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IMPACT OF THE MEDITERRANEAN OSCILLATION ON CLIMATE ELEMENTS AND STREAMFLOW IN THE SOUTH MORAVA RIVER BASIN

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Abstract: This study investigates the relationship between climate elements and river flow in the South Morava basin, emphasizing their dependence on the Mediterranean Oscillation Index (MOI). Data from the Korvingrad hydrological station, the Vranje synoptic station, and MOI records were analyzed over a 30-year period (1991–2020). Results indicate a positive trend in mean monthly temperatures across all months, with significant increases in February, March, and April. Significant trends were also observed in mean annual temperature and precipitation. Flow trends exhibited notable changes in March, with an annual flow value of 3.265 m^3s^{-1}. The Pearson correlation coefficient revealed significant seasonal relationships between flow and precipitation, particularly in winter, summer, and autumn, while flow-temperature correlations were significant in summer and autumn. To further quantify these relationships, multiple linear regression was applied, using temperature and precipitation as independent variables and river flow as the dependent variable. The results demonstrated statistically significant associations in 11 out of 12 months, with the strongest linkage observed in November. Seasonal models indicated that precipitation had a dominant influence on flow in winter, spring, and autumn, while temperature had a relatively greater impact during the summer. The autumn model yielded the highest explanatory power ($R^2 = 0.517$). These findings underscore the Mediterranean Oscillation's role in shaping both climate variability and hydrological dynamics in the South Morava basin, while highlighting the importance of integrating statistical modeling to better understand seasonal patterns of flow response to climatic drivers.

Keywords: Temperature, precipitation, streamflow, standard multiple linear regression model, Mediterranean Oscillation, South Morava River

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Introduction

Changes in climate elements and global warming have been the focus of extensive research by scientists worldwide. Historical evidence supports the theory that climate variability is a natural phenomenon. However, many scientists agree that human activities contributed to the rise in global temperatures during the 20th century (Loo, Billa and Singh, 2015). The IPCC AR6 confirms that human influence has unequivocally warmed the atmosphere, ocean, and land, leading to widespread and rapid changes in the climate system (IPCC, 2021). Climate changes impact both natural and anthropogenic systems. The global increase in average temperature intensifies temperature differences between land and sea, as well as between northern and southern latitudes. Precipitation patterns are also shifting, with an increase observed at higher latitudes, while tropical and subtropical land regions experience a decline in precipitation (IPCC, 2007). These alterations are consistent with observed changes in the water cycle, including more intense rainfall and associated flooding, as well as more intense droughts in many regions (IPCC, 2021).

Human-induced climate change is expected to significantly affect the distribution, frequency, and intensity of precipitation, as well as the occurrence of floods and droughts (O'Gorman and Schneider, 2009; Trenberth, 2011; Dankers et al., 2014; Cahyono, Astuti and Rahmat, 2018). Global circulation models confirm a warming trend, and IPCC AR6 projects increasingly extreme weather events—hot spells, heavy rainfall, and droughts—with further warming (Easterling et al., 1997; IPCC, 2007; Fabiano, Meccia, Davini, Ghinassi and Corti, 2021; IPCC, 2021). Air temperatures rose across most of Europe in the 20th century, especially in Southern and Southeastern regions, primarily due to human activity (Brazdil et al., 1996; Brunetti, Buffoni, Maugeri and Nanni, 2000; IPCC, 2007). Future projections show higher summer temperatures and lower annual precipitation in Southern Europe, with warming exceeding global averages and more frequent heat extremes (IPCC, 2021).

Changes in climate elements significantly affect river flow regimes and regional weather patterns. Modeling studies show that river flows respond strongly to climatic shifts, particularly snowmelt dynamics, and may be more influenced by climate change than dam construction by 2050 (Adam et al., 2009; Adam, Hamlet and Lettenmaier, 2009; Doll and Zhang, 2010; Fung, Lopez and New, 2011; Arnell and Gosling, 2013). Historical data link global temperature variations to flow changes, with a 4% increase in river discharge per 1°C warming (Labat, Godderis, Probst and Guyot, 2004). In Southern Europe and the Mediterranean, cyclones moving from west to east, particularly during the winter months, significantly influence precipitation patterns (Sušelj and Bergant, 2006; Burić, Ducić and Luković, 2011; Burić, Ducić, Luković and Doderović, 2014; Martić-Bursać et al., 2017), while climate variability is largely governed by the Mediterranean Oscillation (MO) and its connection to

the North Atlantic Oscillation (NAO) (Corte-Real, Zhang and Wang, 1995; Trigo et al., 2006; Cenk and Turgay, 2020). The NAO has a stronger impact on precipitation in the Iberian and Apennine peninsulas and significantly influences temperatures in Serbia and other regions (Piervitali, Colacino and Conte, 1998; Brown, Caesar and Ferro, 2008; Unkašević and Tošić, 2013; Criado-Aldeanueva and Soto-Navarro, 2020).

The Mediterranean Oscillation (MO) is an atmospheric teleconnection that influences weather conditions in the Mediterranean region (Dunkeloh and Jacobeit, 2003; Cenk and Turgay, 2020). Often, the MO is associated with a pattern of favorable weather and high temperatures in the western Mediterranean, and rainy conditions with low temperatures in the eastern Mediterranean (Maheras and Kutiel, 1999; Burić et al., 2014). During the positive phase of the MO, precipitation is below average across most of the Mediterranean, except along the coasts of the Aegean Sea and the Levant. In contrast, during the negative phase of the MO, the depression center typically shifts near the British Isles or north of the Iberian Peninsula. In this phase, a moist and unstable air mass from the west brings substantial precipitation to the western Mediterranean (Dunkeloh and Jacobeit, 2003; Burić et al., 2014). High temperatures in both the western and eastern Mediterranean are a result of warm air masses circulating from North Africa (Maheras and Kutiel, 1999).

Future changes in air temperature are anticipated across Europe, but similar trends cannot be confirmed for precipitation. Precipitation and flow trends in Serbia require careful analysis, as the European Environmental Protection Agency identifies the Pannonian Basin as a transitional zone between higher latitudes, where increased precipitation is expected, and Southern Europe, where a decrease in precipitation is anticipated (Burić, Stanojević, Luković, Gavrilović and Živković, 2012). Smadi (2006) highlights that the trend of increasing mean annual air temperatures is a result of global warming and changes in atmospheric circulation. Gocic and Trajkovic (2013) concluded that future temperature increases will influence evaporation rates and the frequency of droughts in Serbia. Malinovic-Milicevic, Radovanovic, Stanojevic and Milovanovic (2016) determined that dry periods were more frequent than wet periods in Serbia between 1961 and 2010. They also noted that the temperature shift occurred in the 1980s, followed by a warmer regime at most stations in Serbia.

The primary objective of this study is to identify the trends in average monthly, seasonal, and annual temperatures and precipitation at the Vranje synoptic station, as well as to determine the trends in average monthly, seasonal, and annual streamflows at the Korvingrad hydrological station. The main goal was to apply specific statistical methods to assess the relationship between changes in meteorological and hydrological parameters and variations in the Mediterranean Oscillation index (MOI). To facilitate a clearer understanding of the influence and dependence of the MOI on

the examined climate variables and hydrological flow, parameters were selected to define this relationship using a standard multiple linear regression model.

Database and study area

A dataset was used that includes average monthly air temperature values, total precipitation, streamflow, and the MOI index for the standard 30-year climatic period (1991–2020) (Table 1). The Mediterranean Oscillation index (MOI) is defined as the standardized difference in sea level pressure between stations located in the western and eastern Mediterranean. The index consists of two distinct indicators. The first indicator, denoted as MOI-1, represents the pressure difference between Algeria (36.4° N, 3.1° E) and Cairo (30.1° N, 31.4° E). The second indicator, denoted as MOI-2, represents the pressure difference between Gibraltar (36.1° N, 5.3° E) and Tel Aviv, Israel (32° N, 34.5° E) (Conte, Giuffrida and Tedesco, 1989; Maheras and Kutiel, 1999; Palutikof, 2003; Burić et al., 2014).

Table 1. List of institutions from which data were taken and their relation to the study purpose

Institution	Website	Data	Relation to the study purpose
Republic Hydrometeorological Service of Serbia (RHMSS)	https://www.hidmet.gov.rs	Air temperature, total precipitation, streamflow	Analysis of linear trends, significance, correlation, multiple linear regression, and spectral analysis of fundamental periodicity
University of East Anglia website (Climatic Research Unit)	https://crudata.uea.ac.uk/cru/data/moi/	MOI-1 (MOI: Algiers and Cairo) MOI-2 (MOI: Israel and Gibraltar)	Correlation analysis with the mentioned climatic elements and streamflow, as well as spectral analysis of fundamental periodicity

Average monthly data were obtained from the Vranje synoptic station (MS Vranje) and the Korvingrad hydrological station (HS Korvingrad) (Figure 1), both located within the South Morava Basin, which covers an area of 15,469 km² (Pavlović, 2019). The basin includes parts of southern, eastern, and southeastern Serbia. A small portion extends into North Macedonia, covering the northern slopes of Skopska Crna Gora. Additionally, the upper basin of the Nišava River, the largest right tributary of the South Morava, extends into western Bulgaria (Đokić, 2015). MS Vranje (42° 33’

N, 21° 55' E) is situated on the edge of the Vranje Basin at an altitude of 432 m a.s.l. It receives relatively low annual precipitation (less than 600 mm), evenly distributed between the summer and winter halves of the year. The duration of snow cover typically lasts up to 30 days per year. According to the Köppen Climate Classification (KCC), the Vranje synoptic station falls under the *Cfb* climate type, characterized as a temperate climate without a dry season and with a warm summer. Its specific climatic formula is *Cfs'w'bx* (Mihajlović, 2018). HS Korvingrad is located on the South Morava River at an altitude of 188.09 m a.s.l., approximately 105.7 km from its confluence. The catchment area draining into HS Korvingrad covers 9,396 km².

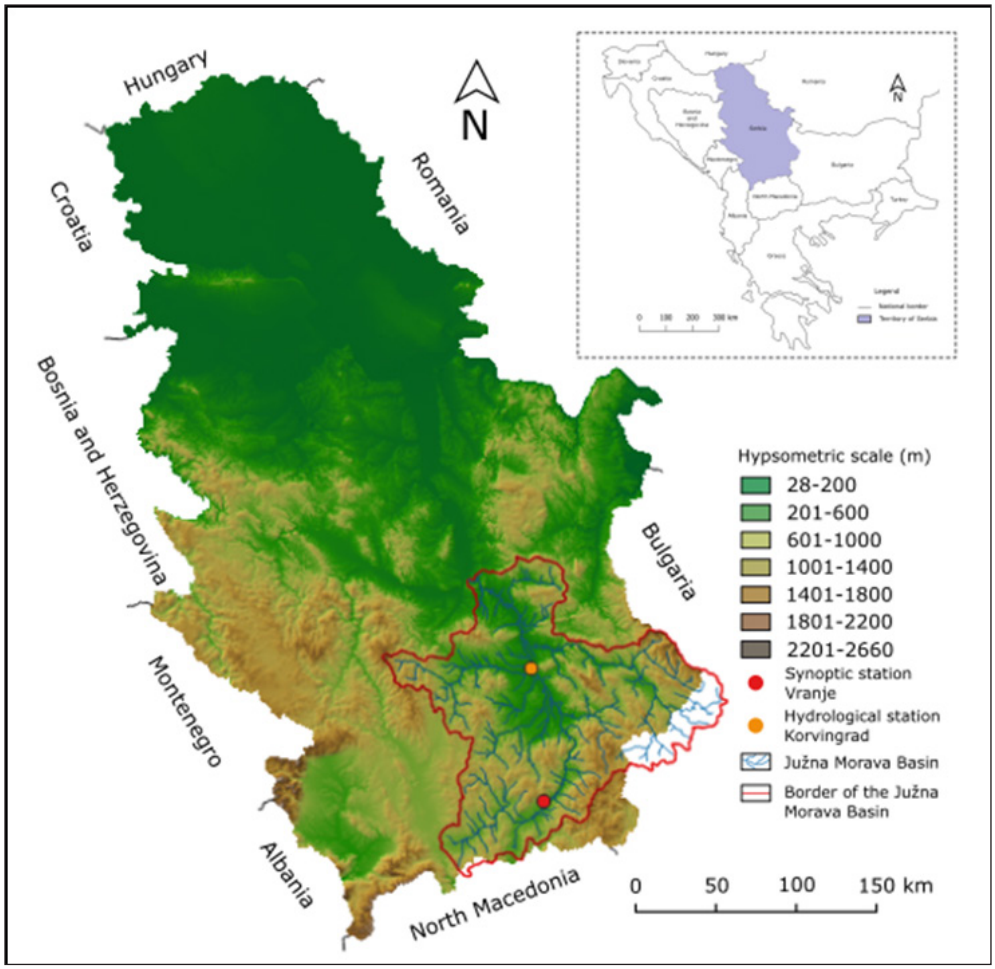


Figure 1. Location of the Vranje synoptic station and the Korvingrad hydrological station relative to the South Morava Basin

For data processing and graphical representation, the software packages Microsoft Office Excel 2003 and PAST[2] 5.1 were used, while Figure 1 was created using the free GIS software QGIS 3.28.2.

Methodology

To better observe changes in the dynamics of air temperature, total precipitation, and streamflow during the 1991–2020 period, the trend line was graphically represented using simple linear regression. Linear regression is a forecasting method that mathematically establishes the relationship between two phenomena, i.e., between a dependent variable and another factor that influences its behavior (independent variable). If the dependent variable exhibits a clear trend over time, the least-squares regression line or linear trend line can be used to predict the dependent variable. The general form of the linear equation is:

$$y = a + bx, \tag{1}$$

where a is the value on the y-axis when x is zero, b is the slope of the line, x represents the time period, and y is the predicted value of the variable for the given x period. The slope is positive if an increase in x corresponds to an increase in y, and negative if an increase in x corresponds to a decrease in y.

The statistical significance of the correlations was determined using a two-tailed Student's t-test, while the trends were assessed using the following equation:

$$y = R\sqrt{\frac{n-2}{1-R^2}}, \tag{2}$$

where R is the Pearson correlation coefficient[3], R^2 is the coefficient of determination, and n is the length of the series.

To better determine and understand the influence and dependence of the examined climatic elements (temperature and precipitation), as well as streamflow, on the MOI index, parameters that define this relationship were determined using the standard multiple linear regression model in PAST (Hammer, Harper and Paul, 2001; Press, Teukolsky, Vetterling and Flannery, 1992) , whose general regression equation is:

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[2] https://www.nhm.uio.no/english/research/resources/past/

[3] The Pearson simple linear correlation coefficient (p) is defined as follows:

$$p = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - (\sum x)^2}\sqrt{n\sum y^2 - (\sum y)^2}}$$

where n is the sample size, and x, y are the variables.

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i}, \quad (3)$$

Where:

- y_i: The dependent variable or response variable for observation *i*. It's what you're trying to predict or explain.
- x_{1i}, x_{2i}: The independent variables (also called predictors, features, or explanatory variables) for observation *i*. These are the inputs used to predict y_i.
- β_0 (b0): The intercept term. It represents the expected value of *y* when both x_1 and x_2 are zero.
- β_1 (b1): The coefficient for x_1. It represents the change in *y* for a one-unit increase in x_1, holding x_2 constant.
- β_2 (b2): The coefficient for x_2. It represents the change in *y* for a one-unit increase in x_2, holding x_1 constant.

This equation models how *y* depends linearly on two predictor variables, x_1 and x_2.

Results and discussion

The average annual air temperature at the Vranje synoptic station during the study period (1991–2020) was 11.2°C. Throughout the year, temperatures rose steadily until July and August, followed by a consistent decline through December. The highest average monthly temperatures, 21.5°C, were recorded in July and August, while December had the lowest average monthly temperature at -0.2°C. The trend in annual temperature change from 1991 to 2020 was 0.058°C, with the ten-year trend change reaching 0.558°C. The results indicate that the trend in the change of the average annual air temperature over the analyzed period is statistically significant (Table 2).

A positive trend in average monthly air temperatures was observed for all months. Statistically significant trends were identified in February, March, and April. The highest mean monthly trend, at an annual rate of 0.092°C, was recorded in April. Turkes and Sumer (2004) and Tabari and Marofi (2011) found a positive trend in mean monthly and annual air temperatures in the eastern Mediterranean, which aligns with the results of this study. The significant trend observed in March also corresponds with an increasing precipitation trend in the same month.

Positive air temperature trends were recorded across all seasons, with the most pronounced change occurring in spring (Table 2). On an annual basis, the trend in average spring temperatures was 0.063°C. Significant changes were also observed in winter and autumn. These findings are consistent with those of Gocic and Trajkovic (2013), who also reported significant increases in mean seasonal temperatures during spring and autumn for the period 1980–2010.

Table 2. Seasonal and Annual Values of Temperature Trend Change (1991-2020)

Season	Winter	Spring	Summer	Autumn	Annual
A	0.069	0.063	0.034	0.058	0.058
B	0.690	0.625	0.341	0.575	0.558
T	2.525*	3.576*	1.674	2.500*	4.831*

Note: A – Temperature change trend expressed in °C; **B** – The trend of change at the ten-year level expressed in °C; **T** – *t*-test value; *Values marked with an asterisk (**) are considered significant.

During spring, a statistically significant trend was recorded in March, which largely contributed to the overall spring temperature trend being classified as statistically significant (Table 2). Significant seasonal and monthly trend changes also influenced the increase in mean annual temperatures over the analyzed period. The observed rise in temperatures across all months and seasons directly contributes to the occurrence of droughts. The increasing temperature trend may help explain the frequency of droughts between 1991 and 2020. Tošić and Unkašević (2014) analyzed drought periods and concluded that drought events became more frequent toward the end of the 20th and the beginning of the 21st century.

The average annual precipitation in Vranje during the period 1991–2020 was 613.5 mm. The highest average monthly precipitation was recorded in May, June, and November, while the lowest values occurred during the summer and winter months. Analyzing the average monthly precipitation reveals two distinct maxima and two minima throughout the year. The second hydrological maximum, observed in late spring and early summer, is more pronounced than the first, which occurs in November. The first minimum appears at the beginning of winter and lasts until early spring, while the second, more pronounced minimum occurs in mid-summer, peaking in August.

During the analyzed period, average annual precipitation showed an increasing trend (Table 3), with an annual rise of 5.6 mm, which was statistically significant. Over a decade, this trend amounted to an increase of 55.99 mm. Anđelković et al. (2018) found that higher annual precipitation amounts were more frequent in the late 20th and early 21st centuries, aligning with the findings of this study for the period 1991–2020.

Negative values of precipitation trend change were recorded in April, July, August, and September. The lowest precipitation trend value during the analyzed period was recorded in April. The annual trend value was -0.366 mm. Although there is a trend of decreasing precipitation in April, it was not statistically significant. The negative precipitation trend in July had an annual value of -0.181 mm. There is some agreement with the results obtained by Milovanović, Schuster, Radovanović,

Vakanjac and Schneider (2017), who analyzed the spatial and temporal variability of precipitation in Serbia from 1961 to 2010 and observed a decrease in monthly precipitation in certain regions. The negative value of the precipitation trend in April can be attributed to the shift of the precipitation maximum to earlier months, primarily in March.

Table 3. Seasonal and Annual Values of Precipitation Trend Change (1991-2020)

Season	Winter	Spring	Summer	Autumn	Annual
A	2.154	2.145	0.177	1.133	5.599
B	21.541	21.454	1.770	11.326	55.986
T	2.728*	1.928	0.118	0.777	2.076*

Note: A – Temperature change trend expressed in °C; **B** – The trend of change at the ten-year level expressed in °C; **T** – *t*-test value; *Values marked with an asterisk (**) are considered significant.

Analysis of seasonal precipitation revealed a significant trend of change during winter. The trend of change was 2.154 mm on an annual level. Other seasons also recorded positive precipitation trends, but these could not be considered significant. The lowest trend value of 0.177 mm at the annual level was recorded during the summer (Table 3). This was primarily influenced by the negative values of the precipitation trend in July and August. The trend value in June was positive but not significant.

The average annual flow at the Korvingrad hydrological station for the period 1991–2020 was 50.9 m^3/s. The average monthly flows during the winter and spring months were high. The highest average monthly flow of the South Morava at the hydrological station was recorded in March (112.2 m^3/s). The flow value in April was 108 m^3/s, which resulted from snowmelt in the higher parts of the South Morava basin. Higher flows in the spring period are influenced by the second hydrological maximum of precipitation, which occurs in May and June. The values of average monthly flows decline during the summer and early autumn. The lowest average monthly flow was recorded in September, at 14.5 m^3/s.

The annual trend in flow change for the period 1991–2020 had a positive value of 0.606 m^3/s (Table 4). This value was positive but not significant. Only in March was the flow value significant. An increase in flow was observed, with an annual value of 3.265 m^3/s. One reason for the increase in flow in March is the increase in precipitation during the same period, which was also significant. Additionally, a significant increase in the average monthly air temperature was recorded in March, contributing to snowmelt. As a result, the water balance of surface waters, reflected through flows at the Korvingrad hydrological station, increases.

The average flow values in April showed a negative trend, though it was not statistically significant. The annual decreasing trend was -0.177 m³/s. In the other months, the mean flow values recorded positive trends, but these were also not significant.

Table 4. Seasonal and Annual Values of flow Trend Changes at the Korvingrad Hydrological Station (1991-2020)

Season	Winter	Spring	Summer	Autumn	Annual
A	0.710	1.228	0.317	0.169	0.606
B	7.097	12.276	3.174	1.688	6.059
T	1.073	1.343	1.393	0.720	1.500

Note: A – Temperature change trend expressed in °C; **B** – The trend of change at the ten-year level expressed in °C; **T** – *t*-test value

The trend in flow changes during these seasons showed positive values, although they were not statistically significant. The highest trend value was recorded in the spring period (Table 4), with an annual value of 1.228 m³/s. This increase is likely influenced by the significant flow observed in March, which contributed to the rise in average seasonal flow. The spring period (especially May) is known for the occurrence of the second hydrological maximum of precipitation, as well as snowmelt in the higher elevations of the South Morava basin. The lowest annual trend value of 0.169 m³/s was recorded during the autumn.

The Pearson correlation coefficient was calculated by analyzing the average seasonal discharges at the Korvingrad hydrological station and the average seasonal air temperatures and precipitation at the Vranje synoptic station. The Pearson correlation coefficient between flow and precipitation was statistically significant for the winter, summer, and autumn seasons. The highest coefficient value was recorded in autumn, at 0.7. The correlation coefficient was 0.43 in winter and 0.40 in summer.

A decrease or increase in precipitation during autumn was accompanied by a corresponding change in flow. Discrepancies occurred in two periods. The first period, from 2003 to 2005, saw high precipitation values, but these did not lead to an increase in flow (Figure 2 – A). One possible explanation is that the precipitation occurred in the part of the basin where the Vranje weather station is located, i.e., in the upper reaches of the South Morava basin. Lower precipitation in the middle basin of the South Morava, downstream of Vranje, along with a negative water regime in that area, may explain the lower flows recorded during this period. The second period of disagreement occurred in 2016. A soil moisture deficit, high temperatures, and the size of the catchment may explain the discrepancy in flows.

The Pearson correlation coefficient between flow and temperature during the winter period was 0.05, though it was not statistically significant. The correlation

coefficient values for spring, summer, and autumn were negative. The lowest value of the flow-temperature correlation coefficient was recorded in the summer at -0.51 (Figure 2 – B). A negative Pearson coefficient indicates an increase in one parameter accompanied by a decrease in the other, which helps to understand the climatic conditions in the South Morava basin. The absolute value of the t-test statistic was 3.13, which was statistically significant. A statistically significant correlation was also observed in the autumn, with a coefficient of -0.44.

The correlation coefficient between MOI-1, temperature, and precipitation did not show statistically significant seasonal values. However, the correlation coefficient between MOI-1 and winter flow was statistically significant at -0.4 (Figure 2 – C). Periods when one parameter increased while the other decreased occurred every 2–4 years, which can be explained by the cyclicity of MOI-1.

The correlation coefficient between MOI-2 and temperature was statistically significant during the summer, with a value of 0.39. In contrast, the correlation was lower during the other seasons. The lowest correlation value, recorded in winter, was -0.17, but it was not statistically significant. The correlation coefficient between MOI-2 and precipitation did not show statistically significant values, which aligns with the results for MOI-1 and precipitation. The agreement between MOI-2 and flow was significant during both winter and summer. The correlation value in winter was -0.39, consistent with the correlation between MOI-1 and flow. The lowest correlation value of -0.40, recorded during summer, was statistically significant (Figure 2 – D).

Multiple linear regression requires the definition of one dependent variable and two independent variables. In this analysis, data on average monthly, seasonal, and annual flows recorded at the Korvingrad hydrological station were used as the dependent variable. Data on average monthly, seasonal, and annual precipitation and temperatures recorded at the Vranje synoptic station served as the independent variables.

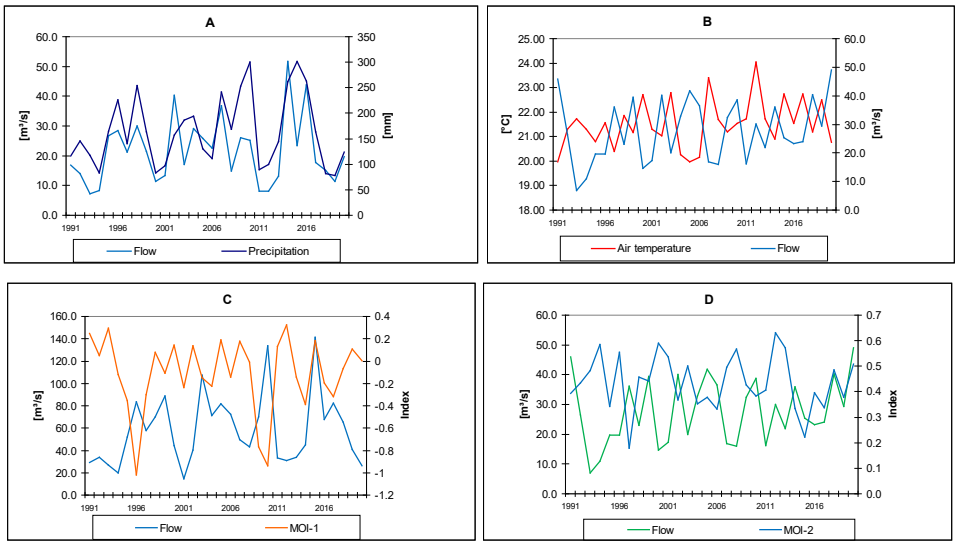


Figure 2. Time series of flow at the Korvingrad hydrological station [m³/s] and precipitation at the Vranje synoptic station [mm] in autumn (A); Time series of flow at the Korvingrad hydrological station [m³/s] and temperature at the Vranje synoptic station [°C] in summer (B); Time series of MOI-1 and flow at the Korvingrad hydrological station [m³/s] in winter (C);Time series of MOI-2 and flow at the Korvingrad hydrological station [m³/s] in summer (D) for the period 1991–2020

Analysis of the results from the multiple linear regression revealed that the values were significant during 11 months, during which the interdependence between flow, precipitation, and temperature was established. The highest *t*-test statistic was recorded in November, indicating a significant relationship between precipitation, temperature, and flow. In contrast, October was a month in which the relationship between flow, precipitation, and temperature was not statistically significant; however, a stronger influence of temperature on flow was observed during that month.

Temperatures had a greater impact on flows in July and August. Measured temperatures in July at the Vranje synoptic station accounted for a 2.21% impact on flows, while measured precipitation had a 0.15% impact on the South Morava flows at the Korvingrad hydrological station. In the other months, the interdependence between runoff and precipitation was greater compared to temperatures. November was the month in which the dependence of flow on precipitation was 48.62%.

The mean annual value of the multiple linear regression is represented by the function:

$$y_i = 50.335 + 0.081x_{1i} - 4.193x_{2i} \quad (4)$$

The coefficient of determination (R^2) was 0.312, meaning the model explains 31.2% of the variation in flow. The *t*-test value of 3.562 exceeded the critical value, indicating statistical significance. Based on the results, it was determined that 2.88% of the annual precipitation at the Vranje synoptic station affects the flow of the South Morava at the Korvingrad hydrological station.

To facilitate a clearer determination and understanding of the influence and interdependence of the examined climatic elements (precipitation and temperature) on streamflow at the seasonal level, parameters were identified that can define streamflow using a standard multiple linear regression model. The corresponding regression equations are as follows:

spring (MAM): $y_i = 137.9 + 0.305x_{1i} - 7.941x_{2i}$, (5)

summer (JJA): $y_i = 126.6 + 0.019x_{1i} - 4.721x_{2i}$, (6)

autumn (SON): $y_i = 32.8 + 0.101x_{1i} - 2.311x_{2i}$, (7)

winter (DJF): $y_i = 12.7 + 0.330x_{1i} - 1.104x_{2i}$ (8)

The results of seasonal multiple linear regression showed that the lowest R^2 value occurred in spring (0.150), while the highest value (0.517) was recorded in autumn. The *t*-test values for all seasons were above the critical value, confirming statistical significance. During winter, spring, and autumn, flows were predominantly influenced by precipitation. The greatest interdependence between flow and precipitation was observed in autumn, where the dependence of flow on precipitation was 4.95%.

In contrast, the interdependence of runoff from precipitation and temperature during summer was different. During the summer, flows were more influenced by temperature, with a dependence of 2.57%, while precipitation contributed 1.07%. The weak interdependence of runoff with both precipitation and temperature in the summer can be attributed to the large area of the South Morava basin up to the Korvingrad hydrological station, as well as the location of the Vranje synoptic station, which is situated in the upper reaches of the South Morava River.

Conclusion

This study analyzed data on average monthly, seasonal, and annual temperatures and precipitation at the Vranje synoptic station for the period 1991–2020. Additionally, data on average monthly, seasonal, and annual flows at the Korvingrad hydrological station on the South Morava River, as well as the Mediterranean Oscillation Index (MOI-1 and MOI-2), were examined.

The results indicate a positive trend in average monthly, seasonal, and annual temperatures, with significant values observed in February, March, and April. These

significant trends in the specified months also led to the significance of winter and spring seasonal temperature trends. The trend values for temperature, precipitation, and runoff were notably significant in March. A significant increase in precipitation was recorded both on an annual basis and during the winter period.

The correlation analysis revealed a clear seasonal pattern of precipitation and runoff, with a strong correlation during the winter, summer, and autumn periods. The Pearson correlation coefficient recorded its highest value of 0.7 in the autumn. A significant correlation between flow and temperature was observed during the summer and autumn.

To complement the correlation analysis, multiple linear regression was employed to quantify the influence of precipitation and temperature on river flows. The analysis confirmed statistically significant relationships during 11 months of the year, with the strongest association found in November. Seasonal regression models demonstrated that autumn had the highest coefficient of determination ($R^2 = 0.517$), indicating that nearly 52% of the variation in flow could be explained by climatic variables. While precipitation predominantly influenced flows in winter, spring, and autumn, temperature had a relatively greater impact during the summer months. These findings underscore the complex seasonal dynamics between climatic factors and hydrological response in the South Morava River basin, highlighting the importance of region-specific modeling in water resource management.

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