Geografia Fisica e Dinamica Quaternaria
GFDQ 46 (2023), 179-192

DOI 10.4454/78fejkn7

Dragan BURIĆ[1,*], Ivana PENJIŠEVIĆ[2]

Flow dynamics and the influence of atmospheric oscillations on the hydroclimate along the course of the West Morava River (Serbia)

Abstract: Burić D., Penjišević I., *Flow dynamics and the influence of atmospheric oscillations on the hydroclimate along the course of the West Morava River (Serbia).* (IT ISSN 0391-9838, 2023). The West Morava River (length of 308 km), situated in Serbia's Central region, boasts the largest reservoir of freshwater resources within the country. Research results for the period 1961-2023 revealed a significantly higher frequency of low flows on a monthly, seasonal, and annual basis. In the first part of the 21st century (2001-2023), there was an increase in the number of days with very high flows (Qd91th) and high flows (Qd75th), as well as very low flows (Qd9th) and low flows (Qd25th). This indicates a trend of decreasing average flows alongside an increase in the number of extreme flow days, both very high and very low, highlighting the impact of climate change. Compared to the 1961-2000 sub-period, the early 21st century (2001-2023) has seen slightly higher average precipitation and lower river flow, but significantly higher air temperatures. Summer months are now, on average, up to 2°C warmer than before. We conclude that this significant warming has led to increased evaporation, which has had a greater impact on river flow than changes in precipitation overall. The results further indicate that, in certain months, there is a significant relationship between hydroclimatic elements (flow, precipitation, and air temperature) and variations in atmospheric oscillations: North Atlantic Oscillation (NAO-slp and NAO-500hPa), North Sea-Caspian Pattern (NCP), Arctic Oscillation (AO), Mediterranean Oscillation (MO), Western Mediterranean Oscillation (WeMO), East Atlantic-West Russian Oscillation (EAWR), Summer North Atlantic Oscillation (SNAO), East Atlantic Oscillation (EA), and Scandinavian Oscillation (SCAND). Given the crucial importance of the River for Serbia, it is necessary to define as soon as possible certain plans related to flow equalization and sustainable management of water resources, but also mitigation and adaptation to current and specially projected future climate changes.

Key words: Flow, Trend, Standardized Deviations, Percentiles, Oscillations, West Morava, Serbia.

INTRODUCTION

Rivers stand as pivotal surface water bodies, historically drawing human interest and engagement. Presently, they serve as vital conduits for a multitude of economic endeavors such as agriculture, tourism, hydropower generation, navigation, fish farming, and various other essential activities. Rivers essentially epitomize a "product" of the climate, rendering them exceptionally susceptible to contemporary climatic shifts. The flow dynamics of rivers are subject to temporal and spatial fluctuations, influenced by factors including precipitation patterns and temperature variations. However, it is crucial to acknowledge that human activities within the basin, both direct and indirect, increasingly exert influence on river flow, further complicating the dynamics of these essential watercourses.

Research indicates that global warming is accelerating the hydrological cycle, which is expected to result in more frequent and intense precipitation events (Pratap and Markonis, 2022). Over the past few decades, the combination of a warming climate and human activities has brought about significant increase in the flowof river in the Arctic Ocean region (Rawlins *et al.*, 2021; Hu *et al.*, 2023). Studies conducted from the early 1960s to the early 2000s have revealed distinct hydrological trends across European rivers. Specifically, during winter months, there was a discernible rise in flow observed in numerous European rivers, particularly prevalent in Western and Northern Europe. Conversely, contrasting trends emerged for rivers in Southern and parts of Eastern Europe, where negative flow trends were predominant, particularly evident during summer months (Stahl *et al.*, 2012; Kalugin, 2023). Kwadijk *et al.* (2016) highlight significant interannual and decadal variability in the annual flow of rivers that flow into the North Sea.

---

[1] *Department of Geography, Faculty of Philosophy, University of Montenegro, Danila Bojovica bb, 81400 Niksic, Montenegro.*

[2] *Department of Geography, Faculty of Sciences and Mathematics, University of Priština in Kosovska Mitrovica, Lole Ribara 29, 38220 Kosovska Mitrovica, Serbia.*

[*] *Corresponding author: Dragan Burić (draganburic33@gmail.com)*

They attribute this variability to fluctuations in the North Atlantic Oscillation (NAO), with its influence being particularly pronounced during winter months. Consequently, the effects of climate change are often more discernible in the mountainous regions of a basin, where human influence is relatively limited, compared to lowlands, where human activities are more pronounced (Mankin *et al.*, 2015). Loss of snow and ice has disrupted the natural regulation of runoff, leading to increased river flow in downstream areas (Matti *et al.*, 2017; Hernández-Henríquez *et al.*, 2017).

One of the longer tributaries of the Danube is the Great Morava (along with its longer tributary, the West Morava, with the length of the Great Morava being 493 km). This river contributes an average of 297 m^3/s of water into the Danube annually. The results of the trend for the period 1926-2005 show that the flow of the Great Morava slightly increases during winter and spring, and decreases in summer and autumn (Stojković *et al.*, 2014). The Great Morava is formed by the joining of the South Morava and West Morava near Stalać and is the national and largest river of Serbia. For the period 1946-2020, the South Morava registers a significant decrease in mean annual flow (Langović *et al.*, 2022), but its tributary, the Toplica River, for the period 1957-2018 registers a positive flow trend (Martić-Bursać *et al.*, 2022). When it comes to the West Morava, it should be pointed out that the largest part of renewable internal freshwater resources in Serbia is located precisely in the basin of this river (Simić and Matic, 2017).

Serbia possesses several geographical attributes: it is a Balkan, Central European, Southern European, Carpathian, Alpine, Dinaric, Mediterranean, and Danubian country. As a landlocked nation, Serbia has no access to the sea. North of the Sava and Danube rivers, and along the valley of the Great Morava, lowlands prevail, forming part of the Pannonian Plain, while to the south, the terrain is characterized by basins and mountains. The 45°N parallel passes near Belgrade, the capital and largest city in Serbia. The continental boundary of the Balkan Peninsula lies south of the Sava River valley, extending from its confluence with the Danube and downstream along the Danube to its mouth at the Black Sea. North of these valleys lies Central Europe and the Pannonian Basin. Thus, Serbia is situated in the central part of the Northern Hemisphere, at the crossroads of the Mediterranean and Central Europe. This geographical positioning indicates that Serbia is influenced by both Mediterranean and continental synoptic and climatic factors from the north, resulting in the convergence of air masses with different physical characteristics. Air masses associated with cyclogenesis over the Mediterranean Sea (particularly the Genoa Cyclone and those forming over the Adriatic Sea) significantly impact the weather in southern Serbia. Additionally, moist and unstable air masses from the west (the Atlantic) and the barometric trough associated with the Icelandic Depression, when extending over the Western Mediterranean – especially when its axis stretches across Italy or the Adriatic – have a stronger influence on the weather in western and southern Serbia, often bringing higher amounts of precipitation than in other regions of the country. Cold air masses frequently invade from northern and northeastern Europe, causing temperature drops and often bringing strong, cold winds known as "košava", which blow across northern and eastern Serbia. In a broader context, Serbia's transitional geographic location makes it an excellent regional and global example for studying hydroclimatic changes in the context of contemporary climate change and the influence of variations in atmospheric and oceanic oscillations. This is particularly relevant for the West Morava River, as it is located nearly in the central part of the country.

Taking into account the significance of the West Morava River for Serbia, the main objective of this study is to analyze daily, monthly, seasonal, and annual flows from the hydrological station (HS) Jasika. This hydrological station (HS) was selected because it provides the most complete empirical flow (Q) data and is situated closest to the confluence of the West Morava and South Morava rivers. As such, it effectively represents the flow regime dynamics of the West Morava along its entire course. Flow is primarily influenced by precipitation, but also by temperature (through evaporation). Therefore, in addition to assessing the significance of changes in river flow, the analysis will also include changes in average monthly, seasonal, and annual air temperatures and precipitation, based on data from three meteorological stations (MS) evenly distributed along the river's course. Finally, the aim is to investigate the correlation between 10 indicators of atmospheric with the fluctuation of monthly flow values, temperature, and precipitation. All calculations were made for the period 1961-2023.

STUDY AREA

The study area focuses on the West Morava River with the aim of identifying changes in flow patterns in the context of contemporary climate change. Flow data were collected from the Jasika Hydrological Station, located near the confluence of the West Morava with the South Morava. The Jasika HS is situated 18 km from the confluence with the South Morava, which marks the beginning of the Great Morava. The drainage area of the West Morava at the Jasika HS profile is 14,721 km^2, with the gauge datum set at 138.6 m above sea level in relation to the Adriatic Sea. The closest meteorological station to this site is in Kruševac (at an elevation of 166 m), providing temperature and precipitation data. To verify changes in precipitation and temperature, data from two additional meteorological stations, Kraljevo and Požega, located further upstream along the river (fig. 1), were utilized.

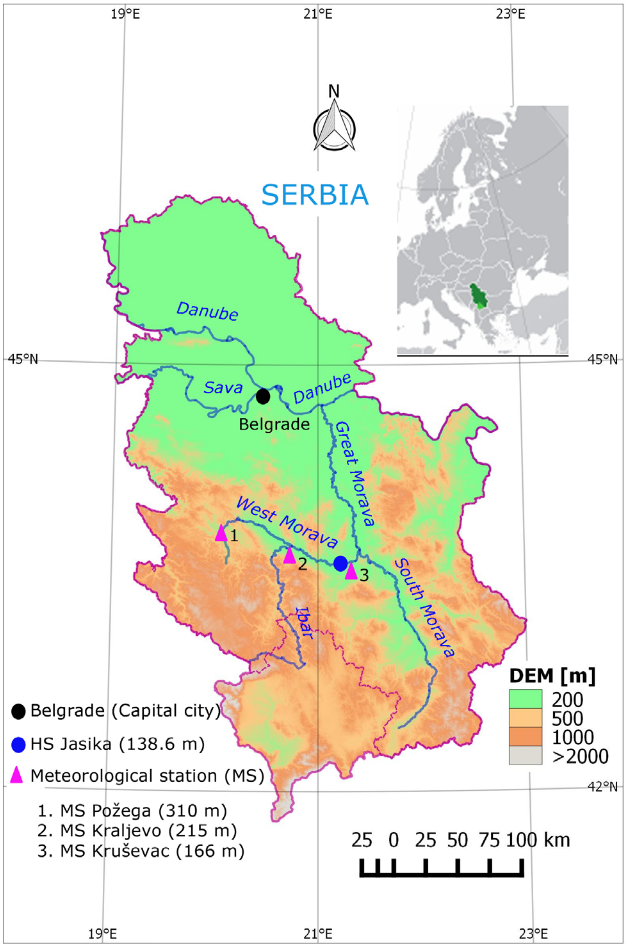

Figure 1 - The position of the West Morava River in Serbia, along with the locations of the Jasika Hydrological Station (HS Jasika) and meteoroloških stanica (MS): Požega, Kraljevo i Kruševac

The West Morava is a river in Central Serbia formed in the Požega Valley by the confluence of three rivers: Golijska Moravica, Đetinja, and Skrapež (Penjišević, 2022). Its total length from the source of its longest tributary, the Golijska Moravica, located at an elevation of 1350 m a.s.l., to its confluence with the South Morava, measures 308 km. The river flows eastward through a diverse valley landscape. Within the relief of the West Morarava valley, there exists a substantial variation in elevation, ranging from 144 to 1321 m a.s.l. (Milosavljević *et al.*, 2023). In addition to its hydropower potential, the West Morava River valley holds substantial economic significance for Serbia (Lukić *et al.*, 2018). The diverse mineralogical composition of the rocks and the presence of deep faults have led to the formation of significant accumulations of mineral and thermal-mineral waters in the West Morava River valley (Gulan *et al.*, 2020). In accordance with the Köppen climate classification, the upper reaches of the West Morava basin, situated in southwest and west Serbia above 1000 meters, exhibit characteristics of a moderately cold climate (D climate), while lower regions experience a moderately warm climate (C climate). Annual precipitation averages around 1100 mm in the western part of the basin, gradually decreasing downstream to approximately 650 mm in the eastern direction. Likewise, the average annual temperature ranges from approximately 6-7 °C in the western basin, increasing to around 10-11 °C in the eastern region.

DATA AND METHODS

For this study, flow data from the downstream HS Jasika station, as well as precipitation and air temperature data from three meteorological stations along the course of the West Morava River, were used for the period 1961-2023 (see fig. 1). These data were sourced from the Republic Hydrometeorological Institute of Serbia (https://www.hidmet.gov.rs/data/, last accessed: 13 September 2024). Throughout the entire time series (1961-2023), 3% of the data for mean daily flow were missing. To address this, missing data were estimated as the arithmetic mean of the daily flow values of the preceding and following day. Using daily average flows, monthly, seasonal, and annual values were calculated. For the period 1961-2023, there were no missing data for the average monthly air temperatures and precipitation at two meteorological stations (Kraljevo and Kruševac). However, for the Požega station, 1.7% of the data was missing. Missing data for the Požega station were estimated based on the data from the two aforementioned stations (Kraljevo and Kruševac) using a matrix method. The analysis of temperature and precipitation changes was conducted for all three meteorological stations. However, due to the qualitatively similar results obtained and to ensure efficiency, the results primarily related to the Kruševac station will be presented, as it is located near the HS Jasika.

Rivers are a product of climate, meaning that flow is primarily influenced by precipitation and temperature. In this context, the study examined the correlation between hydroclimatic elements (flow, temperature, and precipitation) at HS Jasika and the three meteorological stations with indicators of atmospheric oscillations (teleconnections). Table 1 provides sources for the data on variations in global and regional atmospheric oscillations. In summary, each teleconnection is defined by an index, represented by a single number, indicating the distribution of pressure over a broader area. The indices of all oscillations considered in this study are presented as standardized (normalized) deviations relative to their respective baseline periods. Further details regarding these and other global and regional teleconnections can be found in the study by Burić and Stanojević (2020).

Table 1 - Used indices of teleconnections with sources and based parameters.

Index	Unit*	Institution**	Period
North Atlantic oscillation (NAO-slp) http://www.cru.uea.ac.uk/cru/data/nao/nao.dat	hPa	UAE-CRU	1961-2022
Summer North Atlantic Oscillation (SNAO) https://climexp.knmi.nl/data/isnao_ncepncar.dat	hPa	UAE-CRU	1961-2023
Arctic oscillation (AO) https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii.table	hPa	NOAA-CPC	1961-2023
Mediterranean oscillation (MOI) http://www.cru.uea.ac.uk/cru/data/moi/moi1.output.dat;	hPa	UAE-CRU	1961-2022
Western Mediterran osc. (WeMO) http://www.ub.edu/gc/documents/Web_WeMOi-2020.txt	hPa	UB-GC	1961-2020
East Atlantic oscillation (EA) https://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/ea_index.tim	gpm	NOAA-CPC	1961-2023
East Atlantic-West Russian oscillation (EAWR) https://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/eawr_index.tim	gpm	NOAA-CPC	1961-2023
Scandinavian oscillation (SCAND) https://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/scand_index.tim	gpm	NOAA-CPC	1961-2023
North Atlantic oscillation (NAO-500hPa) https://ftp.cpc.ncep.NOAA.gov/wd52dg/data/indices/NAO_index.tim	gpm	NOAA-CPC	1961-2023
North Sea-Caspian Pattern (NCP) https://crudata.uea.ac.uk/cru/data/ncp/ncp.dat	gpm	UAE-CRU	1961-2005

* hPa - Mean Sea Level Pressure (mb); gpm - geopotential.
** UAE-CRU: University of East Anglia - Climatic Research Unit; NOAA-ESRL (CPC): National Oceanic and Atmospheric Administration - Earth System Research Laboratory's (Climate Prediction Center); UB-GC: University of Barcelona-Climatology Group.

The research was conducted using the following methods: trend analysis, standardized deviations, percentiles, differentiation, and correlation methods. Trend calculation and significance assessment were conducted using the non-parametric Sen's slope estimator and the Mann-Kendall test (Kendal, 1975; Hirsch and Slack, 1984) at significance levels of 99.9% ($p < 0.001$), 99% ($p < 0.01$), 95% ($p < 0.05$), and 90% ($p < 0.10$). The mentioned method is described in detail in Burić and Doderović (2022). The categorization of flow deviations was carried out using standardized deviations (SD) and percentiles (PC) (table 2). Normal fluctuations, falling between -1 and +1 SD, are considered within the expected range. Positive SD values indicate flows higher than the average, while negative values signify lower flows.

The SD method was applied to monthly, seasonal, and annual values, while the PC method was utilized to determine the frequency of days with high (75th percentile) and low (25th percentile) flows, as well as very high (91st percentile) and very low (9th percentile) flows. Flow values between the 25th and 75th percentiles are classified as "permissible" (typical) deviations. Values above the 98th percentile and below the 2nd percentile are considered extremely rare events, making trend calculation impossible. Therefore, the analysis focuses on "moderate" extremes, which are more frequent and allow for trend calculation (9th, 25th, 75th, and 91st percentiles).

Table 2 - Categorization of flow anomalies based on standardized deviation (SD) and percentiles (PC).

Regime of flow	Range of SD values	Range of PC values
Extremely high flow	> 3	> 98th percentile
Very high flow	2 - 3	91-98th percentile
High flow	1 - 2	75-91th percentile
Normal flow	-1 - 1	25-75th percentile
Low flow	-1 - (-2)	9-25th percentile
Very low flow	-2 - (-3)	2-9th percentile
Extremely low flow	< -3	< 2th percentile

Standard deviations (SD) were calculated separately for monthly, seasonal, and annual levels based on flow values for the period 1961-2023. For example, when calculating the SD for January, all mean January flows during the observed 63-year period (1961-2023) are categorized into defined classes. The percentile thresholds were calculated for each month based on the entire time series data (1961-2023). Therefore, in both cases, the base period for calculating SD and percentiles is the entire period (1961-2023). When determining the threshold for the 91st (or 9th) percentile for a given month, such as January, the number of days with mean daily flows above (or below) the obtained percentile value during the period 1961-2023 is counted. For instance, by summing the number of such days across all 12 months of a particular year, such as 2020, the total number of days for that year is obtained.

Consequently, four sets of time series were generated for the mentioned percentiles (9th, 25th, 75th, and 91th), with 12 time series formed for each month, totaling 48. Subsequently, trend analysis was conducted to observe the direction in which the annual and monthly number of days featuring high and low flows, including those with significantly high or low flows, is moving.

To better understand the potential impact of contemporary climate changes on hydroclimate, the period 1961-2023 was divided into two subperiods: 1961-2000 and 2001-2023. This division allowed for the straightforward comparison of changes in flow, temperature, and precipitation in the studied area. To assess the relationship between monthly oscillation values and hydroclimatic parameters, Pearson's correlation coefficient was calculated, and its significance was verified using the t-test at the 95% ($p < 0.05$) and 99% ($p < 0.01$) confidence levels (Vukadinović, 1981). It is important to note that when calculating the correlation coefficient between oscillation indicators and hydroclimatic elements, the period for which the standardized deviations of atmospheric oscillation indicators are computed is irrelevant, as the coefficient values remain unchanged (i.e., they do not vary).

Table 3 - Frequency of Mean Monthly Flows According to Standardized Deviations (SD) at the Jasika Hydropower Station Profile of the West Morava River (1961-2023).

Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Extremely high flow	1	0	1	0	0	1	3	1	1	2	1	1
Very high flow	1	2	2	2	5	1	2	4	5	0	1	1
High flow	11	10	5	8	3	6	6	6	3	5	11	7
Normal flow	41	43	46	42	50	52	51	49	50	55	47	41
Low flow	9	8	9	11	5	3	1	3	4	1	3	13
Very low flow	0	0	0	0	0	0	0	0	0	0	0	0
Extremely low flow	0	0	0	0	0	0	0	0	0	0	0	0
Total	63	63	63	63	63	63	63	63	63	63	63	63
Negative SD	40	36	34	34	41	42	41	38	40	43	38	34
Positive SD	23	27	29	29	22	21	22	25	23	20	25	29

RESULTS

Categorization of mean flow deviations

Over the observed 63-year period (1961-2023), the average monthly flow in January experienced negative deviations 40 times, while in 23 years, the flow exceeded the normal value for this month. Normal deviations (±1 SD) occurred in January for 41 years, representing 65.1% of cases. The average January flow fell into the high flow category for 11 years (17.5% of cases), with only one instance (1.6%) classified as very high flow. Extremely high flows (deviation > 3 SD) were classified only once, specifically in January 2023. Conversely, there were 9 instances of January flows falling into the category of small flows, with no occurrences of very small flows. Notably, no January had a mean flow deviating < -3 SD, indicating the absence of extremely low flows. Similar observations can be made for other months as well (table 3).

Similar results were obtained at the seasonal and annual levels. For instance, over 33 years (52.4%), the mean annual flow experienced negative deviations, while positive deviations were observed 30 times (47.6%). Mean annual flow fell into the category of small flows for 11 years, while there were no occurrences of very small or extremely small flows in the observed 63-year period. The categories of large and very large flows were observed for 9 and 2 years.

The relationship between flow, precipitation, and temperature is illustrated through the seasonal and annual dynamics of these three hydroclimatic elements for the observed period. The graphical representation shows the actual values of temperature, flow, and precipitation (fig. 2) along with the average, depicted as a horizontal line. Values above this average (horizontal line) represent higher temperature, increased flow, and greater precipitation, and vice versa. Generally, it is observed that since 2000, temperature has shown a clear dominance of positive deviations, particularly pronounced in the summer season. Flow also exhibits interannual oscillations, but negative deviations have been predominant since 2000. Regarding precipitation, there has been a noticeable surplus in the summer season and on an annual basis over the past decade. These observations suggest that under current conditions, the rise in temperature poses a greater threat to the flow of the West Morava River by increasing evaporation rates, leading to flows below the average.

When examining all time units (months, seasons, and years), two common characteristics emerge. Firstly, over the analyzed 63-year period (1961-2023), there is an overwhelming prevalence of negative deviations, signifying that occurrences of low flows are far more frequent, with no instances of very small or extremely small flows. Secondly, at least once or twice, flows classified as very large flow were recorded across almost all time units, with nearly every category experiencing at least one instance of extremely large flow. Thus, the prevalence of “dry” flows, alongside those categorized as very large and extremely large flows, primarily suggests the influence of contemporary climate changes. To better understand this impact, further examination of daily flows is necessary.

Changes in daily flows

Based on the available data, the period of instrumental measurements at HS Jasika revealed notable extremes in the water regime of the West Morava. The absolute lowest flow recorded was a mere 14 m^3/s, documented on September 11, 2017, at 1:30 p.m. In contrast, the absolute maximum flow peaked at 2150 m^3/s, occurring three years earlier on May 14, 2014, at 1:00 a.m. This vast disparity illustrates an absolute fluctuation amplitude of 2136 m^3/s, corresponding to a ratio of 1:154. Such a significant fluctuation amplitude underscores the torrential nature of the West Morava. To mitigate these extremes and ensure a more balanced flow, it is imperative to implement measures within the basin to enhance the river’s suitability for various water management purposes. It is noticeable that both extremes were recorded in the last 10 years of the observed period, which is most likely a consequence of contemporary climate changes.

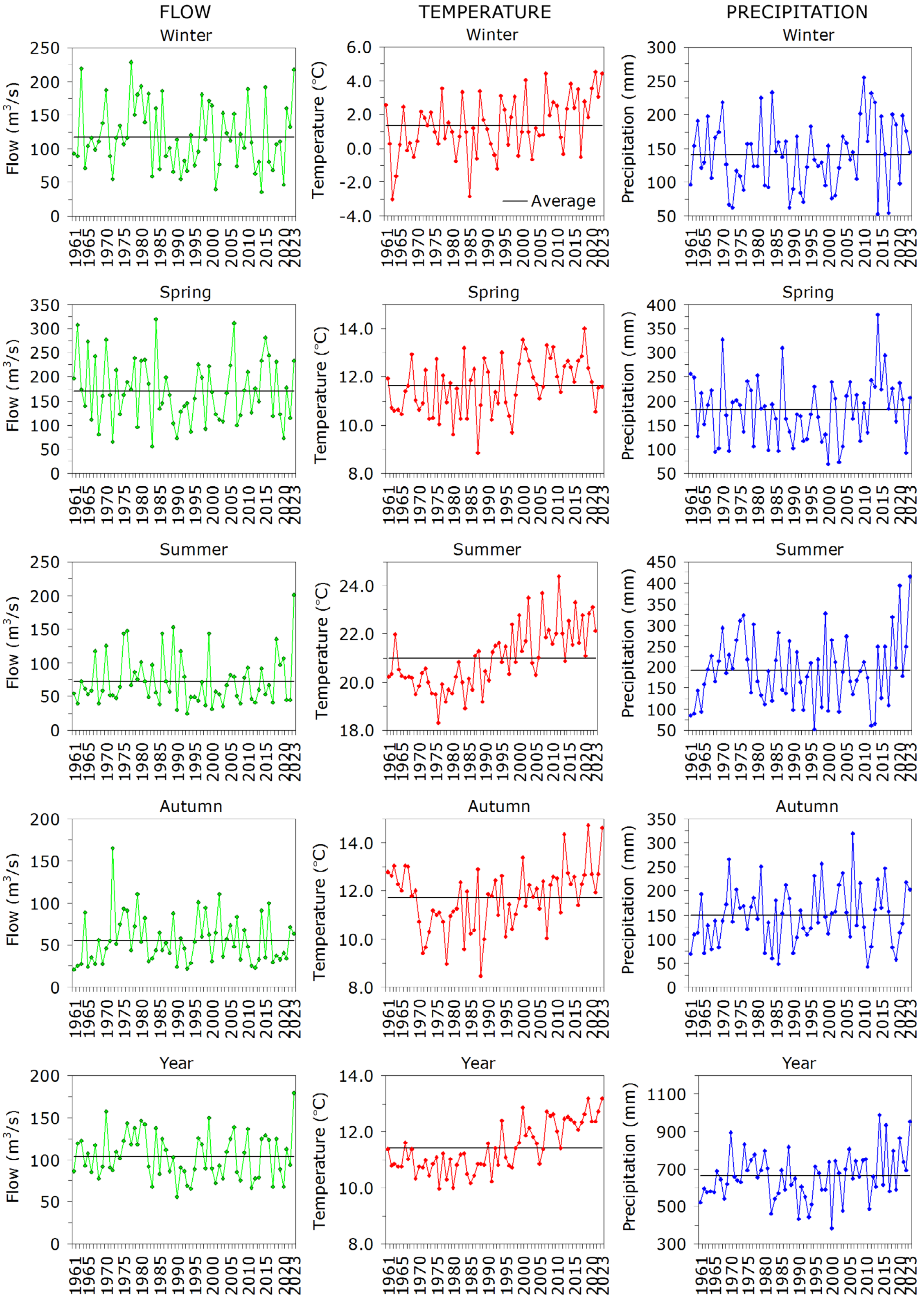

Figure 2 - Seasonal and annual values of flow at the West Morava River gauge Jasika, and temperature and precipitation at the meteorological station Kruševac, for the period 1961-2023.

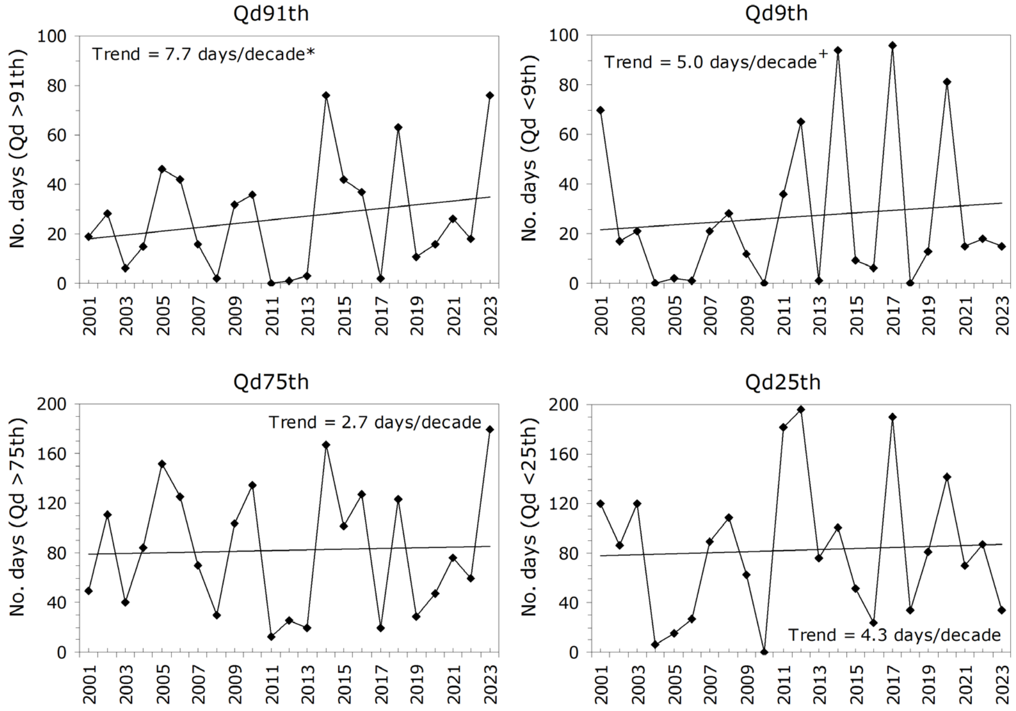

Figure 3 - Trend of the annual number of days with small and large flows (Qd25th and Qd75th), as well as very small and very large flows (Qd9th and Qd91th) at the HS Jasika profile of the West Morava River for the period 2001-2023 (Significance: *p < 0.05 and +p < 0.1).

In mid-May 2014, Serbia experienced unprecedented floods that affected a large part of the country (https://sr.wikipedia.org/sr/Poplave_u_Srbiji_2014, last accessed: 13 September 2024). Flood also occurred at the end of January 2015 (https://www.telegraf.rs/vesti/1407022-poplave-2015-pogledajtesta-ostavlja-pobesnela-juzna-morava-iza-sebe-video, last accessed: 13 September 2024), in the first decade of March 2016 (https://www.glasamerike.net/a/serbia-floods/3226316.html, last accessed: 13 September 2024), in June 2020 (https://nsuzivo.rs/srbija/poplave-sirom-srbije-vanredna-situacija-u-15-opstina, last accessed: 13 September 2024), and again in June 2023 (https://www.bbc.com/serbian/lat/srbija-65823230, last accessed: 13 September 2024). According to Petrović (2021), the West Morava River basin registers the highest number of flash floods in Serbia. The author highlights a statistically significant increasing trend in the number of flash floods both in Serbia and in the West Morava basin during the period 1915-2019. She notes that the highest number of flash floods and casualties occurred between 1991 and 2019. On the other hand, after 2010, Serbia has experienced several extreme droughts in 2011, 2012, 2013, 2015, 2017, 2019, 2021, and 2022 (Djurdjević *et al.*, 2024). These are just some of the facts pointing to the impact of contemporary climate change and global warming, but further research is required.

For the period 1961-2023, the trend analysis showed a decrease in the annual number of all observed days (from -1.3 days/decade to -1.7 days/decade). The results of statistical significance indicate that the trend rates are insignificant for all four indicators. In order to more precisely determine the changes in flow, trend calculations were performed for each month separately. In this case, too, the changes were negligible, as the trend value for all four percentile indices at the monthly level did not exceed ±0.3 days per decade. However, it should be noted that the number of days increases with: very low flows (Qd9th) in January, March, and April, low flows (Qd25th) in January and June, high flows (Q75th) in March, August, September, October, and December, and very high flows (Qd91st) in March and June.

To better discern the potential impact of climate change on the fluctuations of the West Morava flow, trend calculations were conducted for the recent portion of the 21st century (2001-2023). The obtained results for the 23-year period showed an increase in the number of all days (fig. 3). The trend of increasing the number of very large flows (Qd91th = 7.7 days/decade) and very small flows (Qd9th = 5.0 days/decade) is statistically significant at the level of correctness risk of 95% and 90% ($p < 0.05$ and $p < 0.1$). It could be said that the increase in the frequency of extreme flows is the most indicative indicator of the effects of contemporary climate change.

Trend of Monthly, Seasonal, and Annual Flows, Temperature, and Precipitation

The average annual flow of the West Morava at the Jasika HS, observed from 1961 to 2023, is 105.1 m^3/s. The lowest average monthly flow occurs in September, at 43.1 m^3/s, while the highest is in March, at 187.2 m^3/s. On a seasonal basis, the lowest flow occurs in autumn (57.4 m^3/s), while the highest occurs in spring (170.8 m^3/s). Based on the obtained results, the changes in the average flows of the West Morava at the HS Jasika profile are not significant throughout the period from 1961 to 2023, both on a monthly and annual as well as seasonal basis, statistically speaking. Only the month of May and July shows a significant decrease in flow (table 4). However, it should be noted that the flow values during seven months, as well as on an annual level, and particularly in winter, spring, and summer, exhibit a slight downward trend.

When the data on precipitation from the vicinity of MS Kruševac is analyzed, the dominance of a positive trend is evident, and a significant increase is registered in the months of March and October (6.9% and 8.0%/decade), as well as the annual sums (2.6%/decade). Air temperature exhibits a consistent positive trend across all time intervals (months, seasons, and annually). A significant increase in temperature is recorded in almost all months. The increase in temperature is only insignificant in April and November. The most intense warming is observed in the winter and summer months, with a rate of 0.40-0.52°C per decade. Qualitatively similar results were obtained for the other two meteorological stations (Požega and Kraljevo). Overall, we can conclude that the rise in evapotranspiration due to temperature escalation is counterbalanced by increased precipitation, resulting in no significant alterations in the average flow of the West Morava River.

Difference in Flow, Precipitation, and Temperature Between Two Subperiods: 1961-2000 and 2001-2023

Previous observations have indicated that seasonal and annual temperatures have shown a clear dominance of positive anomalies since 2000, and that flows below the average have been more frequently recorded since then. To better understand the extent of changes in the three hydroclimatic elements under consideration, the period 1961-2023 was divided into two subperiods: 1961-2000 and 2001-2023. Simple differentiation was applied for this analysis. Specifically, the average values for the two subperiods were calculated first, and then the difference between 2001-2023 and 1961-2000 was computed. Regarding flow, the early 21st century (2001-2023) shows higher average values compared to the 1961-2000 period in March, June, and October, as well as in the spring season. In all other instances, the average flow is lower in the 2001-2023 period compared to 1961-2000. Conversely, precipitation shows the opposite trend, with the average amount for 2001-2023 being higher compared to the 1961-2000 period (table 5). The only exceptions are June and September, which have marginally lower precipitation in the second subperiod compared to the first (only 0.4 mm). Regarding temperature, the second subperiod (2001-2023) is warmer compared to the first (1961-2000) across all cases (months, seasons, and years). Qualitatively similar results were obtained for all three meteorological stations, but for efficiency, only the results for Kruševac are presented.

The relationship between these three hydroclimatic elements is complex, as flow is not solely dependent on precipitation and temperature (evaporation). Flow is also influenced by anthropogenic factors (such as river water use for irrigation, hydroelectric power, and other industries, land and forest degradation, etc.). Nonetheless, the interdependence between flow on the one hand and precipitation and temperature on the other is quite logical. In a specific example, let's consider the months of March and July. In March, the average flow for the period 2001-2023 is 32.7 m^3/s higher than in the previous 40-year period (1961-2000). This month has become 1.4°C warmer. Higher temperatures have certainly led to increased evaporation, but the flow has not decreased; on the contrary. This apparent anomaly is explained by the higher amount of precipitation in the second subperiod (2001-2023) compared to the first (1961-2000). Specifically, the average precipitation in March is greater by 16.8 mm or 30.2% in the second subperiod. Another example is July, the month that warms up the fastest. In the second subperiod, July is 2.0°C warmer compared to the first subperiod. This month also experiences a higher precipitation amount by 12.2 mm in the second period. However, the flow is lower in the second period by 10.8 m^3/s. Thus, despite the higher precipitation in July, the flow of the West Morava River at the HS Jasika profile is lower due to higher temperatures, which lead to increased evaporation during this month, the hottest of the year.

The impact of atmospheric oscillations on changes in flow (Q), precipitation (P), and temperature (T)

Variations in atmospheric and oceanic oscillations play a crucial role in shaping weather and climate patterns (Sheridan and Lee, 2012). As previously noted, river flow is influenced by precipitation and temperature. In this specific context, the correlation between river flow (Q) and temperature (T) is statistically insignificant only during the period from November to January. In all other months, especially from May to September, significant correlations are observed, with coefficient values ranging from 0.40 to 0.52. On the other hand, the correlation between Q and P is significant throughout all months, with correlation coefficients reaching up to 0.74. Regarding the connection with atmospheric oscillations, the analysis revealed that the North Atlantic Oscillation (NAO) pattern at sea level (NAO-slp) exhibits a significant relationship with all three hydroclimatic parameters (Q, P, and T) in January, February, and March. In September, the connection is significant with Q and P, while in June and July, it is significant with T. In December, a significant connection is observed only with Q. However, for the months of April, May, and August, none of the considered parameters show statistical significance with NAO-slp.

Table 4 - Trend and Significance of Average Flows (Q), Precipitation (P), and Temperature (T) Along the West Morava River (1961-2023).

	Trend Q	Trend P (%/decade)			Trend T (°C/decade)		
	(m^3/s/decade)	MS Požega	MS Kraljevo	MS Kruševac	MS Požega	MS Kraljevo	MS Kruševac
Jan	-1.2	1.0	1.4	5.3	0.38***	0.44***	0.49***
Feb	-2.5	2.0	1.9	0.6	0.32**	0.39**	0.42**
Mar	1.7	0.9	0.6	6.9^{+}	0.19^{+}	0.27^{+}	0.33*
Apr	1.1	-0.2	-0.8	0.9	0.11	0.11	0.17
May	-7.1*	0.0	-0.1	-1.0	0.14	0.11	0.19^{+}
Jun	-0.1	0.6	-0.3	-1.2	0.34***	0.36***	0.40***
Jul	-1.7^{+}	0.5	1.1	3.5	0.47***	0.50***	0.52***
Aug	0.4	0.6	0.9	5.5	0.45***	0.53***	0.51***
Sep	-0.2	0.3	0.3	1.0	0.18	0.17	0.23^{+}
Oct	1.0	3.6	3.8	8.0^{+}	0.19	0.20^{+}	0.24^{+}
Nov	-0.3	-0.1	-0.8	-1.9	0.16	0.16	0.21
Dec	1.1	0.7	0.6	1.6	0.31**	0.45***	0.47***
Year	-1.3	0.6	1.6	2.6*	0.27**	0.31***	0.33***
Winter	-1.6	2.0	1.9	3.2	0.35**	0.35**	0.41**
Spring	-2.2	0.3	-0.7	1.4	0.18*	0.16*	0.22**
Summer	-0.2	0.4	0.9	2.4	0.39***	0.45***	0.46***
Autumn	0.8	0.9	1.1	3.8	0.18^{+}	0.21*	0.21*

*** $p < 0.001$**, $p < 0.01$, * $p < 0.05$ and $^{+}$ $p < 0.1$.

Table 5 - Difference in flow (Q) at the HS Jasika profile of the West Morava River, and precipitation (P) and temperature (T) at the MS Kruševac between the subperiods 2001-2023 and 1961-2000.

	Q (m^3/s)			P (mm)			T (°C)		
	1961-2000 (A)	2001-2023 (B)	B-A	1961-2000 (A)	2001-2023 (B)	B-A	1961-2000 (A)	2001-2023 (B)	B-A
Jan	111.0	105.4	-5.6	41.2	53.1	11.9	-0.6	1.0	1.6
Feb	152.2	135.8	-16.5	38.0	43.5	5.5	1.9	3.2	1.3
Mar	177.9	210.6	32.7	42.9	59.7	16.8	6.1	7.5	1.4
Apr	181.0	174.1	-6.9	55.1	64.0	8.8	11.5	12.2	0.8
May	150.7	127.3	-23.4	73.0	74.9	1.9	16.2	17.0	0.7
Jun	104.1	112.6	8.5	79.5	79.1	-0.4	19.5	20.9	1.5
Jul	70.7	59.9	-10.8	59.7	71.9	12.2	21.0	22.9	2.0
Aug	45.1	44.6	-0.5	45.1	53.0	7.9	20.7	22.5	1.8
Sep	45.2	41.1	-4.1	47.9	47.5	-0.4	16.6	17.5	0.8
Oct	49.7	51.5	1.8	39.4	56.7	17.3	11.3	12.1	0.8
Nov	73.2	68.5	-4.7	55.2	56.3	1.1	6.0	7.5	1.5
Dec	101.4	96.8	-4.6	53.8	55.8	2.1	1.2	2.5	1.3
Year	105.2	102.3	-2.8	630.9	715.6	84.7	10.9	12.2	1.3
Winter	122.1	110.5	-11.6	133.6	152.2	18.6	0.9	2.2	1.3
Spring	169.9	170.7	0.8	171.1	198.6	27.5	11.3	12.2	1.0
Summer	73.3	72.3	-0.9	184.4	204.0	19.6	20.4	22.1	1.7
Autumn	56.0	53.7	-2.3	142.4	160.5	18.1	11.3	12.4	1.1

Qualitatively similar results were obtained for NAO-500 (table 6). Also, the summer variant of NAO (SNAO) in January shows a significant connection with all three parameters. The SNAO index is defined to better identify the influence of NAO in the summer months, as the calculations have shown, resulting in a stronger correlation with two out of three parameters compared to NAO. On the other hand, the influence of NCP is present in January and February on all three hydroclimatic parameters, and in July, August, October, and December on two each. EA showed the strongest connection with T, especially in February, April, and August, with correlation coefficients ranging from 0.61 to 0.71. Oscillations over the Mediterranean basin (MOI and WeMO) mostly influence some of the considered parameters in winter, and similar results were obtained for EAWR. The influence of the SCAND pattern is mostly felt on T.

The results obtained indicate that variations in atmospheric oscillations affect the hydroclimate of the studied area. This impact is directly manifested on air temperature and precipitation, while the relationship between atmospheric oscillations and flow is indirect, mediated through these two climatic elements (precipitation and temperature, i.e., evaporation).

Table 6 - Correlation coefficients between the index of teleconnections and monthly flows (Q), temperature (T) and precipitation (P) according to data from HS Jasika and MS Kruševac.

Teleconnection	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NAO-slp	Q	-0.36**	-0.42**	-0.29*						-0.27*			-0.26*
	T	0.26*	0.32*	0.33**			-0.30*	-0.34**					
	P	-0.26*	-0.50**	-0.33**						-0.39**			
SNAO	Q	-0.25*							0.36**	0.25*			-0.28*
	T	-0.45**	-0.71**	-0.27*	-0.52**		-0.44**	-0.35**	-0.40**	-0.41**	-0.50**	-0.58**	-0.54**
	P	-0.28*		-0.29*			0.34**	0.26*					
AO	Q	-0.36**	-0.47**	-0.31*				0.25*	0.25*			-0.28*	-0.26*
	T			0.31*									
	P	-0.45**	-0.47**							-0.33**	-0.27*	-0.28*	-0.31*
MOI	Q	-0.31*	-0.36**							-0.28*			
	T				-0.27*							-0.25*	
	P		-0.36**	-0.29*				-0.30*		-0.36**			
WeMO	Q												
	T	0.26*	0.39**								0.32*	0.47**	0.42**
	P	0.43**											0.31*
NCP	Q	-0.32*	-0.47**					0.36**	0.36**				-0.31*
	T	-0.27*	-0.48**		-0.44**				-0.38**	-0.29*	-0.45**	-0.54**	-0.50**
	P	-0.60**	-0.36**	-0.41**				0.38**			-0.51**		
EA	Q						-0.31*			-0.27*			
	T	0.43**	0.71**	0.32*	0.61**	0.51**	0.39**	0.47**	0.61**	0.42**		0.32*	
	P					-0.30*	-0.32*			-0.35**	-0.25*		
EAWR	Q												
	T	-0.43**	-0.27*							-0.25*	-0.33**		-0.41**
	P	-0.36**	-0.38**								-0.33**		-0.32*
SCAND	Q								0.25*				
	T		-0.36**	-0.36**	0.25*		-0.34**		-0.37**			0.40**	
	P						0.27*	0.26*		0.25*			
NAO-500	Q	-0.25*	-0.44**	-0.38**					0.29*				
	T	0.29*		0.29*			-0.30*	-0.29*			-0.30*	-0.28*	
	P	-0.25*	-0.34**	-0.25*			0.25*						

** $p < 0.01$, * $p < 0.05$.

DISCUSSION

There is no doubt that the temperature on our planet is rising (Burić and Penjišević, 2023), and the detrimental effects of climate change on water resources are being witnessed globally. The demand for clean water is escalating, yet the availability is diminishing. Therefore, preserving the world's water resources stands as the foremost imperative for both present and future generations. However, freshwater reservoirs face vulnerabilities not only from climate change but also from direct human interventions and the expanding global population (Vörösmarty *et al.*, 2000). Wang *et al.* (2024) examined alterations in average monthly river flows across 10,120 hydrological stations spanning from 1965 to 2014. Their findings revealed that climate change is disrupting seasonal flow patterns, particularly in the higher latitudes of America, Russia, and Europe. The authors contend that the escalating air temperatures are fundamentally altering natural river flow patterns. Their research reveals a troubling decline in seasonal flows across most rivers, directly linked to anthropogenic greenhouse gas emissions. Ultimately, they conclude that continued temperature increases could lead to a permanent and significant reduction in seasonal flows. Projections suggest that water resources will face even greater pressures from climate change and human activities in the future compared to the present (van Vliet *et al.*, 2023). Predictions through 2050 indicate a 10-40% runoff increase in eastern equatorial Africa, the La Plata basin, and higher latitudes of Eurasia and North America. Conversely, southern parts of Africa and Europe, alongside the Middle East and mid-latitudes in western North America, are anticipated to see a runoff reduction of 10-30% (Milly *et al.*, 2005).

The impact of anthropogenic climate change on hydroclimate has been extensively documented in numerous studies (e.g. Andualem *et al.*, 2020; Sharma *et al.*, 2020; Malede *et al.*, 2024). It is widely believed that global warming accelerates the hydrological cycle, leading to increased water evaporation (resulting in more water vapor in the atmosphere) and altering precipitation patterns (Chen and Grasby, 2014). However, when considering the drivers of contemporary climate changes, it is imperative to account for the influence of natural factors, such as fluctuations in solar activity, volcanic eruptions, and variations in atmospheric and oceanic oscillations. For instance, research has established connections between the flow of major rivers that discharge into the Arctic Ocean (such as the Mackenzie, Ob, Lena, and Yenisei rivers) and phenomena like ENSO, AO, NAO, and the Pacific Decadal Oscillation (PDO) (Ahmed *et al.*, 2021). Additionally, other studies have demonstrated the relationships between hydroclimatic parameters and teleconnections (e.g. Xiao *et al.*, 2014; Shi *et al.*, 2021).

In the context of Serbia, it is important to emphasize the significant economic, social, and ecological value of the catchment area of the West Morava River. This region holds particular importance for the country due to its abundance of renewable domestic freshwater resources, with the majority located within the catchment of this river. The detailed analysis of the flow of the West Morava, presented in this paper for the period 1961-2023, showed that there is a dominance of low flows, and in the last two decades, an increased number of extreme cases. This tendency is not favorable for the ecology and economy of the part of Serbia with the most important water resources in the country.

Rivers across the Balkan Peninsula, including those in Serbia, exhibit a characteristic seasonal flow pattern, with lower flows during the summer and higher flows during the winter and early spring, rendering them susceptible to flooding. Papadaki and Dimitriou (2021) highlight that in recent decades, the flow of Balkan rivers has experienced a decline due to a combination of factors including reduced precipitation and anthropogenic influences such as mismanagement of water resources. Pekarova *et al.* (2018) conducted an examination of changes in the flow of the Danube River, utilizing data obtained from the Ceatal Izmail hydrological station situated in Ukraine, near the river's mouth. Their analysis, spanning from 1840 to 2015, revealed that the average flow of the Danube did not undergo significant alterations over this period. However, the study identified a notable shift in the timing of spring high waters in recent years, occurring approximately 40 days earlier than historical norms. The Sava River is the second longest tributary of the Danube (after the Tisza), but it contributes the largest amount of water (Komatina and Grošelj, 2015). For the period 1971-2010, as well as for the longer period from 1931-2010, it has been determined that the Sava River shows a significant negative trend in mean annual flow (Lutz *et al.*, 2016; Orešić *et al.*, 2017). Using RCP2.6 and RCP8.5 emission scenarios, Probst and Mauser (2023) analyzed changes in several hydroclimatic elements (temperature, precipitation, soil water content, etc.), including flow dynamics in the Danube River basin for the near future (2031-2060) and distant future (2071-2100) compared to the baseline period of 1971-2000. The authors note that "climate change impacts remain moderate for RCP2.6 and become severe for RCP8.5", but both scenarios predict an increase in winter flow and a decrease in summer flow, as well as an increased risk of high flows along the entire Danube River, with a heightened risk of low flows in the lower reaches of the river (through Serbia and downstream). During the period 1961-2020, a trend of decreasing flow has also been observed in rivers in neighboring Bosnia and Herzegovina (Gnjato *et al.*, 2023). Research on the annual flow of seven major rivers in Greece has shown that significant drought periods occurred in the late 1980s and early 2000s, with a wet period recorded in the last decade (Mentzafou *et al.*, 2015).

CONCLUSION

This study aimed to analyze changes in the flow of the West Morava River based on data from HS Jasika, situated near the confluence of the West Morava with the South Morava, where the Great Morava begins. Furthermore, the study aimed to explore the potential impact of various teleconnections on hydroclimatic changes in the observed area. An in-depth examination of the flow patterns of the West Morava at the HS Jasika profile spanning from 1961 to 2023 reveals significant fluctuations across all temporal scales (daily, monthly, seasonal, yearly), indicating the river's torrential nature. Furthermore, throughout the 63-year duration under scrutiny (1961-2023), negative standardized deviations dominate (> 50% of occurrences), signifying a higher frequency of low-flow episodes. Upon examining mean daily flows, it was observed that the annual count of observed days is declining, contrary to expectations. However, in the recent period (2001-2023), there was an increase in the number of days with very high (Qd91th) and high (Qd75th) flows, as well as very low (Qd9th) and low (Qd25) flows. At the same time, the increase in Qd91th and Qd9th is statistically significant. So, on the one hand, we have increasingly lower average flows on a monthly, seasonal and annual level, and on the other hand, an increase in the number of days with very large and very small flows, which indicates the impact of climate change.

The trend calculations showed a dominance of negative values, and a significant decrease in flow was registered in May and July. In the observed 63-year period (1961-2023), the trend in monthly, seasonal, and annual precipitation along the West Morava River is insignificant at all three meteorological stations. However, the temperature trend is positive and statistically significant, with the most intense warming occurring in summer, which also experiences the highest evaporation rates of the year. It can be concluded that significant warming during the observed period has led to increased evaporation, which has had a greater impact on river flow than precipitation, in general. This is supported by the fact that the 2001-2023 period is somewhat wetter in terms of precipitation compared to the previous 40-year period (1961-2000), while river flow has decreased. On the other hand, the current part of the 21st century (2001-2023) is significantly warmer compared to the last four decades of the 20th century (1961-2000). Summer months are now, on average, up to 2.0°C warmer than before. There is no doubt that this increase in temperature has heightened evaporation and contributed to the river flow trend towards drier conditions. Indeed, hydroclimatic variables are influenced by changes in atmospheric and oceanic oscillations, and some studies suggest that climate change also impacts teleconnections (e.g., Rind *et al.*, 2005; Givati and Rosenfeld, 2013). The findings of this study reveal that NAO and NCP exert an influence on the fluctuations of flow, precipitation, and air temperature (Q, P, and T) in the observed area, particularly during colder months. Additionally, all three hydroclimatic parameters show a connection with SNAO, albeit only in the summer months. EA variability has a statistically significant effect on T in February, April, and August, with correlation coefficients ranging between 0.61 and 0.71. Indicators of atmospheric oscillations over the Mediterranean (MO and WeMO), as well as EAWR, exhibit a significant correlation with the hydroclimate of the analyzed location, primarily during winter. The impact of SCAND oscillations is noticeable only on T.

Based on the findings, it is evident that there is currently little to moderate concern regarding the hydroclimatic conditions. However, there is significant cause for concern regarding the future, given the accelerating pace of climate change. Therefore, it is imperative to proactively develop plans for flow equalization and sustainable water resource management in the West Morava basin. Additionally, measures for both mitigating and adapting to present and, more importantly, future climate changes need to be defined and implemented promptly.

AUTHOR CONTRIBUTION

This study was developed with equal contributions from both authors: DB and IP.

CONFLICT OF INTEREST

The authors declare no competing interests.

FUNDING

The study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (contact number: 451-03-65/2024-03/200123.

REFERENCES

Ahmed R., Prowse T., Dibike Y., Bonsal B., 2021. *Effects of climatic drivers and teleconnections on late 20th century trends in spring freshet of four major arctic-draining rivers.* Water, 13, 179. https://doi.org/10.3390/w13020179

Andualem T.G., Malede D.A., Ejigu M.T., 2020. *Performance evaluation of integrated multi-satellite retrieval for global precipitation measurement products over Gilgel Abay watershed, upper Blue Nile basin, Ethiopia.* Modeling Earth Systems and Environment, 6, 1853-1861. https://doi.org/10.1007/s40808-020-00795-w

Burić D., Stanojević G., 2020. *Trends and possible causes of cloudiness variability in Montenegro in the period 1961-2017.* Climate Research, 81, 187-205. https://doi.org/10.3354/cr01615

Burić D., Doderović M., 2022. *Trend of percentile climate indices in Montenegro in the period 1961-2020.* Sustainability, 14 (19), 12519, 18. https://doi.org/10.3390/su141912519

Burić D., Penjišević I., 2023. *Southern Hemisphere temperature trend in association with greenhouse gases, El Niño Southern Oscillation, and Antarctic Oscillation.* IDOJARAS, 127, 23-42. http://doi.org/10.28974/idojaras.2023.1.2

Chen Z., Grasby S.E., 2014. *Reconstructing river discharge trends from climate variables and prediction of future trends.* Journal of Hydrology, 511, 267-278. https://doi.org/10.1016/j.jhydrol.2014.01.049

Djurdjević V., Stosic B., Tošić M., Lazić I., Putniković S., Stosic T., Tošić I., 2024. *Analysis of recent trends and spatiotemporal changes of droughts over Serbia using high-resolution gridded data.* Atmospheric Research, 304, 107376. https://doi.org/10.1016/j.atmosres.2024.107376

Gnjato S., Popov T., Ivanišević M., Trbić G., 2023. *Long-term streamflow trends in Bosnia and Herzegovina (BH).* Environmental Earth Sciences, 82, 356. https://doi.org/10.1007/s12665-023-11040-9

Givati A., Rosenfeld D., 2013. *The Arctic Oscillation, climate change and the effects on precipitation in Israel.* Atmospheric Research, 132-133, 114-124. https://doi.org/10.1016/j.atmosres.2013.05.001

Gulan L.J., Penjišević I., Stajić M.J., Milenkovic B., Zeremski T., Stevanović V., Valjarević A., 2020. *Spa environments in central Serbia: Geothermal potential, radioactivity, heavy metals and PAHs.* Chemosphere, 24, 125171. https://doi.org/10.1016/j.chemosphere.2019.125171

Hernández-Henríquez M.A., Sharma A.R., Déry S.J., 2017. *Variability and trends in runoff in the rivers of British Columbia's Coast and Insular Mountains.* Hydrological Processes, 31, 3269-3282. https://doi.org/10.1002/hyp.11257

Hirsch R.M., Slack J.R., 1984. *A nonparametric trend test for seasonal data with serial dependence.* Water Resources Research, 20, 727-732. https://doi.org/10.1029/WR020i006p00727

Hu D., Xu M., Kang S., Chen J., Yang C., Yang Q., 2023. *The effects of discharge changes in Siberian rivers on Arctic Sea-ice melting.* Remote Sensing, 15, 3477. https://doi.org/10.3390/rs15143477

Kalugin A., 2023. *Climate change effects on river flow in Eastern Europe: Arctic rivers vs. Southern rivers.* Climate, 11, 103. https://doi.org/10.3390/cli11050103

Kendall M.G., 1975. *Rank Correlation Methods.* Charles Griffin, London.

Komatina D., Grošelj S., 2015. *Transboundary water cooperation for sustainable development of the Sava River basin.* In: Milačič R., Ščančar J., Paunović M (Eds), The Sava River. The Handbook of Environmental Chemistry, 31, 1-25. Springer, Berlin-Heidelberg. https://doi.org/10.1007/978-3-662-44034-6_1

Kwadijk J., Arnell N.W., Mudersbach C., de Weerd M., Kroon A., Quante M., 2016. *Recent change – River flow.* In: Quante M., Colijn F. (Eds), North Sea Region Climate Change Assessment. Regional Climate Studies, 137-146. Springer, Cham. https://doi.org/10.1007/978-3-319-39745-0_4

Langović M., Dragićević S., Živković N., 2022. *Determination of discharge cycles of the South Morava River (Serbia).* International Scientific Conference GEOBALCANICA, 45-57. https://doi.org/10.18509/GBP22045l

Lukić T., Dunjić J., Đerčan B., Penjišević I., Milosavljević S., Bubalo-Živković M., Solarević M., 2018. *Local resilience to natural hazards in Serbia. Case study: The West Morava River Valley.* Sustainability, 10, 2866. http://www.mdpi.com/2071-1050/10/8/2866

Lutz S.R., Mallucci S., Diamantini E., Majone B., Bellin A., Merz R., 2016. *Hydroclimatic and water quality trends across three Mediterranean river basins.* Science of The Total Environment, 571, 1392-1406. https://doi.org/10.1016/j.scitotenv.2016.07.102

Mankin J.S., Viviroli D., Singh D., Hoekstra A.Y., Diffenbaugh N.S., 2015. *The potential for snow to supply human water demand in the present and future.* Environmental Research Letters, 10, 114016. https://doi.org/10.1088/1748-9326/10/11/114016

Malede D.A., Andualem T.G., Yibeltal M., Alamirew T., Kassie A.E., Demeke G.G., Mekonnen Y.G. 2024. *Climate change impacts on hydroclimatic variables over Awash basin, Ethiopia: A systematic review.* Discover Applied Sciences, 6, 27. https://doi.org/10.1007/s42452-024-05640-8

Matti B., Dahlke H.E., Dieppois B., Lawler D.M., Lyon S.W., 2017. *Flood seasonality across Scandinavia. Evidence of a shifting hydrograph?.* Hydrological Processes, 31, 4354-4370. https://doi.org/10.1002/hyp.11365

Martić-Bursać N.M., Radovanović M.M., Radivojević A.R., Ivanović R.D., Stričević Lj.S., Gocić M.J., Golubović N.M., Bursać B.L. 2022. *Observed climate changes in the Toplica River Valley. Trend analysis of temperature, precipitation and river discharge.* IDOJARAS, 126, 403-423. http://doi.org/10.28974/idojaras.2022.3.8

Milly P., Dunne K., Vecchia A., 2005. *Global pattern of trends in streamflow and water availability in a changing climate.* Nature, 438, 347-350. https://doi.org/10.1038/nature04312

Milosavljević S., Penjišević I., Lukić T., 2023. *Hypsometrical distribution of settlements as a factor of regional differentiation of the gender-age structure of the populaion of West Morava Valley.* Bulletin of the Serbian Geographical Society, 103, 1-26. https://doi.org/10.2298/GSGD2301001M

Mentzafou A., Dimitriou E., Papadopoulos A., 2015. *Long-term hydrologic trends in the main Greek rivers: A statistical approach.* In: Skoulikidis N., Dimitriou E., Karaouzas I. (Eds), The Rivers of Greece. The Handbook of Environmental Chemistry, vol 59. Springer, Berlin-Heidelberg. https://doi.org/10.1007/698_2015_446

Orešić D., Čanjevac I., Maradin M., 2017. *Changes in discharge regimes in the middle course of the Sava River in the 1931-2010 period.* Prace Geograficzne, 151, 93-119. https://doi.org/10.4467/20833113PG.17.024.8036

Papadaki C., Dimitriou E., 2021. *River flow alterations caused by intense anthropogenic uses and future climate variability implications in the Balkans.* Hydrology, 8, 7. https://doi.org/10.3390/hydrology8010007

Pekarova P., Gorbachova L., Bacová Mitkova V., Pekar J., Miklanek P., 2018. *Statistical analysis of hydrological regime of the Danube River at Ceatal Izmail Station.* IOP Conference Series: Earth and Environmental Science, World Multidisciplinary Earth Sciences Symposium (WMESS 2018) 3-7 September 2018, Prague, Czech Republic, 221, 012035. https://doi.org/10.1088/1755-1315/221/1/012035

Penjišević I., 2022. *Zapadno Pomoravlje - regionalni razvoj.* Istorijski institut, Kraljevo, Srbija (eng. *Western Pomoravlje. Regional development.* Institute of History, Kraljevo, Serbia).

Petrović A., 2021. *Torrential floods in Serbia.* Serbian Geographical Society, Belgrade, v. 73, 167 pp. https://www.researchgate.net/publication/355646649

Pratap S., Markonis Y., 2022. *The response of the hydrological cycle to temperature changes in recent and distant climatic history.* Progress in Earth and Planetary Science, 9, 30. https://doi.org/10.1186/s40645-022-00489-0

Probst E., Mauser W., 2023. *Climate change impacts on water resources in the Danube River Basin: A hydrological modelling study using EURO-CORDEX climate scenarios.* Water, 15, 8. https://doi.org/10.3390/w15010008

Rawlins M., Yang D., Ge S., 2021. *Regional and basin streamflow regimes and changes: Climate impact and human effect*. In: Yang D., Kane D.L. (Eds), Arctic Hydrology, Permafrost and Ecosystems, 159-186. Springer, Cham. https://doi.org/10.1007/978-3-030-50930-9_6

Rind D., Perlwitz J., Lonergan P., Lerner J., 2005. *AO/NAO response to climate change: 2. Relative importance of low- and high-latitude temperature changes.* Journal of Geophysical Research: Atmospheres, 110, D12108. https://doi.org/10.1029/2004JD005686

Simić Z., Matic B.B., 2017. *Low flow conditions evaluation within the western Morava River Basin.* European Water, 60, 293-298. https://www.ewra.net/ew/pdf/EW_2017_60_40.pdf

Stahl K., Tallaksen L.M., Hannaford J., van Lanen H.A.J., 2012. *Filling the white space on maps of European runoff trends: Estimates from a multi-model ensemble.* Hydrology and Earth System Sciences, 16, 2035-2047. https://doi.org/10.5194/hess-16-2035-2012

Stojković M., Plavšić J., Prohaska S., 2014. *Long-term changes of annual and seasonal flows: A case of the Sava River.* Vodoprivreda, 46, 39-48. https://grafar.grf.bg.ac.rs/handle/123456789/572

Sharma T., Vittal H., Karmakar S., Ghosh S., 2020. *Increasing agricultural risk to hydro-climatic extremes in India.* Environmental Research Letters, 15, 034010. https://doi.org/10.1088/1748-9326/ab63e1

Sheridan S., Lee C.C., 2012. Sy*noptic climatology and the analysis of atmospheric teleconnections.* PPG: Earth and Environment, 36, 548-557. https://doi.org/10.1177/030913331244

Shi X., Huang Q., Li K., 2021. *Decomposition-based teleconnection between monthly streamflow and global climatic oscillation.* Journal of Hydrology, 602, 126651. https://doi.org/10.1016/j.jhydrol.2021.126651

van Vliet M.T.H., Thorslund J., Strokal M., Hofstra N., Flörke M., Macedo H.E., Nkwasa A., Tang T., Kaushal S.S., Kumar R., van Griensven A., Bouwman L., Mosley L.M., 2023. *Global river water quality under climate change and hydroclimatic extremes.* Nature Reviews Earth & Environment, 4, 687-702. https://doi.org/10.1038/s43017-023-00472-3

Vörösmarty C.J., Green P., Salisbury J., Lammers R.B., 2000. *Global water resources: Vulnerability from climate change and population growth.* Science, 289, 284-288. https://doi.org/10.1126/science.289.5477.284

Vukadinović S. 1981. *Elementi teorije verovatnoće i matematičke statistike.* Privredni pregled, Beograd (eng. *Elements of probability theory and mathematical statistics*. Business review, Belgrade), 492 pp.

Wang H., Liu J., Klaar M., Chen A., Holden J., 2024. *Anthropogenic climate change has influenced global river flow seasonality.* Science, 383, 1009-1014. https://doi.org/10.1126/science.adi9501

Xiao M., Zhang Q., Singh V.P., 2014. *Influences of ENSO, NAO, IOD and PDO on seasonal precipitation regimes in the Yangtze River basin, China*. International Journal of Climatology, 35, 3556-3567. https://doi.org/10.1002/joc.4228

(Ms. received 18 July 2024, accepted 29 August 2024)