović et al. 2014). Milanović Pešić (2019) analysed the water regime and discharge trends of rivers in the Šumadija Region for the period 1961–2019 and concluded that these rivers have low amounts of water, especially in summer, with the lowest discharges in August and September and the highest discharges in March and April.

Despite the richness of water, due to the influence of geological features (karst terrains cover over 60% of the territory), rivers in Montenegro have a significantly uneven distribution of water regimes during the year. In rainy seasons, discharges could reach a thousand times higher values compared with the dry seasons (Sekulić and Radulović 2019). Rajović and Bulatović (2014) also stated spatial and temporal discharge variability in north-eastern Montenegro. According to this study, the maximum discharge of Lim River, which occurs in May, is about six times higher than the minimum discharge in September (Rajović and Bulatović 2014).

This study aims to address discharge changes in annual and monthly discharges of rivers in the Šumadija Region in Serbia and the Lim River basin in Montenegro for the periods 1961–1990 and 1991–2020. Also, the paper aims to analyse the impact of various factors (climate changes, land cover and use, anthropogenic impacts), as well as to explain how discharge changes impact on erosion and human activities.

MATERIALS AND METHODS

The study area

The study area includes seven rivers in the central part of Serbia and two rivers in the northern part of Montenegro (Fig. 1). All rivers belong to the Black Sea Drainage Basin and are characterized by a natural regime with no or minor hydropower and hydromorphological alteration, which makes them suitable for comparative analysis of changes in discharge trends. In Serbia, the following rivers were selected: Kubršnica (48 km, 743.2 km^2), Lepenica (55.4 km, 638.9 km^2), Belica (36.8 km, 222.7 km^2), Lugomir (19.5 km, 447.7 km^2), Čemernica (41 km, 625 km^2), Peštan (32.1 km, 171 km^2) and Ljig (31.3 km, 559.4 km^2). These rivers are located in the Šumadija Region, one of the central areas of Serbia. The high abundance of Neogene sediments causes landslides and erosion in this area. Šumadija Region is a lowland area because 91.6% of this territory is below 500 m a.s.l. (Milanović Pešić 2015). This area is characterized by a moderate continental climate with a continental pluviometric regime, which indicates that the maximum precipitation is registered in May and June. In the period 1961–2010, the mean annual temperature was 11–11.6 ºC at most meteorological stations in this area (Milanović Pešić and Milovanović 2016), and the mean annual precipitation ranged between 700 and 800 mm (Milovanović et al. 2017a). According to Milovanović et al. (2017b), who modified Köppen's classification for Serbia, Cfaq climate is present in the largest part of the Šumadija Region, and Dfbq on lowland terrains. The selected rivers have a pluvio-nival regime, with frequent occurrence of extreme water discharges.

In Montenegro, the Lim River (123 km, 2807 km^2) and its tributary Ljubovidja (35.8 km, 351 km^2) were selected (Hrvačević, 2004). Hydrologically, the Lim River is the most significant river in Montenegro. Its total length is 219 km, of which 123 km are in the territory of Montenegro (Ćulafić, 2020). The rest of this river basin is located in Serbia, and a small part of it is in Bosnia and Herzegovina. In this study, only the data of Lim River was analysed in Montenegro because four hydropower plants were built in the Lim River basin in Serbia, which affects the river regime. In Montenegro, the Lim River basin is located in the northeastern part of the country (600–1500 m a.s.l.) (Fig. 1), framed by high mountains (Komovi, Prokletije and Bjelasica). These mountains are dissected by streams and rivers that are Lims tributaries. Considerable parts of the area are underlain by clastic and flysch, clayey-sandy-marly sediments. Therefore, landslides and degradation processes often occur in this territory (Radojičić 2008). The Lim River basin has a moderate continental climate, which belongs to the following types by Köppen's classification: Cfsb, Cfb, Cfws"bx' and Dfbx., with cold winters (-1.2ºC) and mild summers (17.7–19.1ºC) (Burić et al. 2012). Mean annual air temperature values rangesfrom 8.4 to 9.4ºC, while precipitation ranges from 900 to 1004 mm. Maximum precipitation occurs in November and minimum in August. The Lim River and its tributaries have the nival-pluvio regime (Dukić and Gavrilović 2008), with the highest water discharge in May, April and June, and the lowest in August and September.

Data

The discharge dataset for the selected rivers was analysed based on mean annual and monthly values in the 1961–2020 period from seven hydrological stations in Serbia and three hydrological stations in Montenegro. They are: Bogovađa (Ljig River), Zeoke (Peštan River), Preljina (Čemernica River), Smederevska Palanka (Kubršnica River), Batočina (Lepenica River), Jagodina (Belica River) and Majur (Lugomir River) in Serbia; and Plav (Lim River), Bijelo Polje (Lim River) and Ravna Rijeka (Ljuboviđa River) in Montenegro. The criteria for selecting the hydrological stations implied that they are located on rivers with almost natural regimes and had continuity in long-term measurements of the discharge. Data were collected from hydrological yearbooks of the Republic Hydrometeorological Service of Serbia (RHSS) and the Institute of Hydrometeorology and Seismology (IHMS) of Montenegro. At the stations where small recording gaps were observed during 60-year measurements (for a particular month or year), the data were obtained from neighbouring stations the best correlation on a monthly basis.

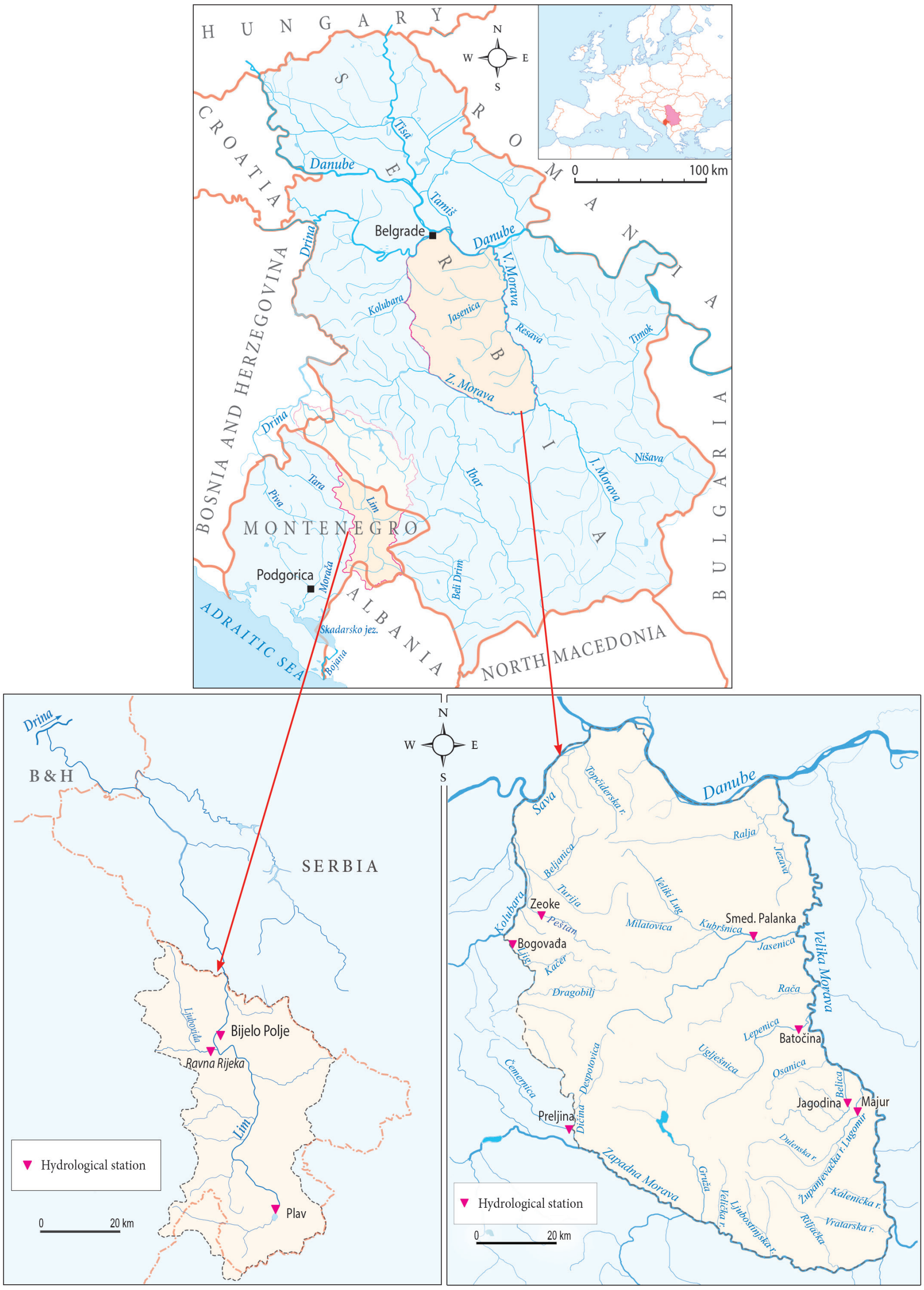

Fig. 1. Study area

Methodology

Previous analysis of the discharge datasets by using the non-parametric Mann–Kendall test and Sen's slope showed water regime variation in some rivers in the Šumadija Region in Central Serbia (Milanović Pešić 2019). In addition, it was observed that a significant change in annual and seasonal discharge occurred around 1990. Hence, the discharge datasets can be divided into two 30-year periods (1961–1990 and 1991–2020) for further analysis. These two data subsets can be used to assess whether there were statistically significant changes in annual and monthly discharge, as well as the level of difference in the two time periods. By using a t-test, discharge values were compared in these two periods to estimate differences in distributions. Calculations were performed for statistical significance specified at the 99% (p value≤0.01) and 95% (0.01<p value≤0.05) levels applying Paired-Samples t-tests within the SPSS Statistics 20.

As the t-test enables to examine whether the means of two subsamples are statistically different (Zheng et al. 2007), it is commonly accepted and often used in hydrological studies. Among others, it was applied for trend analysis in annual maximum, mean and 1-day and 7-day low discharge of rivers in 24 hydrological regions of Turkey (Cigizoglu et al. 2004), for identifying the trends and change points in discharge, precipitation and potential evapotranspiration in Taoer River in China (Li et al. 2010), to examine trend and abrupt changes in discharge regime of the Yellow River (Zheng et al. 2007) and East River in China (Zhang et al. 2012), to determine the statistical significance of the daily discharge variability and trends of Mackenzie River in Canada (Yang et al. 2015) and for analysing runoff variability due to land use changes in Puhe River Basin in China (Zhang and Yu 2020).

RESULTS

Annual discharge variability

In this study, rivers of various mean discharges are selected for analysis. For all selected rivers in Serbia, results showed a decrease in mean annual discharge in the latter period compared to the earlier one (Fig. 2). This decrease in the Lepenica and Lugomir rivers is statistically very significant (Table 1). These findings are in line with some other studies. Kovačević-Majkić and Radovanović (2006) stated that discharge decrease of the Ljig River in the period 1993–2003 compared with the period 1961–1989. Milanović Pešić (2019) found a decreasing trend in the annual discharge of the Lepenica River for 55-year periods.

The results in Montenero showed a decrease in annual discharge in the latter period compared to the earlier one (Fig. 3). This decrease in the Lim River is statistically significant (Table 3). These results are similar to those of Spalević et al. (2016) findings, who concluded that the discharge peak of the Seoski Potok in Lim River basin decreased from 1975 to 2015, due to changes in vegetation cover. Forest increase in the period from 1975 to 2020 also caused discharge decrease in Miocki Potok basin in the upper Lim River basin (Spalević et al. 2020).

Monthly discharge variability

The inter-annual distribution of discharges shows that the maximum discharge in the rivers in Serbia is recorded mainly in March and the minimum discharge mainly in September. In general, river discharge decreases from March to September and increases from October to March. It is interesting to note that, in the first period, in two rivers (Ljig and Peštan) the maximum discharges were recorded in February, while in the second period, they were recorded in March, and the lowest discharge recording moved from the autumn months (September and October) to August. The possible reason for the maximum discharge move could be the result of increased amount of monthly precipitation and heavy rainfall in March and the minimum discharge move by extremely high air temperatures and the absence or little precipitation. At the meteorological station Kragujevac, located in Šumadija Region, amount of precipitation in March increased from 44.4 mm in the first period to 46.6 mm in the second period. At the same station, temperature in February increased from 2.2 °C in the first period to 3°C in the second period (Jovanović et al. 2023). Sudden snow melt, followed by heavy rainfall in early spring, mainly in March, also contributed the highest discharges in this month (Petrović et al. 2024). The shift of the lowest discharge from autumn to August is caused by increased temperatures in July and August and decreased precipitation from May to July in the second period. At

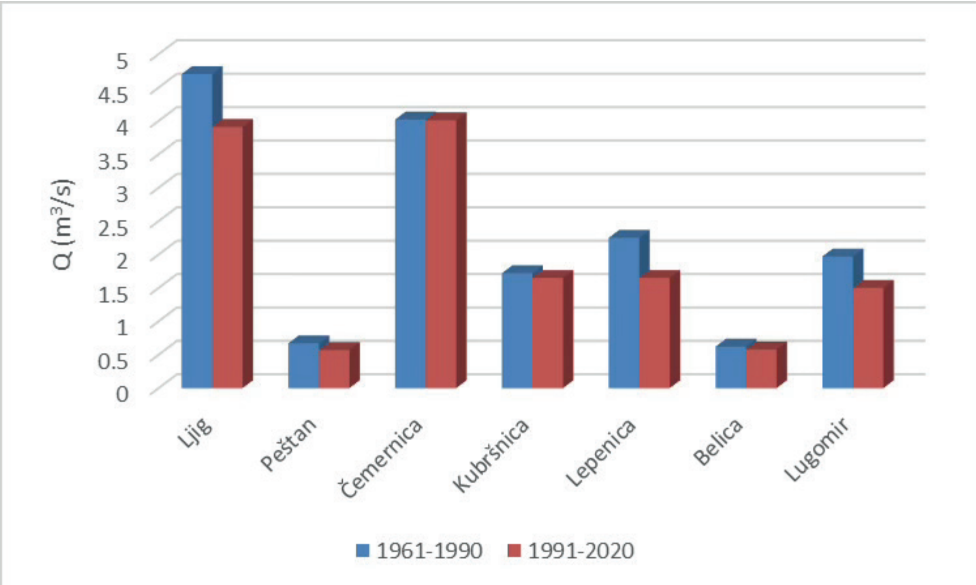

Fig. 2. Mean annual discharges (m³/s) at the selected rivers in Serbia in 1991–2020 relative to 1961–1990

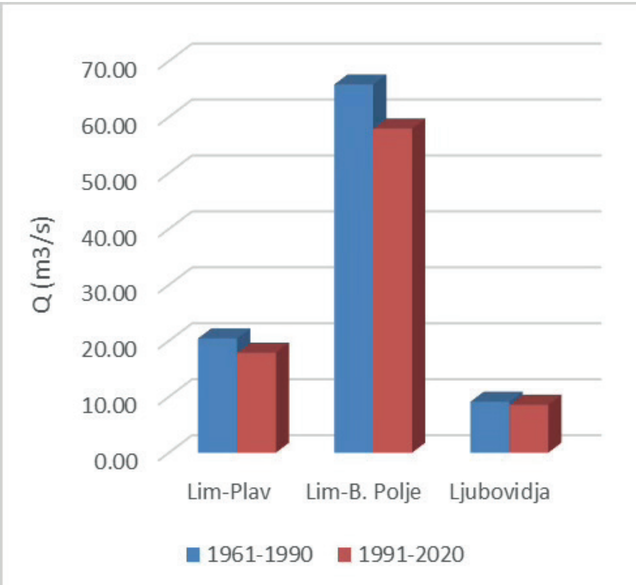

Fig. 3. Mean annual discharges (m³/s) at the selected rivers in Montenegro in 1991–2020 relative to 1961–1990

the meteorological station Kragujevac, temperatures increased from 20.6 °C in the first period to 22.6 °C in the second period in July and from 20.2 °C to 22.3 °C in the second period in August. Comparing these two periods, the amount of precipation decreased in the second period from: 73.8 mm to 70.3 mm in May, 84.7 mm to 77.2 mm in June, and 68 mm to 65.8 mm in July (Jovanović et al. 2023).

In the 1991–2020 period, all rivers experienced a discharge decrease from January to June and a slightly increased from July to December compared to the 1961–1990 period (Table 1).

According to the results obtained in Table 1, the changes in monthly discharges between two thirty-year periods are generally not statistically significant, but there are some exceptions. A significant decrease ($p \leq 0.01$) in discharge was observed on the Lepenica River in February and May and on the Lugomir River in June and September. In addition, a significant decrease ($p \leq 0.05$) was registered at Lepenica River in January and March. Contrary to that, a significant increase ($p \leq 0.05$) in discharge was observed on the Kubršnica River in September and October and Peštan River in October, which can be related to significant precipitation. For example, at rain gauge Mihajlovac, near Kubršnica River, daily amount of precipitation recorded 15 September, 2014 were 180.3 mm, which was the absolutely maximum for the whole period of measurement of 57 years (Petrović. 2021).

Table 1. Mean monthly and annual discharges (m³/s) at the selected rivers in 1991–2020 relative to 1961–1990

Station	Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Bogovađa	Ljig River													
	1961–1990	5.33	9.86	9.61	6.85	6.88	5.81	2.56	1.09	0.93	0.97	2.20	4.32	4.7
	1991–2020	4.30	6.82	9.03	5.53	4.60	3.90	2.58	1.22	1.28	1.55	2.24	3.83	3.91
	Difference	1.03	3.04	0.58	1.32	2.28	1.91	-0.02	-0.13	-0.35	-0.58	-0.04	0.49	0.8
Zeoke	Peštan River													
	1961–1990	0.82	1.50	1.35	0.74	0.97	0.95	0.32	0.36	0.15	0.13	0.27	0.55	0.68
	1991–2020	0.68	0.91	1.04	0.79	0.76	0.48	0.41	0.20	0.24	0.25	0.40	0.66	0.57
	Difference	0.14	0.59	1.31	-0.05	0.21	0.47	-0.09	0.16	-0.09	-0.12	-0.13	-0.11	0.11
Preljina	Čemernica River													
	1961–1990	4.39	7.25	7.71	5.16	6.58	4.68	2.29	1.48	1.30	1.49	2.32	3.63	4.02
	1991–2020	3.78	6.23	8.80	5.87	5.03	3.73	2.89	1.65	1.71	2.00	2.58	3.67	3.99
	Difference	0.61	1.02	-1.09	-0.71	1.55	0.95	-0.6	-0.17	-1.41	-0.51	-0.26	-0.04	0.02
Smed. Palanka	Kubršnica River													
	1961–1990	1.76	4.33	3.71	2.28	2.22	2.35	0.77	0.37	0.32	0.40	0.67	1.16	1.7
	1991–2020	2.05	3.21	3.57	2.01	1.77	1.52	1.47	0.62	0.49	0.63	0.79	1.65	1.65
	Difference	0.29	1.12	1.14	0.27	0.45	0.83	-0.7	-0.25	-0.17	-0.23	-0.12	-0.49	0.05
Batočina	Lepenica River													
	1961–1990	1.98	3.71	4.45	2.88	2.95	2.72	1.43	1.43	1.08	1.12	1.39	1.82	2.25
	1991–2020	1.45	2.17	2.49	2.26	1.65	1.93	1.80	1.22	1.11	1.08	1.15	1.45	1.65
	Difference	0.53	1.54	1.96	0.62	1.30	0.79	-0.37	0.21	-0.03	0.04	0.24	0.37	0.60
Jagodina	Belica River													
	1961–1990	0.67	1.17	1.35	0.88	0.95	0.67	0.30	0.19	0.18	0.23	0.33	0.50	0.62
	1991–2020	0.59	0.87	1.07	1.02	0.83	0.66	0.42	0.26	0.17	0.25	0.31	0.51	0.58
	Difference	0.08	0.30	0.28	-0.14	0.12	0.01	-0.12	-0.07	0.01	-0.02	0.02	-0.01	0.04
Majur	Lugomir River													
	1961–1990	2.01	3.62	4.53	3.01	2.90	2.51	0.93	0.66	0.53	0.54	0.87	1.51	1.97
	1991–2020	1.48	2.58	3.67	2.84	2.22	1.27	0.89	0.42	0.31	0.50	0.59	1.24	1.50
	Difference	0.53	1.04	0.86	0.17	0.68	1.24	0.04	0.24	0.22	0.04	0.28	0.27	0.47

Statistical significance – $p \leq 0.01$ and *p*≤0.05

On Lim River in Montenegro, the maximum discharge is observed in May and in its tributary Ljubovidja in April. The minimum discharges were recorded mainly in August. Generally, river discharge decreases from December to February, increases from March to April or May, then decreases by August, and increases from September to December. By comparing two thirty-year periods, it was noted that at the upstream hydrological station Plav, the minimum discharge was moved from September to August in the later period. At the downstream hydrological station Bijelo Polje, the maximum discharge moved from May to April. The recording of maximum discharge in April at this station coincides with secondary maximum of precipitation amount, contributed by the earlier snow cover melting in the downstream sector of the Lim River basin due to the increased trend in air temperature. The lowest discharges coincide with the lowest amount of precipitation and highest air temperatures (Ćulafić and Krstajić, 2024).

According to the inter-annual distribution, discharge generally decreased in almost all months, except March (and April in one station) and December in 1991–2020 compared to 1961–1990.

According to the results, the decrease in monthly discharges between two thirty-year periods is statistically very significant from May to August in the Lim River and August on the Ljubovidja River. Also, a significant decrease (p≤0.05) was registered at Ljubovidja River in July. During the other months, changes in monthly discharges are not statistically significant (Table 2).

DISCUSSION

Studies worldwide found discharges correlation with climate variation, such as air temperature, precipitation, snow cover melting, as well as anthropogenic activities. General decrease of discharges is caused by global change, such as precipitation, land use change and increase of water consumption (Billi and Fazzini, 2017). The discharge decrease resulting from this study indicate its correlation with the variability of climatic elements, especially with air temperature. In the Šumadija Region, for instance, a statistically significant increase in air temperature was recorded in the 50 year period. According to Milanović Pešić and Milovanović (2016), the calculated trends of mean annual air temperatures in the Šumadija Region for 1961–2010 indicate a statistically significant increase in almost all meteorological stations and ranges from 0.02 to 0.04 ºC/year. The absolute maximum air temperature trends have a statistically significant increase in half of the analyzed stations and range from 0.05 to 0.07 ºC/year. At the monthly level, the calculated trends of mean air temperatures in July and August showed that almost all stations have a statistically significant increase (0.04 to 0.07 °C/year), while the trends of the mean air temperatures in January are not statistically significant, although is recorded slight temperature increasing.

Regarding precipitation, the calculated changes in Serbia ranged from -2 mm to +2 mm/year from 1961–2010, and there is no statistically significant trend (Milovanović et al. 2017a). In the Šumadija Region, a decrease in the mean annual precipitation was observed in parts of the Zapadna Morava River basin (from Kraljevo to Prokuplje). At the same time, in the rest of the area, there was an increase in the mean annual precipitation. As regards the spring and summer precipitation, there were no statistically significant changes in the observed period. In the entire territory of Serbia, a slight decrease in precipitation in spring and a slight increase in precipitation in summer were observed. In addition, a slight increase in precipitation is recorded during autumn and winter (Milovanović et al. 2017a). Analyzing the water balance in Serbia, it was calculated that about 75% of the precipitation evaporates. Considering air temperature increasing, evaporation is even more pronounced, which has an unfavourable effect on discharge. This trend is also observed in Region Šumadija, and it was calculated that about 81.4% of precipitation evaporates in the Lepenica River basin (Milanović 2007). Therefore, it can be concluded that the discharge decrease in the selected river of Region Šumadija is mainly influenced by significant air temperature increases. In addition, a decrease in discharge could be caused by human activities, including land cover change, urbanization, and population increase. As it was stated by Vuksanović-Macura et al. (2018), in the 20th century,

Table 2. Mean monthly and annual discharges (m^3/s) at the selected rivers in 1991–2020 relative to 1961–1990

Station	Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Plav	Lim River													
	1961–1990	15.62	14.08	15.64	32.46	46.04	31.18	15.45	8.17	7.91	14.78	22.67	21.33	20.44
	1991–2020	15.07	12.57	16.67	31.43	37.09	20.91	9.78	4.90	6.70	12.81	22.60	24.17	17.89
	Difference	0.55	1.49	-1.03	1.03	**8.95**	**10.27**	**5.67**	3.27	1.21	1.97	0.07	-2.84	2.55
Bijelo Polje	Lim River													
	1961–1990	61.05	61.72	72.34	120.60	136.32	77.99	36.46	20.69	22.77	38.77	64.88	76.27	65.82
	1991–2020	52.62	50.49	77.92	119.45	109.23	53.07	23.54	15.27	20.40	33.89	62.02	77.70	57.97
	Difference	8.43	11.23	-5.58	1.15	**27.09**	**24.92**	**12.92**	**5.42**	2.37	4.88	2.86	-1.43	7.85
Ravna Rijeka	Ljubovida River													
	1961–1990	9.93	11.16	12.71	17.02	13.47	7.75	4.29	2.96	3.26	5.61	9.39	11.87	9.12
	1991–2020	9.03	8.50	13.55	17.16	12.26	6.65	3.38	2.03	2.63	4.78	9.83	13.23	8.59
	Difference	0.90	2.66	-0.84	-0.14	1.21	1.1	0.91	**0.93**	0.63	0.83	-0.44	-1.36	0.53

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

the population in the Šumadija Subregion of the capital Belgrade area increased from 68,480 to 930,000, forest and agricultural areas gradually decreased, and artificial land cover increased from 6.0% to 34.6% of the subregion area, which was an increase of 479.7%. Based on the results of Drobnjaković et al. (2021), changes in the population of the Šumadija Region and the type of settlement took place in favour of urban settlements from 1948 to 2011. The most intensive migrations occurred in 1961–1981 when the urban population of several municipalities increased by up to 50%. Demographic changes and intensive urbanization also caused changes in the land cover.

Our results and interpretations are in line with several studies provided for other areas of Serbia. These studies examined the connection of discharges with precipitation, air temperatures and human influence, as well as the consequences of discharge changes on human activities. Krtolica et al. (2024) concluded that decreasing annual discharge trends were observed in many rivers in Serbia, including Velika Morava, Nišava, Južna Morava, Timok and Toplica rivers, as a consequence of climate variables (increased air temperatures and decreased precipitation), land use changes and natural vegetation changes, as well as increased water demand for irrigation. On the other side, Đokić et al. (2022) found that discharge decreased due to vegetation growth during June, with the highest precipitation in the Nišava River basin. Idrizović et al. (2020) have projected changes in discharges, precipitation and temperature for two periods: 2021–2050 and 2071–2100 compared with the reference period 1971–2000 in the Toplica River basin. The authors forecasted no notable changes on an annual scale but an increase in discharge, air temperature and precipitation during the winter months and a decrease in discharges during the warm season. Discharges in Južna Morava River and Zapadna Morava River basins are determined by air temperature and precipitation, terrain slope and geological structure, pedological and vegetation cover and human impact (Langović 2019; Langović et al. 2017). Manojlović et al. (2021) found a significant decrease in discharge for the Južna Morava River basin in the 1961–2007 period but no significant changes in precipitation. Decreased discharge has been caused by human activities and interventions such as water extraction, agricultural irrigation, industrial and urban use, engineering works, and conservation measures in the 1960s and 1970s (Manojlović et al. 2021).

In the selected rivers of the northern part of Montenegro, the statistically significant decrease in discharge from May to August is a direct consequence of climatic elements variability, especially the air temperature increasing trend. Ćulafić et al. (2017) analysed the impact of climate change in the Lim River basin and concluded that there was a tendency for the mean annual discharge to decrease in in 1948–2014, along with an increase in air temperature, especially with high oscillations during the winter months. Analysing the relationship between discharge and precipitation in the Lim River basin for the 1966-2014 period, Ćulafić (2020) found that there is a decrease in discharge during the summer (July and August), especially from 1989, while on the other hand, a constant increase in air temperature is recorded, as well as a slight decrease in the amount of precipitation.

The decreasing trend in the discharge of the selected rivers in 1991–2020 compared to 1961–1990 carries significance in water resources management, especially through the negative effect on water supply, water quality, agriculture, biodiversity, etc. Although the studied rivers in Šumadija Region are not directly used for the water supply of settlements, they have multiple purposes, and preserving their good water quality is important. Continuous monitoring is necessary to analyse the correlation of discharge variability and the impact on water quality. Unfortunately, some of these rivers do not have water quality monitoring, and others are not continuously monitored. By analysing data in the water quality of the Lepenica River in 2001–2005, Milanović and Kovačević (2007) concluded that the Lepenica River is a polluted watercourse. The highest level of water pollution is during the summer and early autumn, when the discharge rate is the lowest, and it is mainly polluted by wastewater from industrial facilities. In recent years, water quality testing of Lim River has been carried out 3 to 4 times per year. Reports indicate that the water quality in the upstream sector near Andrejevica is good. The water quality is moderate in the downstream sector near Bijelo Polje and on its tributary Ljuboviđa (IHMS, 2024). However, it is necessary to provide continuous water quality measurements in the Lim River basin to research the impact of discharge change on its water quality.

Discharge variability also has an impact on erosion processes in watersheds. Until now, no studies have dealt with the influence of discharge changes on erosion intensity in this study area. Ristić et al. (2013) analysed the impact of land-use changes in the Dičina River basin from 1966 to 2012 and concluded that maximal discharges had been reduced since 2002 due to land-use changes, including erosion and control torrent works. Spalević et al. (2020) analysed land-use changes and their impact on erosion, primarily on fluvial erosion in the Miocki Potok basin, Lims tributary. They found that changes in land use in the last 50 years have reduced soil erosion intensity by 14%.

According to the Erosion Map of Serbia (1983), made in the 1966–1971 period, 86.39% of Serbia was affected by varying erosion intensities, and excessive and very strong erosion covered about 14.3% of the territory. However, during that time, the relationship between erosion categories changed, and according to data from 2009, the area under excessive erosion decreased by 50–70%, and the areas under severe erosion were reduced by about 75% and moved into the medium erosion category (Lazarević 2009). According to Dragićević et al. (2011), areas with strong erosion potential cover about 3.76% of the territory in Serbia. Numerous factors influenced the change in erosion intensity, and it would be significant to examine the correlations between the discharge decrease and erosion intensity changes in specific river basins.

CONCLUSIONS

In this study, discharge changes during sixty years on selected rivers of the Danube basin in central Serbia and northern Montenegro were analysed. The maximum discharge on the rivers in Serbia is recorded mainly in March, and the minimum discharge is mainly in September, while on the analysed rivers in Montenegro, maximum discharges were in May (or April) and minimum in August.

By using a t-test, it is concluded that in all the study rivers, a decrease in mean annual discharge was recorded in the 1991–2020 compared to the 1961–1990 period. This discharge decrease is statistically very significant ($p \leq 0.01$) in rivers Lepenica and Lugomir in Serbia and statistically significant ($p \leq 0.05$) in Lim in Montenegro. The monthly discharges decrease observed in the 1991–2020 period is statistically very significant ($p \leq 0.01$) from May to August on Lim River and in August on its tributary Ljuboviđa River in Montenegro, in February and May on Lepenica River and in June and September on Lugomir River in Serbia, and statistically significant ($p \leq 0.05$) in July Ljuboviđa River in

Montenegro and in January and March on Lepenica River in Serbia. In contrast a statistically significant (p≤0.05) discharge increase is registered in September and October on the Kubršnica River and in October on the Peštan River in Serbia. In other months, no statistically significant changes in monthly discharges were observed between the two 30-year periods.

Discharge decreases in selected rivers correlate with a statistically significant air temperature increase in the entire region, whereas it is barely influenced by precipitation, which has slightly changed. Further research on discharge variation in the study rivers should consider additional factors, such as snow cover and melting, geological structure, land-use changes, etc. Considering that the decreasing trends of discharge negatively affect the water resources management, their use, water quality degradation and other natural processes, further research on the factors affecting the hydrological changes outlined in the study rivers should be undertaken.

REFERENCES

Balistrocchi M., Tomirotti M., Muraca A., and Ranzi R. (2021). Hydroclimatic variability and land Cover transformations in the Central Italian Alps. Water, 13, 963, DOI: 10.3390/w13070963

Billi, P. and Fazzini, M. (2017). Global change and river flow in Italy. Global and Planetary Change, 155, 234-246. DOI: 10.1016/j.gloplacha.2017.07.008

Botero-Acosta A., Chu M.L., Guzman J.A., Starks P.J., and Moriasi, D.N. (2017). Riparian erosion vulnerability model based on environmental features. Journal of Environmental Management, 203, 592-602, DOI: 10.1016/j.jenvman.2017.02.045

Brown D.R., Brinkman T.J., Bolton W.R., Brown C.L., Cold H.S., Hollingsworth T.N., and Verbyla D.L. (2020). Implications of climate variability and changing seasonal hydrology for subarctic riverbank erosion. Climatic Change, 162, 1-20, DOI: 10.1007/s10584-020-02748-9

Burić M., Micev B., and Mitrović L. (2012). Atlas klime Crne Gore [Climatic Atlas of Montenegro]. Podgorica: CANU (in Serbian).

Cigizoglu H.K., Bayazit M., and Önöz B. (2005). Trends in the maximum, mean, and low flows of Turkish rivers. Journal of Hydrometeorology, 6(3), 280-290. DOI: 10.1175/JHM412.1

Ćulafić G., Mitrović L., Ivanov M., and Golijanin J. (2017). Uticaj klimatskih promjena na vodni režim u slivu Lima. Zbornik radova povodom obilježavanja 20 godina rada Prirodno–matematičkog Fakulteta Univerziteta u Banjoj Luci. Banja Luka: Republika Srpska, Bosna i Hercegovina, p. 141-147 (in Serbian).

Ćulafić G. (2020). Impact of climate change on river discharge regimes in the Danube river basin: Example of Lim River (Montenegro). In: A. Milanović Pešić, and D. Jakovljević, eds., Water Resources Management: Methods, Application and Challenges, 35-68. New York: Nova Science Publishers.

Ćulafić G. and Krstajić J. (2024). Hydrology of Surface Water and Climate Characteristics of Montenegro. In: G. Barović, ed., Speleology of Montenegro, 51-65. Cham: Springer International Publishing.DiBiase R.A. and Whipple K.X. (2011). The influence of erosion thresholds and runoff variability on the relationships among topography, climate, and erosion rate. Journal of Geophysical Research: Earth Surface, 116(F4), DOI: 10.1029/2011JF002095

Dragićević S., Pripužić M., Živković N., Novković I., Kostadinov S., Langović M., Milojković B., and Čvorović Z. (2017). Spatial and temporal variability of bank erosion during the period 1930–2016: Case Study—Kolubara River Basin (Serbia). Water, 9(10), 748. DOI: 10.3390/w9100748

Dragićević S., Ristić R., Živković N., Kostadinov S., Tošić R., Novković I., Borisavljević A., and Radić B. (2013). Floods in Serbia in 2010–case study: the Kolubara and Pcinja River basins. In: D. Lóczy, ed., Geomorphological impacts of extreme weather: Case studies from Central and Eastern Europe. Dordrecht: Springer, 155-169, DOI: 10.1007/978-94-007-6301-2_10

Dragicevic S., Filipovic D., Kostadinov S., Ristic R., Zivkovic N., Andjelkovic G., Abolsamov B., and Djurdjic S. (2011). Natural Hazard Assessment for Land-use Planning in Serbia. International Journal of Environmental Research, [online] Volume 5(2), 371-380. Available at: https://www.sid.ir/paper/300933/en [Accessed 20 Feb. 2024]

Drobnjaković M., Petrović G., Karabašević D., Vukotić S., Mirčetić V., and Popović, V. (2021). Socio-economic transformation of Šumadija District (Serbia). Journal of the Geographical Institute "Jovan Cvijić" SASA, 71(2), 163-180, DOI: 10.2298/IJGI2102163D

Dukić D. and Gavrilović Lj. (2008). Hidrologija. [Hydrology]. Belgrade: Zavod za udžbenike i nastavna sredstva (in Serbian).

Đokić M., Stričević L.J., Gocić M., Golubović N., and Miletić M. (2022). Analysis of Discharge Fluctuation Using Modified Streamflow Drought Index (SDI) and Standardized Precipitation Index (SPI) in the Upper Nišava River Basin. Serbian Journal of Geosciences, 8, 15-26. DOI: 10.18485/srbjgeosci.2022.8.1.3

Đorđević B., Dašić T., and Plavšić J. (2020). Impact of climate change on Serbian water management and measures for protection against negative impacts. Vodoprivreda, [online] Volume 305-309, p. 39-68 (in Serbian with English abstract). Available at: https://grafar.grf.bg.ac.rs/handle/123456789/2520 [Accessed 20 Feb. 2024]

Gao P., Li Z., and Yang H. (2021). Variable discharges control composite bank erosion in Zoige meandering rivers. Catena, 204, 105384, DOI: 10.1016/j.catena.2021.105384

Georgiadi A.G., Milyukova I.P., Borodin O.O., and Gusarov A.V. (2023). Water Flow Changes in the Don River (European Russia) during 1891–2019. Geography, Environment, Sustainability, 16(2), 6–17, DOI: 10.24057/2071-9388-2022-083

Haddeland I., Langsholt E., Lawrence D., Wong W.K., Andjelic M., Ivkovic M. and Vujadinovic M. (2013). Effects of climate change in the Kolubara and Toplica catchments, Serbia, Report number 62 [online]. Oslo: Norwegian Water Resources and Energy Directorate. Available at: https://publikasjoner.nve.no › rapport2013_62 [Accessed 20 Feb. 2024]

Hrvačević S. (2004). Resursi površinskih voda Crne Gore, Elektroprivreda Crne Gore AD Nikšić, Nikšić (in Serbian).

Idrizovic D., Pocuca V., Mandic M.V., Djurovic N., Matovic G., and Gregoric, E. (2020). Impact of climate change on water resource availability in a mountainous catchment: a case study of the Toplica River catchment, Serbia. Journal of Hydrology, 587, 124992, DOI: 10.1016/j.jhydrol.2020.124992

Institute of Hydrometeorology and Seismology (IHMS) (2024). Stanje kvaliteta vode u Crnoj Gori 2023 (in Montenegrin).

Jovanović S., Petrović J., Nikolic D., Djordjevic Z., and Sustersic V. (2023). Climate changes – Trends and perspectives in the Republic of Serbia. In: 14th International Quality Conference , Conference Manual (Kragujevac, Serbia, 2023). Kragujevac: Faculty of Engineering, University of Kragujevac, pp. 1753-1760

Kärkkäinen M. and Lotsari E. (2022). Impacts of rising, peak and receding phases of discharge events on erosion potential of a boreal meandering river. Hydrological Processes, 36(10), e14674, DOI: 10.1002/hyp.14674

Kovačević-Majkić J. and Radovanović M. (2006). Hydrological features of Ljig municipality. Journal of the Geographical Institute "Jovan Cvijic" SASA, 55, 37-52 (in Serbian with English abstract).

Kovačević-Majkić J. and Urošev M. (2014). Trends of mean annual and seasonal discharges of rivers in Serbia. Journal of the Geographical Institute "Jovan Cvijić" SASA, 64(2), 143-160, DOI: 10.2298/IJGI1402143K

Krtolica I., Todorov M., Prohaska S., and Stojković, M. (2024). Annual and Low-Flow Trends in Serbia. Journal of Hydrologic Engineering, 29(3), 05024008. DOI: 10.1061/JHYEFF.HEENG-6030

Langović M. (2019). Annual and seasonal variations of river discharges in the South Morava River Basin (Republic of Serbia). In: Proceedings of the International Scientific Symposium "New Trends in Geography" (Ohrid, North Macedonia, 2019). Ohrid: Macedonian Geographical Society, pp. 27-36.

Langović M., Dragićević S., Novković I., Živković N., Tošić R., Milojković B., and Čvorović Z. (2021). Assessment of the soil loss caused by riverbank erosion in Serbia. Bulletin of the Serbian Geographical Society, 101(1), 31-47, DOI: 10.2298/GSGD2101031L

Langović M., Manojlović S. and Čvorović Z. (2017). Trends of mean annual river discharges in the Zapadna Morava river basin. Bulletin of the Serbian Geographical Society, 97(2), 19-45. DOI: 10.2298/GSGD1702019L

Larsen, E.W., Premier A.K., and Greco S.E. (2006). Cumulative effective stream power and bank erosion on the Sacramento river, California, USA. JAWRA Journal of the American Water Resources Association, 42(4), 1077-1097, DOI: 10.1111/j.1752-1688.2006.tb04515.x

Lazarević R. (2009). Erozija u Srbiji. Belgrade (in Serbian).

Leščešen I., Dolinaj D., Pantelić M., Telbisz T., and Varga G. (2020). Hydrological drought assessment of the Tisza River. Journal of the Geographical Institute "Jovan Cvijić" SASA, 70(2), 89-100, DOI: 10.2298/IJGI2002089L

Li L.J., Li B., Liang L.Q., Li J.Y., and Liu Y.M. (2010). Effect of climate change and land use on stream flow in the upper and middle reaches of the Taoer River, northeastern China. Forestry Studies in China, 12, 107-115, DOI: 10.1007/s11632-010-0301-1

Manojlović S., Sibinović M., Srejić T., Hadud A., and Sabri I. (2021). Agriculture land use change and demographic change in response to decline suspended sediment in Južna Morava River basin (Serbia). Sustainability, 13(6), 3130, DOI: 10.3390/su13063130

Miao C., Ni J. and Borthwick A.G.L. (2010). Recent changes of water discharge and sediment load in the Yellow River basin, China. Progress in Physical Geography: Earth and Environment, 34(4), 541-561, DOI: 10.1177/0309133310369434

Milanović A. (2007). Analiza rečnog režima i vodnog bilansa u slivu Lepenice [Analysis of river regime and water balance in the Lepenica River basin]. Journal of the Geographical Institute "Jovan Cvijić" SASA, 56, 35-50, DOI: 10.2298/IJGI0756035M (in Serbian)

Milanović A. and Kovačević-Majkić J. (2007). Evaluation of surface water quality and pollution in Lepenica River basin Bulletin of the Serbian Geographical Society, 87(1), 175-184, DOI: 10.2298/GSGD0701173M (in Serbian with English abstract).

Milanović Pešić A. (2019). Water regime and discharges trends of the rivers in the Šumadija region (Serbia). In: Proceedings of the International Scientific Symposium "New Trends in Geography" (Ohrid, North Macedonia, 2019). Ohrid: Macedonian Geographical Society, pp. 3–13.

Milanović Pešić A. (2015). Geographical Aspects of Natural Disasters in Šumadija. University of Belgrade, Faculty of Geography, PhD Dissertation (in Serbian with English abstract)

Milanović Pešić A. and Milovanović B. (2016). Thermic Regime and Air Temperature Trends in Šumadija Region (Serbia). Journal of the Geographical Institute "Jovan Cvijić" SASA, 66(1), 19-34, DOI: 10.2298/IJGI1601019M

Milovanović B., Radovanović M., Stanojević G., Pecelj M., and Nikolić J. (2017a). Klima Srbije [Climate of Serbia]. In M. Radovanović ed., Geografija Srbije (Posebna izdanja, Knjiga 91) [Geography of Serbia (Special issues, Book 91)]. Belgrade: Geographical Institute "Jovan Cvijić" SASA, 94-156 (in Serbian).

Milovanović B., Ducić V., Radovanović M., and Milivojević, M. (2017b). Climate regionalization of Serbia to Köppen climate classification. Journal of the Geographical Institute "Jovan Cvijić" SASA, 67(2), 103–114, DOI: 10.2298/IJGI1702103M

Moody J.A. (2022). The effects of discharge and bank orientation on the annual riverbank erosion along Powder River in Montana, USA. Geomorphology, 403, 108134. DOI: 10.1016/j.geomorph.2022.108134

Petrović A.M. (2015). Challenges of torrential flood risk management in Serbia. Journal of the Geographical Institute "Jovan Cvijić" SASA, 65(2), 131-143, DOI: 10.2298/IJGI1502131P

Petrović A.M. (2021). Bujične poplave u Srbiji [Torrential floods in Sebia]. Belgrade: Serbia Geographical Society, Special Issues, Book 73.

Petrović A. M., Leščešen I., and Radevski I. (2024). Unveiling Torrential Flood Dynamics: A Comprehensive Study of Spatio-Temporal Patterns in the Šumadija Region, Serbia. Water, 16(7), 991, DOI: 10.3390/w16070991

Radojičić B. (2008). Geografija Crne Gore, prirodna osnova. Podgorica: DANU (in Serbian).

Radulović M., Leščešen I., and Pavić, D. (2014). Analysis of River regime and Water balance of the Temštica River Basin (South-East Serbia) during the 1980-2012 Period. Forum Geografic 13(2), 178-184, DOI: 10.5775/fg. 2067-4635.2014.082.d

Rajović G. and Bulatović J. (2014). Water geographic values Northeastern Montenegro. Larhyss Journal, [online] 17. Available at: http://larhyss.net/journal.html [Accessed 20 Feb. 2024]

Ristić R., Ljujić M., Despotović J., Aleksić V., Radić B., Nikić Z., Milčanović V., Malušević I., and Radonjić J. (2013). Reservoir sedimentation and hydrological effects of land use changes-case study of the experimental Dičina river watershed. Carpathian Journal of Earth and Environmental Sciences, 8(1), 91-98. Available at: https://www.cjees.ro/viewTopic.php?topicId=298 [Accessed 20 Feb. 2024]

Sekulić G. and Radulović M.M. (2019). The Hydrology and Hydrogeology of Montenegro. In: V. Pešić, M. Paunović, and A. Kostianoy, eds., The Rivers of Montenegro. The Handbook of Environmental Chemistry, Volume 93. Cham: Springer, pp: 13-42. DOI: 10.1007/698_2019_413

Souza S.A. and Reis, D.S.Jr. (2022). Trend detection in annual streamflow extremes in Brazil. Water, 14, 1805. DOI: 10.3390/w14111805

Spalevic V., Barovic G., Fikfak A., Kosanovic S., Djurovic M., and Popovic S. (2016). Sediment yield and Land use changes in the Northern Montenegrin Watersheds: Case study of Seocki Potok of the Polimlje Region. Journal of Environmental Protection and Ecology, [online] Volume 17(3), 990-1002. Available at: https://scibulcom.net/en/article/QoIOVlG4vl4PtVviS9fY [Accessed 20 Feb. 2024]

Spalevic V., Barovic G., Vujacic D., Curovic M., Behzadfar M., Djurovic N., Dudic B., and Billi P. (2020). The impact of land use changes on soil erosion in the river basin of Miocki Potok, Montenegro. Water, 12(11), 2973, DOI: 10.3390/w12112973

Urošev M., Dolinaj D., and Štrbac D. (2016). At-site hydrological drought analysis: Case study of Velika Morava River at Ljubičevski Most (Serbia). Journal of the Geographical Institute "Jovan Cvijić" SASA, 66(2), 203-220, DOI: 10.2298/IJGI1602203U

Vuksanović-Macura Z., Radulović S., and Macura V. (2018). Land cover changes of the Belgrade area over the past three centuries. Spatium, 42-50, DOI: 10.2298/SPAT1840042V

Yang D., Shi X., and Marsh P. (2015). Variability and extreme of Mackenzie River daily discharge during 1973–2011. Quaternary International, 380, 159-168, DOI: 10.1016/j.quaint.2014.09.023

Zhang J. and Yu X. (2021). Analysis of land use change and its influence on runoff in the Puhe River Basin. Environmental Science and Pollution Research, 28, 40116-40125, DOI: 10.1007/s11356-020-09798-7

Zheng H., Zhang L., Liu C., Shao Q., and Fukushima Y. (2007). Changes in stream flow regime in headwater catchments of the Yellow River basin since the 1950s. Hydrological Processes: An International Journal, 21(7), 886-893. DOI: 10.1002/hyp.6280