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TEMPORAL ANALYSIS OF RAINFALL IMPACTS ON DANUBE RIVER WATER LEVEL AND DISCHARGE AT NOVI SAD, SERBIA (2020–2024)

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ABSTRACT

River water levels and discharge are primarily influenced by precipitation, including rainfall and snowfall, as well as by ice melt. The Danube, the second largest river in Europe, has an extensive catchment area, where different tributaries and their precipitation regimes influence the river, affecting its water levels and discharge. This study analyses the impact of rainfall in Novi Sad, Serbia, over a five-year period (2020–2024), focusing on the effects of precipitation and its extremes, and examining whether they influence the water level and discharge of the Danube in Novi Sad on a daily level. The analysis is based on data obtained from the hydrological yearbooks of the Republic Hydrometeorological Service of Serbia (RHSS). Extremes in rainfall, discharge, and water level, as well as their interrelationships, were assessed using the 10th and 90th percentile method. Moreover, Pearson correlation coefficient was used in defining the statistical correlation between precipitation and water level along with discharge. The study aims to estimate the typical time lag between precipitation events and the hydrological response. The findings indicate a low level of significance in the correlation between precipitation and both water level and discharge for the period of 2020–2024. The time lags in response to extreme precipitation increased from the first to the third day, with the highest values observed on the third day. Furthermore, a positive correlation (>0) between precipitation and water level was recorded during 2020, while a positive correlation between precipitation and discharge was observed during 2020, 2023, and 2024. This research demonstrates that the impact of local precipitation on the local hydrological station is small and short-lived, which is expected, given that the Danube is a very long river with a large catchment area and complex flow regime.

Keywords: *Danube river, rainfall, water level, river discharge, hydrological extremes, Novi Sad*

INTRODUCTION

In the context of climate change, variations in climatic elements, such as air temperature and precipitation, are becoming increasingly pronounced (Easterling et al., 2000; Hegerl et al., 2004; Wu et al., 2022). These changes significantly impact the hydrology of river basins, affecting rivers, their tributaries, and entire watersheds (Grover et al., 2022). Precipitation is the most critical climatic element determining water levels and discharge in rivers (Ezra et al., 2023), a relationship further compounded by snow and ice melt

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linked to rising temperatures (Buitink et al., 2021). Consequently, regional shifts in precipitation, including their annual and seasonal distribution, are a primary driver of changes, exerting a direct cause-and-effect influence on rivers and their basins (Vu et al., 2024).

Water level and river discharge are key hydrological variables used to describe the state and dynamics of river systems. Water level is defined as the height of the water surface at a observed river cross-section (Ždero et al., 2021), while river discharge represents the volume of water flowing through the cross-section per unit of time (Dingman, Bjerklie, 2006). Although they describe different hydrological processes, these two variables are closely interconnected, as river discharge is often indirectly derived from observed water levels using rating curves.

Precipitation, as the dominant driver for both variables, is not limited to local rainfall, but also includes inputs from the entire upstream catchment area. As a result, changes in precipitation, together with snowmelt and temperature variations, spread through the hydrological system, reflected in fluctuations of both water level and discharge. Moreover, the analysis of water levels and discharge requires consideration of multiple interacting processes, including rainfall intensity and distribution, snow accumulation and melt, topography, soil and vegetation characteristics, groundwater contributions, and human activities such as dam regulation, water abstraction, urbanization and river engineering. Consequently, in small and highly urbanized catchments, responses can be rapid and pronounced, while in large river systems they are typically delayed due to the larger spatial scale and storage effects.

Monitoring water levels is essential for understanding both upstream and local changes (Nepal et al., 2024). Intensive and prolonged rainfall leads to increased surface runoff and groundwater inflow into river channels, causing a rise in water levels and discharge, a process whose dynamics and intensity depend on the specific river characteristics, including its size, the number of tributaries, and the overall morphology of the catchment (Bonacci, 2001). This hydrological response can be nearly instantaneous in small, flash-flood-prone catchments, whereas large river systems exhibit a lag between the precipitation event and the river's response due to their greater spatial area (Hewlett et al., 1977). For instance, in urban areas with extensive impervious surfaces, rainfall results in faster and more pronounced changes in water levels, thereby increasing the risk of urban flooding (Savić et al., 2020). Furthermore, the seasonal distribution of precipitation and spatial variability within a watershed influence the dynamics of water levels and discharge (Singh, 1997). Dry periods typically lead to reduced discharge and stabilized water levels, while wet seasons are characterized by higher and more variable values (Patil, Stieglitz, 2011).

Evidence from Southern Cameroon illustrates this complexity. A decrease in annual precipitation has been linked to reduced discharge in the Nyong basin (Olama and Mblamayo), while in the Mefou basin, an increase in precipitation resulted in higher discharge (Ebodé et al., 2022). Hewlett et al. (1977) concluded that river discharges are particularly difficult to predict, noting that rainfall intensity plays a smaller role in controlling river flow in humid regions like the southern Appalachians. Similarly, Wang et al. (2022) emphasized that in the context of urban flooding in Wuhan, rainfall and water level are not the only factors to consider. In the Serbian river network, long-term analyses also reveal non-uniform discharge responses, highlighting strong spatial variability and the influence of multiple hydrological drivers (Leščešen et al., 2025).

Regionally, several extreme precipitation events have been recorded over the past 15 years. In Novi Sad, daily and monthly records were exceeded, notably in June 2010, when a daily maximum of 67.7 mm surpassed the previous record from June 1981. That same month, the total monthly precipitation reached 168.5 mm, exceeding the prior record set in 1972. This period of intense rainfall culminated in a prominent high-water wave registered on the Danube, Sava, and Tisza rivers (RHSS, 2010). Other records include a 2014 event where 118 mm of rain fell over three days, compared to the May average of 57 mm. Significant precipitation amounts were also observed throughout Serbia in 2015 (RHSS, 2016). Given this documented history of precipitation extremes and their profound impact on regional hydrology, a focused local study is warranted.

The aim of this study is to analyse the impact of precipitation on local sections of the river network in the Novi Sad area. Hydrological extremes, normal conditions, and lows were determined using the 10th and 90th percentiles to classify low, normal, and high values for precipitation, discharge, and water level. Consequently, the study presents an analysis of precipitation trends (increase/decrease) for the period 2020-2024, followed by an analysis of water levels and discharge for the same five-year period. Finally, it assesses the influence of precipitation on water level and discharge and examines potential correlations between these variables in the Novi Sad area.

DATA AND METHODS

Study area

The city of Novi Sad (45°15'N, 19°50'E) is situated in the Vojvodina region, the northern part of the Republic of Serbia (Figure 1). The city's topography is predominantly a plain with an average elevation of approximately 80 m. It is bordered to the south by the Fruška Gora mountain range, which has a peak elevation of 539 m. The Danube River flows along the southern and southeastern periphery of the urban area for a distance of approximately 10 km, between river kilometres 1252–1262.

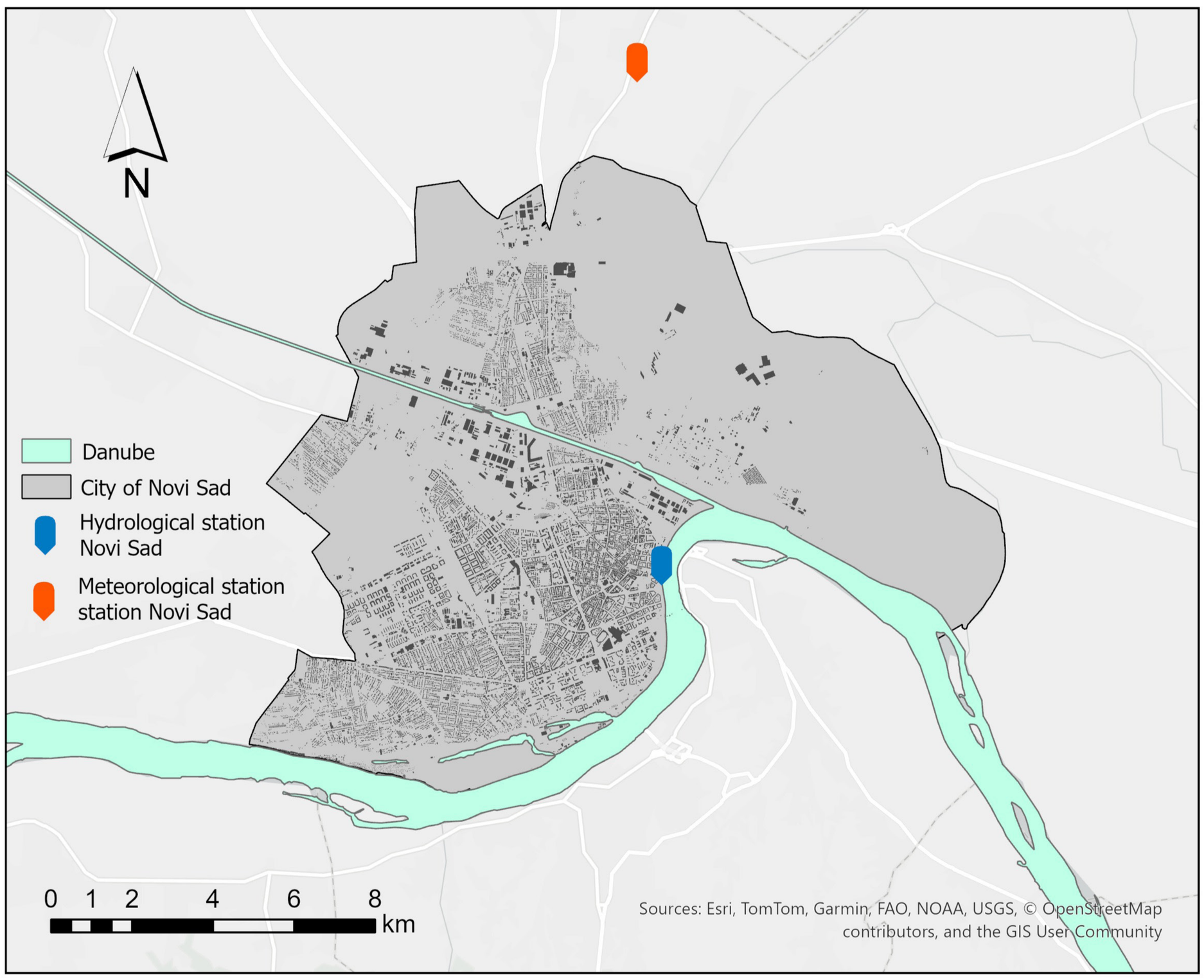

Figure 1. Location of the Danube River in the urban area of Novi Sad

According to the Köppen-Geiger climate classification, Novi Sad has a Cfa climate, defined as a temperate warm climate with a relatively uniform annual distribution of precipitation (Kottek et al., 2006). This climate is characterized by warm summers, occasional intense rainfall, and colder winters with increased

precipitation. Spring and autumn are transitional seasons, though periods of high temperatures often persist into late spring and early autumn. Climate data for the period 1949-2024 show a mean annual air temperature of 11.3 °C. The long-term mean annual precipitation (1949-2024) is 627.3 mm. The wettest month is June, with an average of 84.2 mm of precipitation, while February is the driest, with an average of 37.8 mm (RHSS, 1949-2024).

The hydrological regime of the Danube River at Novi Sad is significantly influenced by upstream conditions. Water levels and discharge are affected by factors including river management, dam operations, and precipitation in countries upstream, leading to variations independent of local climatic conditions. For the period from 1946 to 2024, the mean annual water level recorded at the Novi Sad station was approximately 245 cm. A distinct seasonal pattern is observed, with the highest water levels typically occurring in April (averaging 337 cm) and the lowest in October (153 cm) (RHSS, Hydrological Yearbooks, 1946-2024).

METEOROLOGICAL AND HYDROLOGICAL DATA

Long-term climatological statistics (1949–2024) were calculated by the authors based on long-term daily observational records from the RHSS yearbooks. These values are used for the description of the general climatic context of the study area.

The data used for the main analysis of this study cover the period from 2020 to 2024 and were obtained from official meteorological and hydrological yearbooks of the RHSS. The data were analysed on daily, ten-day, monthly, and annual levels, depending on the type of variable and the purpose of the analysis.

Meteorological Data

Meteorological data used in this research refer to precipitation and were obtained from the Meteorological Yearbooks published by the RHSS. The measurements were taken at the meteorological station Rimski Šančevi (Novi Sad), located at 45°20′N, 19°51′E, at an elevation of 84 m above sea level. The data represent daily, ten-day, monthly, and annual precipitation totals, expressed in mm. They were collected through standard measurement procedures applied by RHSS and verified through the institution's official quality control system before publication. Details are represented in Table 1.

Hydrological Data

Hydrological data used in the study include water levels and discharges of the Danube River at Novi Sad. Historical water level data for Novi Sad has been recorded since 1946, and the data for these analyses were obtained from the Hydrological Yearbooks on Surface Waters of the RHSS for the period from 2020 to 2024. Measurements were carried out at the hydrological station Novi Sad, located on the Danube River, established in 1819 at an altitude of 71.73 m above sea level, approximately 1,254.98 km from the river's confluence with the Black Sea. The station continuously records daily, ten-day, monthly, and annual values of water level [cm] and discharge [m^3/s]. These records represent one of the longest and most reliable hydrological series in Serbia. Details are represented in Table 1.

Table 1. Overview of meteorological and hydrological data used in the study

Type of data	Source	Measurement site	Unit
Precipitation	Meteorological Yearbook, RHSS	RimskiŠančevi (Novi Sad)	mm
Water level	Hydrological Yearbook, RHSS	Novi Sad (Danube)	cm
Discharge	Hydrological Yearbook, RHSS	Novi Sad (Danube)	m^3/s

Methodology

In this study, the 10th and 90th percentiles were applied to determine low, normal, and, most importantly for the purpose of this analysis, extreme values. Data were collected and processed in Excel, where percentiles and corresponding extreme values were calculated. This approach provided the basis for further analysis and comparison.

To examine the distribution of precipitation, the 10th and 90th percentiles were selected in order to better capture the variability in rainfall during the five-year observation period. Percentiles allow the identification of extreme conditions, such as exceptionally dry or wet periods, and help in understanding the overall range and distribution of precipitation.

The 10th percentile represents rainfall amounts lower than 10% of all recorded values, referring to days without rainfall, extremely low precipitation, or dry conditions. The 90th percentile represents rainfall amounts lower than 90% of all recorded values, while values above this threshold indicate high rainfall and are classified as extremes. By applying these percentiles, variations in precipitation were more precisely observed, enabling the identification of periods with extreme conditions.

The specific results obtained for precipitation in this study are as follows:

- 10th percentile: X mm (0.2 mm)
- 90th percentile: Y mm (14.6 mm)

These results show that most precipitation events occurred within the range between X mm and Y mm, while extreme values, representing very wet periods, were less frequent.

To further explore the influence of extreme precipitation on the given month, the Pearson correlation coefficient (Benesty et al., 2009), was also applied. According to Pearson, three types of correlation were considered and incorporated into the analysis:

- r = 1 – perfect positive correlation (as precipitation increases, water level or discharge increases proportionally);
- r = 0 – no correlation (no relationship between precipitation and water level/discharge);
- r = –1 – perfect negative correlation (as precipitation increases, water level or discharge decreases proportionally).

In addition to the overall five-year daily dataset, time lags of 1, 2, and 3 days were also applied to assess the delayed effect of precipitation on water level and discharge. The analysis is presented in the following section.

RESULTS

A key question arises regarding the potential influence of precipitation in the Novi Sad area on river water levels and discharge rates. The subsequent analysis will therefore examine precipitation, water levels, and discharge data, with a specific focus on identifying direct correlations between precipitation and water levels, as well as between precipitation and discharge rates.

Precipitation analysis

The temporal scope of this analysis spans a five-year period from 2020 to 2024. Climate change is increasingly influencing annual precipitation distribution, leading to a higher frequency of extreme weather events.

Based on the mean monthly precipitation data for the period 1949–2024 (RHSS), it can be observed that precipitation values follow a relatively smooth, wave-like pattern, with peaks occurring in May, June, and July. In other months, slightly higher values appear in August, September, November, and December, although these are minor compared to the summer maxima. This pattern is illustrated in Figure 2.

A notable deviation in mean monthly precipitation can be observed when comparing the two periods (1949–2024 and 2020–2024). The curve that previously represented the typical monthly distribution has changed its shape, indicating a shift in precipitation patterns. In the recent period, the highest values occur in September, followed by November, while June and July show a slight decline, now registering precipitation amounts similar to those in August. These changes are particularly evident and indicate a significant modification in the seasonal precipitation regime in the area of Novi Sad.

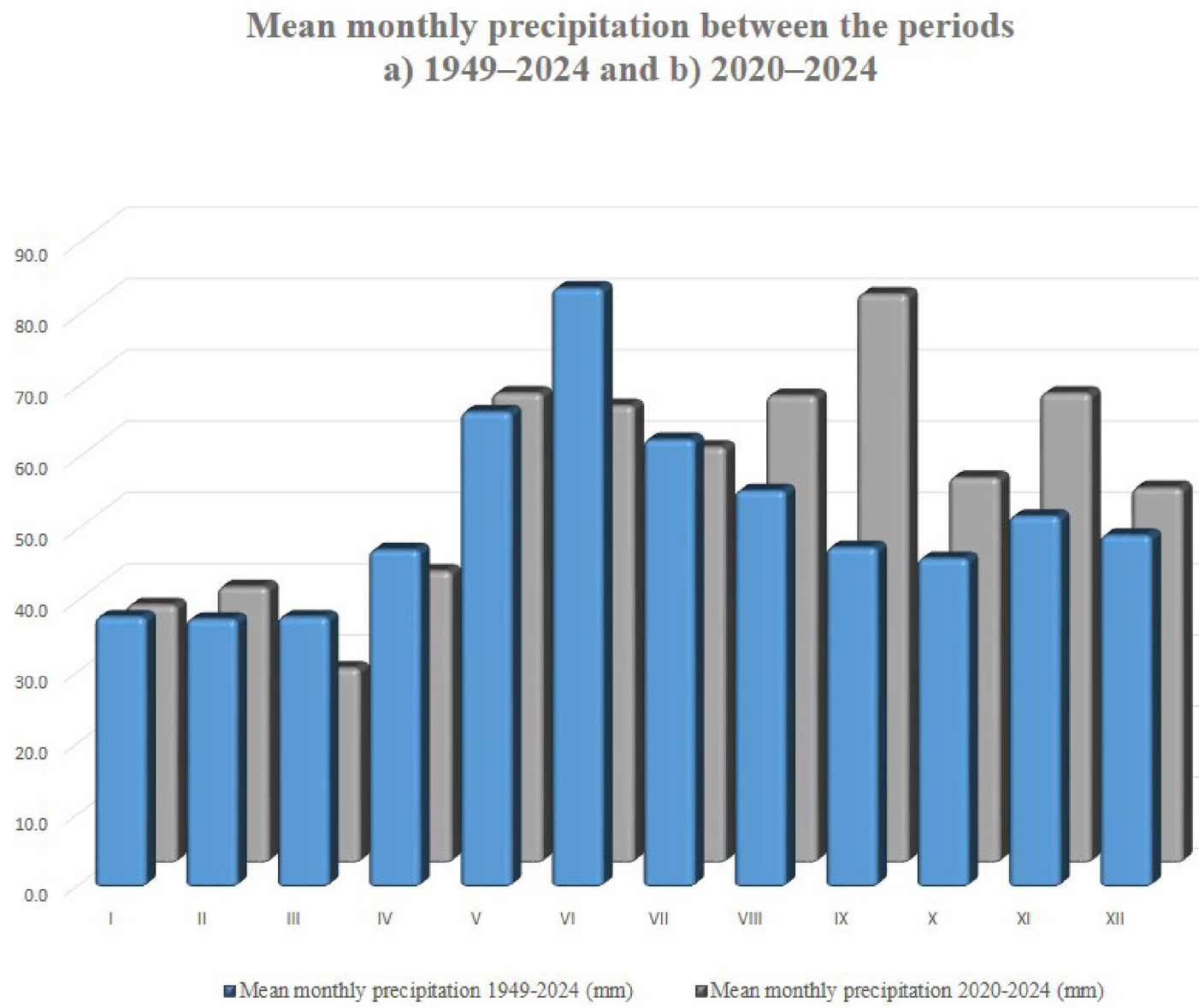

Figure 2. Comparison of mean monthly precipitation for the periods a) 1949–2024 (blue colour) and b) 2020–2024 (grey colour)

Source: RHSS Meteorological Yearbooks (1949-2024)

During the 2020-2024 period, variations were observed in both the annual distribution of precipitation and its average values (Figure 3). The years 2020 and 2021 recorded precipitation levels exceeding the annu-

al average (recording 733.2 mm and 757.6 mm, respectively). In contrast, 2022 and 2024 received below-average precipitation (563.6 mm and 545.8 mm, respectively).

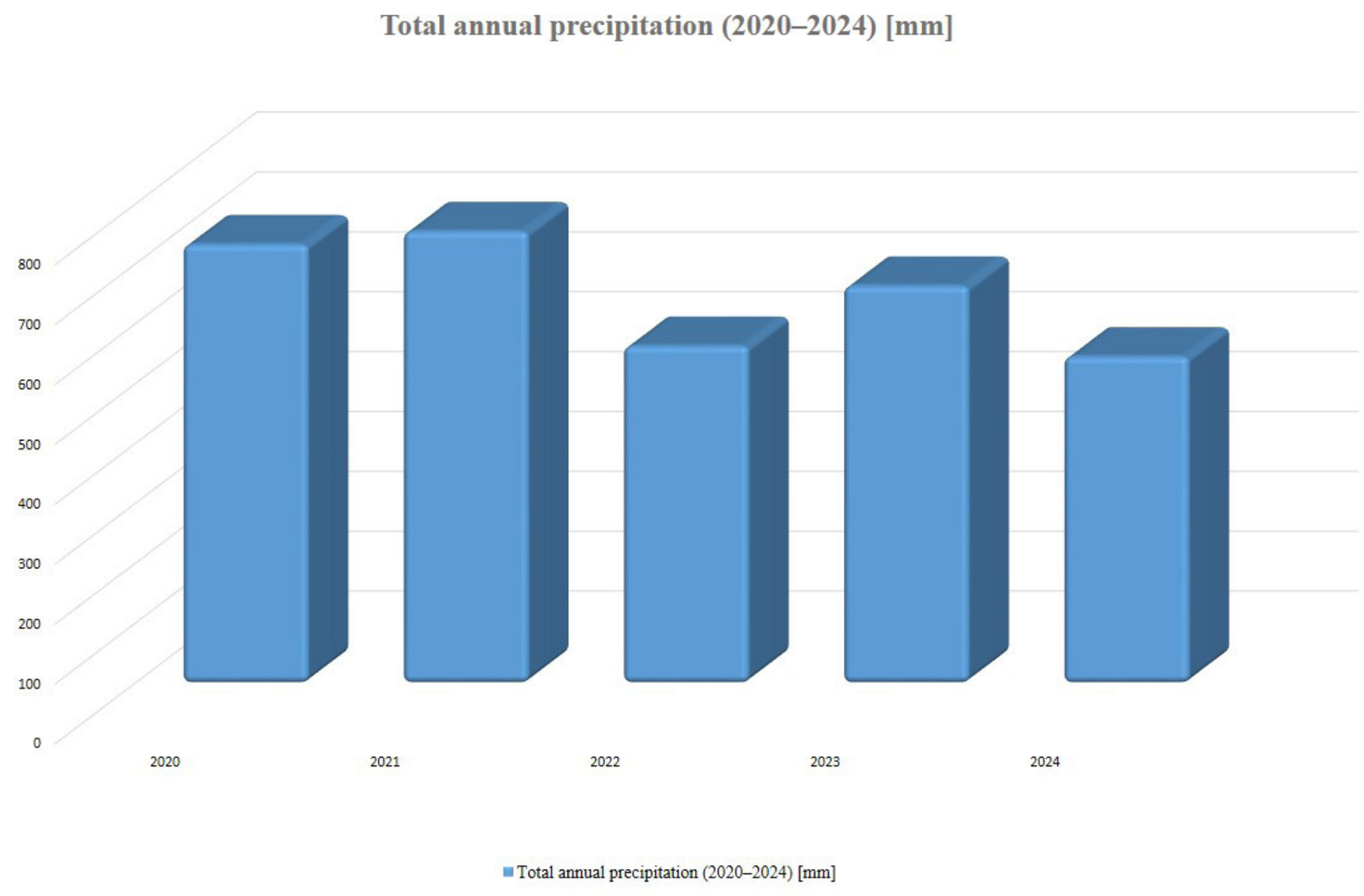

Figure 3. Trend of total annual precipitation at the Rimski Šančevi station (2020–2024).

Source: RHSS, Meteorological Yearbooks (2020-2024)

As illustrated in Figure 4, which depicts the total monthly precipitation [mm] over the five-year period, shifts in the overall precipitation pattern are evident. While May, June, and July typically exhibit the highest total precipitation on an annual basis, the data for this period reveals that September registered the most pronounced peak. A notable increase in precipitation was recorded in September during 2022 and 2024, whereas the same month in 2020 and 2021 registered the lowest monthly rainfall. Furthermore, although 2022 and 2024 were overall drier years, the significant precipitation in September of those years indicates a considerable intra-annual redistribution. This suggests that precipitation in other months was substantially lower than expected, highlighting a shift in both the annual and monthly distribution of rainfall.

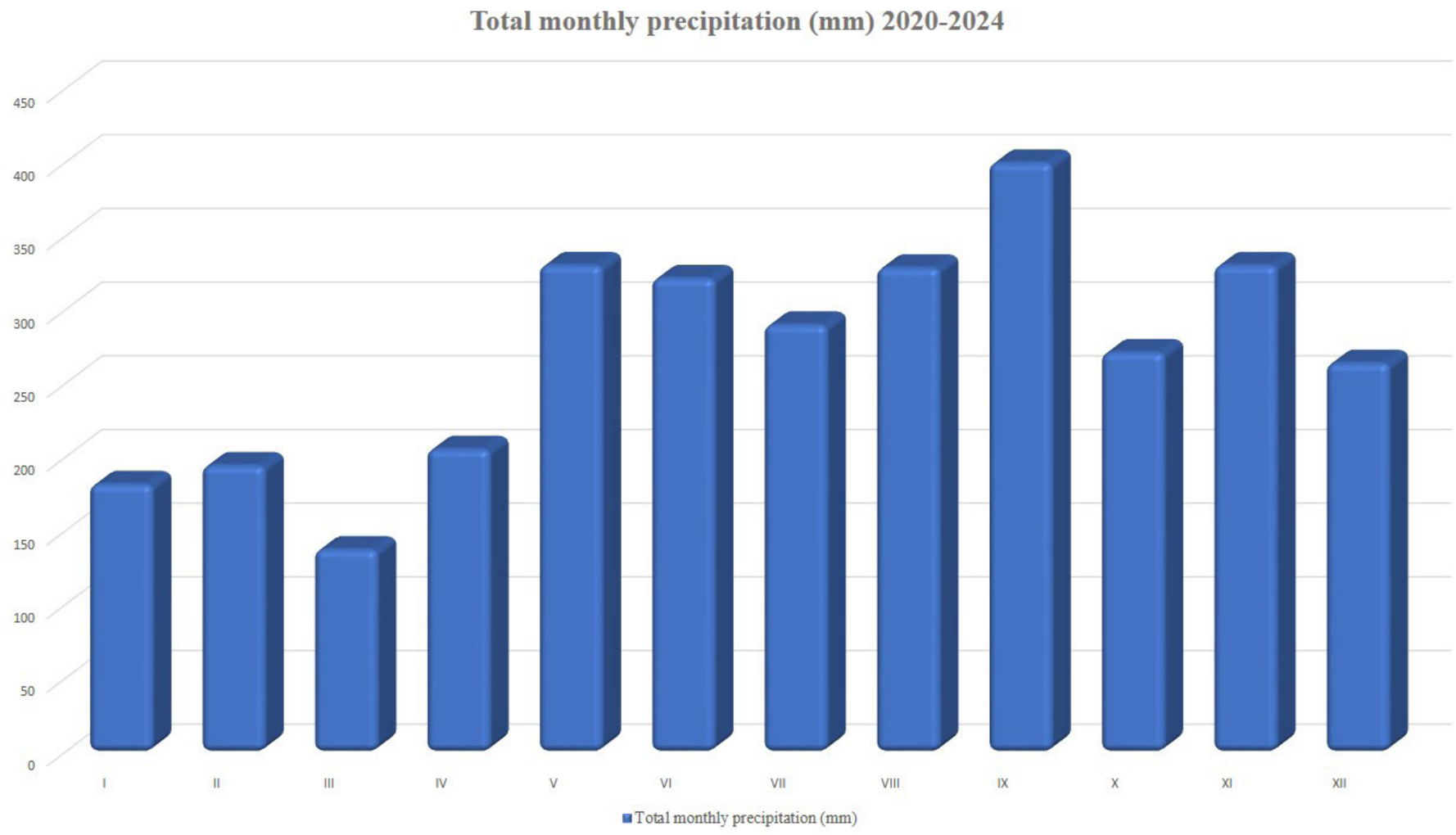

Figure 4. Trend of total monthly precipitation at the Rimski Šančevi station (2020–2024).

Source: RHSS, Meteorological Yearbooks (2020-2024)

Additionally, the 10th and 90th percentiles were used to classify precipitation values as low, normal, or extreme relative to the five-year average. Analysis reveals various extreme events across different years and months.

During January, February, March, April, October, November, and December, extreme events were less frequent, occurring as isolated incidents (one to three times over three years). These extremes were not consecutive but rather appeared as single-day events within a given month. In contrast, the months of May, June, July, August, and September exhibited periods where extremes occurred in succession. These episodes featured consecutive extreme precipitation over two to three days, or intermittently over a span of approximately two weeks.

WATER LEVEL ANALYSIS

For the Novi Sad area, the RHSS provides long-term average monthly water levels based on data from 1946 to 2024. Figure 5 compares this long-term average (1949-2024) against the mean values from our five-year study period (2020-2024), revealing significant deviations.

The long-term data (blue bars in Figure 5) indicates that the lowest water levels typically occur in September, October, November, and December. This pattern reflects the Danube's characteristic hydrological regime at Novi Sad, where winter levels are generally low due to precipitation falling as stored snow, partial freezing in upstream sections, and flow regulation by reservoirs and dams. Conversely, the highest water levels are observed in spring and summer, driven by snowmelt and seasonal rainfall, as the provided figure illustrates. Overall, water levels follow an annual cycle that corresponds to patterns of precipitation and snowmelt.

In contrast, the data from the last five years (red bars in Figure 5) shows considerable oscillation around the long-term mean. A key observation is that water levels in January, February, October, November, and December were consistently higher than their historical averages. Levels in April, May, June, July, and August, however, aligned more closely with the long-term pattern. Several potential factors may explain these anomalies, including the intra-annual redistribution of precipitation, reduced seasonal snowpack, intense rainfall events, and rising temperatures. These climatic changes can lead to atmospheric instability and shifts in air mass circulation, ultimately disrupting traditional hydrological patterns.

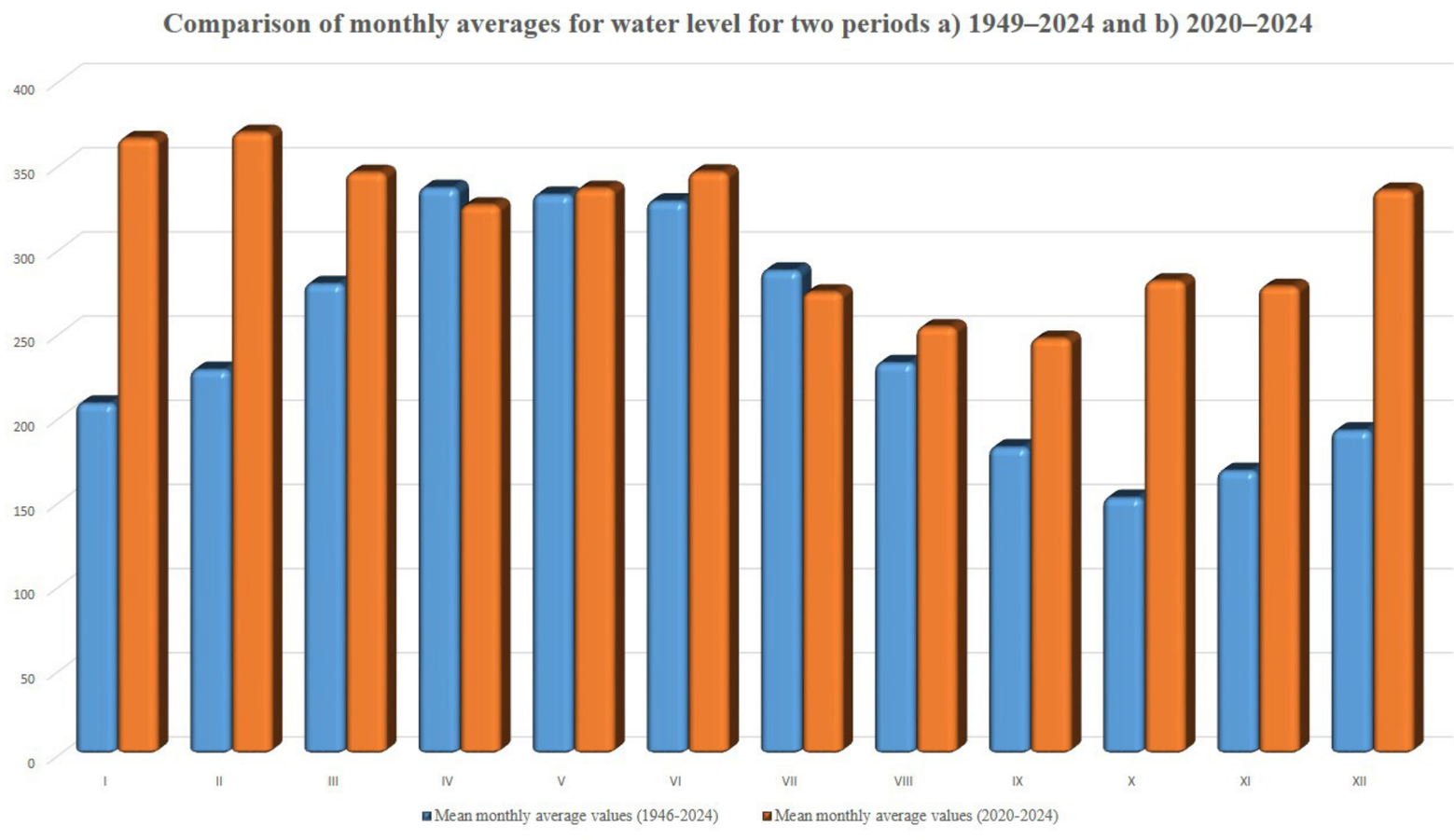

Figure 5. Comparison between monthly averages of water level from year of 1946 to 2024, and from 2020 to 2024

Source: RHSS, Hydrological Yearbooks (1946-2024)

The water level regime in Novi Sad is characterized not only by its seasonal cycle but also by the occurrence of extreme hydrological events. The period of analysis (2020-2024) recorded several instances where water levels exceeded the flood warning stage. A comparison of values within this five-year period reveals distinct extremes and anomalies, classified as low, normal, or extreme. The highest frequency of extreme water levels was observed in 2024, specifically during January, February, March, June, and October. Similarly, extremes were recorded in December and May of 2023. In contrast, the remaining months were predominantly characterized by normal or low water levels, indicating a lower incidence of hydrological extremes during those times.

DISCHARGE ANALYSIS

The following analysis focuses on the average discharge values and the occurrence of extreme events in that matter. As shown in Figure 6, discharge extremes and their variations can be clearly observed. The highest mean discharge occurs in June, with an average of 3471 m^3/s, while the lowest discharge is recorded in October, around 2456 m^3/s. During the winter months, moderately high discharges (2774–2975 m^3/s) are observed, most likely resulting from precipitation in the upstream areas and snowmelt in lower regions.

From April onwards, discharge values increase, reaching their maximum in June (3471 m^3/s), reflecting the combined influence of snowmelt in higher elevations and upstream rainfall. During summer, discharge values gradually decrease, followed by a pronounced decline in autumn, reaching the lowest levels in November (2156 m^3/s). This reduction can be attributed to precipitation in the upper catchment occurring mostly as snow, which is temporarily retained in higher areas, thus reducing inflow. Conditions in December remain similar.

The annual discharge pattern indicates a typical pluvio-nival regime, with a maximum in spring (May to June) caused by a combination of snowmelt and rainfall, and a minimum in late autumn (November) due to reduced precipitation, lower inflow, and higher evapotranspiration

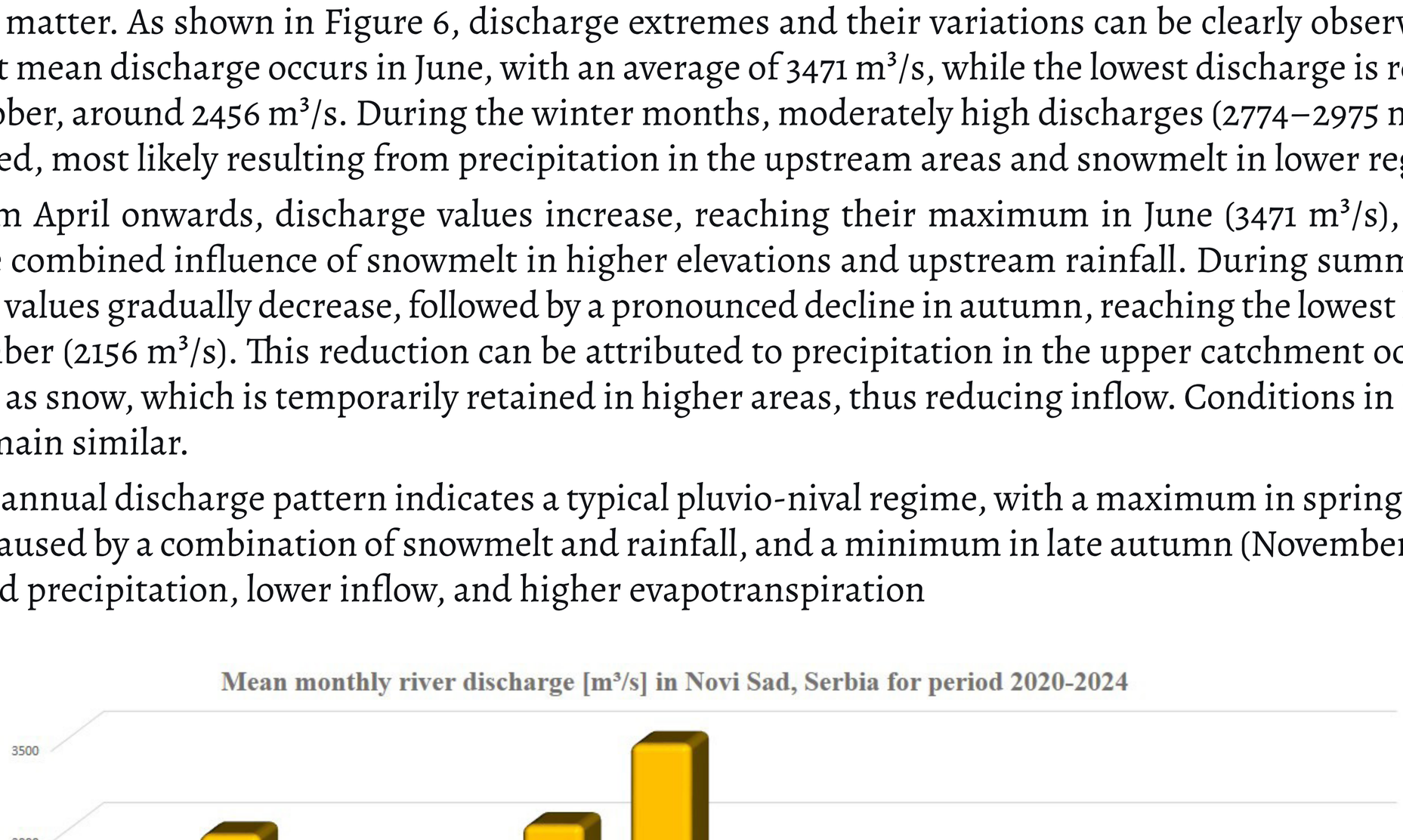

Figure 6. Mean monthly river discharge [m^3/s] in Novi Sad, Serbia for period 2020-2024

Source: RHSS, Hydrological Yearbooks (2020-2024)

Figure 7 allows for a comparison of water level and river discharge in Novi Sad (2020-2024), highlighting potential relationships between the two variables. The left-hand axis represents discharge [m³/s], with the corresponding values for the period shown by the blue line. The right-hand axis represents water level [cm], indicated by the orange line.

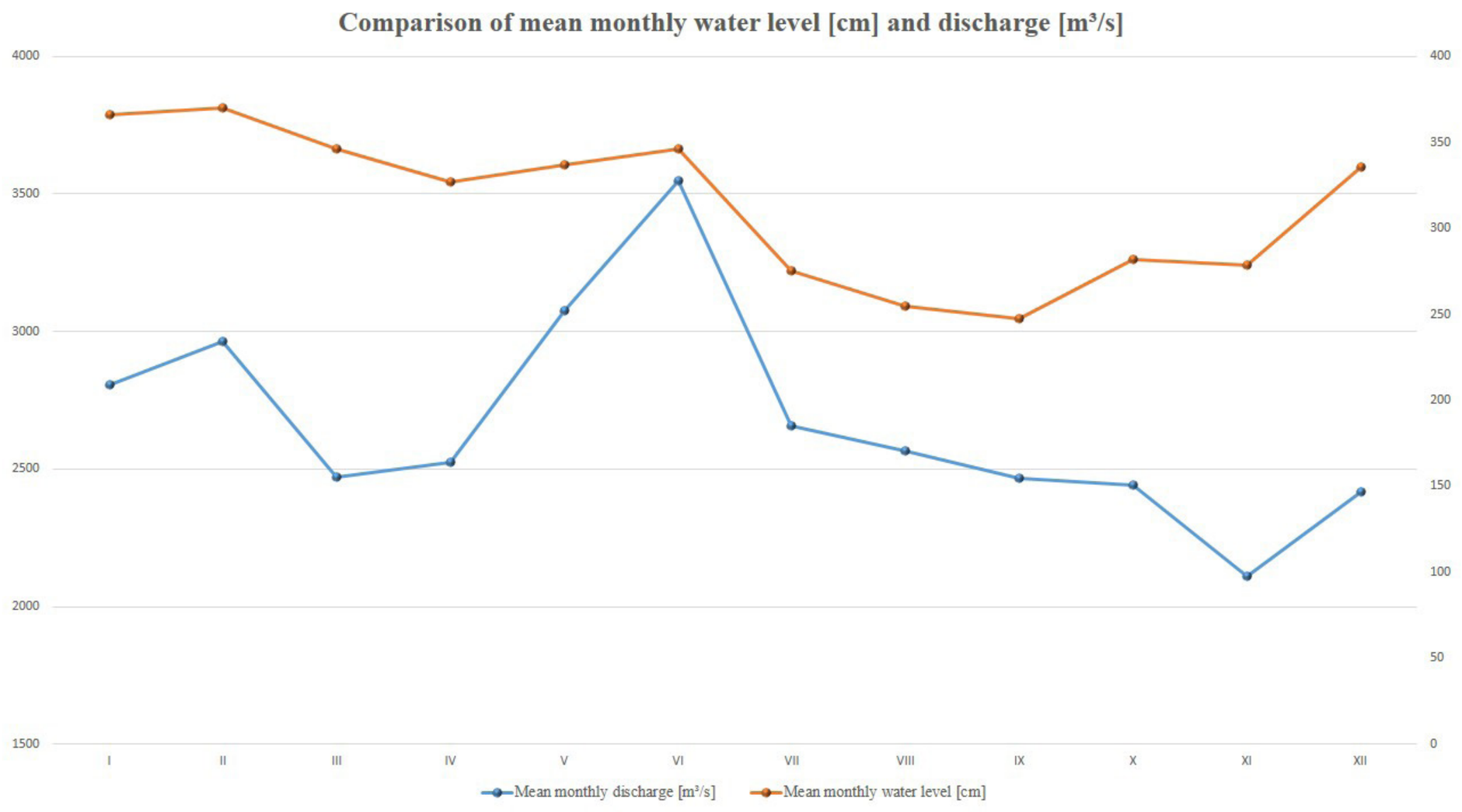

Figure 7. Comparison of mean monthly water level [cm] and discharge [m³/s]

Source: RHSS, Hydrological Yearbooks (2020-2024)

The first noticeable feature is the increase in both water level and discharge in June, as well as their decline in November. However, the timing of the maxima differs: water level reaches its peak in February, with elevated values also observed in January, March and December, whereas the minimum occurs between July and September.

From June to December, both water level and discharge exhibit a nearly linear decreasing trend. In contrast, during the first five months of the year, the relationship between water level and discharge is less consistent. This can be partially explained by winter conditions, where river levels may remain relatively high due to frozen or saturated soils that reduce infiltration, while discharge remains lower because inflow of liquid water is limited. Even small amounts of precipitation can cause noticeable increases in water level without a significant rise in discharge.

Analysis of rainfall impact on water level and discharge

Figure 8 presents the precipitation and water level values measured in Novi Sad for the period 2020–2024. The aim was to assess whether precipitation in Novi Sad has a significant impact on the measured water level. Peaks in precipitation and water level can be observed; however, the two variables do not appear to be strongly correlated. Notably, towards the end of the study period (mid-2023), precipitation was relatively low, while water level reached its highest peaks, indicating that, in most cases, local precipitation in Novi Sad does not directly determine water level. While there are instances where precipitation may influence water level, it is not the sole factor, as other hydrological and upstream processes also play a role, particularly given that the Danube is a large river.

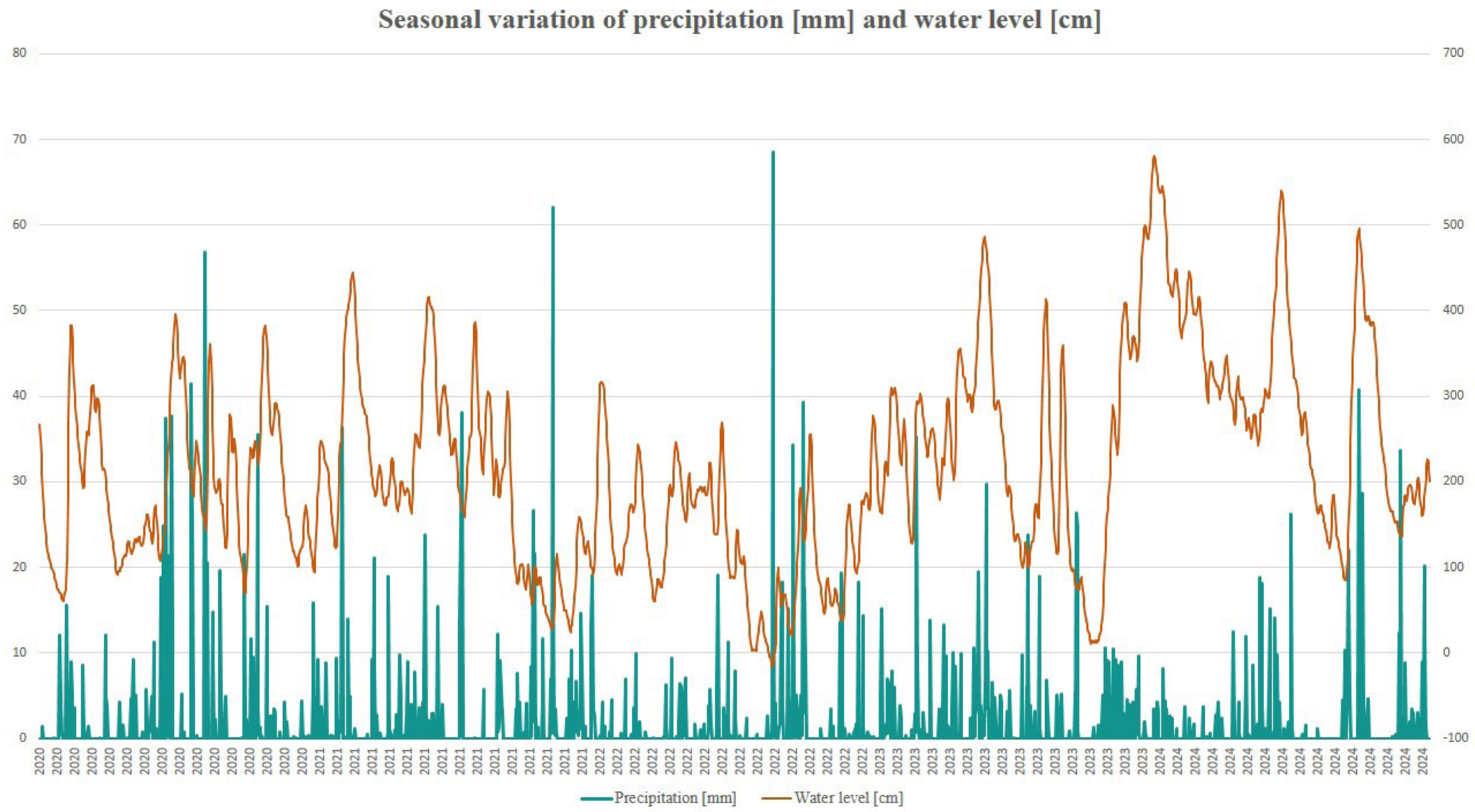

Figure 8. Seasonal variation of precipitation [mm] and water level [cm] for period of 2020 to 2024

Source: RHSS, Hydrological Yearbooks (2020-2024)

Figure 9 similarly illustrates the effect of precipitation on river discharge, showing comparable patterns. For example, in 2020, increases in precipitation corresponded to rises in discharge, and a similar trend is observed at the beginning of 2022 when both water level and precipitation were low. Towards the end of 2024, lower precipitation coincides with higher discharge, followed by an increase in precipitation, demonstrating the complex and non-linear relationship between local rainfall and river discharge.

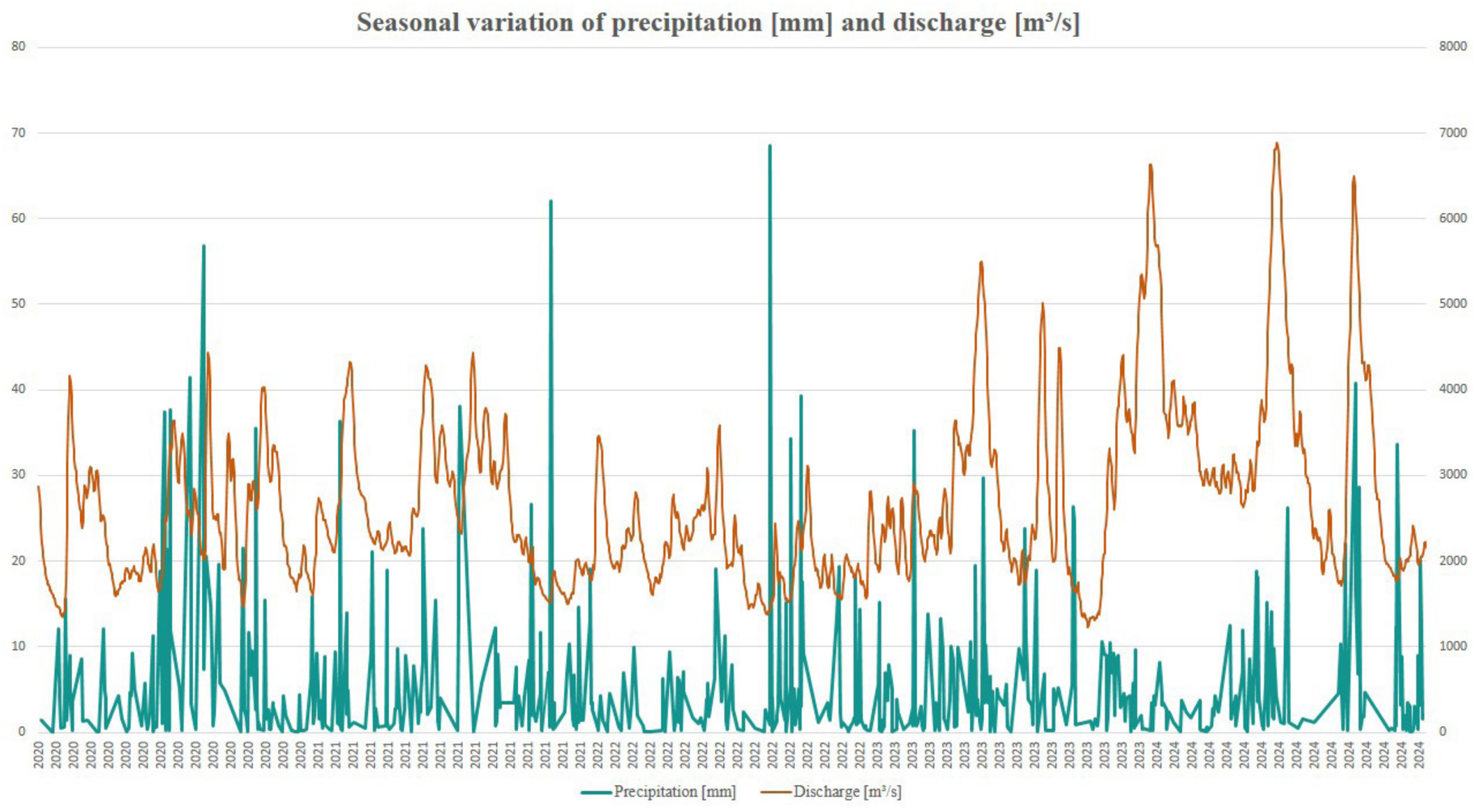

Figure 9. Seasonal variation of precipitation [mm] and discharge [m³/s] for period of 2020 to 2024

Source: RHSS, Hydrological Yearbooks (2020-2024)

STATISTICAL ANALYSIS

For data processing related to precipitation and its impact on water level and discharge, a Pearson correlation was performed. The correlation was calculated for different segments:

- Pearson correlation for precipitation, water level/discharge (from 2020 to 2024);
- Pearson correlation for precipitation and its impact on water level/discharge with a lag of 1, 2, and 3 days;
- Pearson correlation for each year individually (2020, 2021, 2022, 2023, 2024).

Table 2. Pearson's correlation coefficient for the five-year period (2020–2024) with lags of one, two, and three days.

	Correlation (precipitation/water level)	Correlation (precipitation/discharge)
2020-2024	-0.06596	-0.01289
Lag 1	-0.06176	-0.00824
Lag 2	-0.04811	0.002688
Lag 3	-0.02513	0.02548

According to Table 2, we can observe that the calculated Pearson correlation for the period from 2020 to 2024 is -0.06596 for precipitation and water level, while for precipitation and discharge it is -0.01289. Therefore, it can be noticed that the precipitation in the area of Novi Sad does not have a statistically significant value (considering they are less than 0, i.e., negative). Thus, a moderate negative correlation is observed, meaning that precipitation does not necessarily influence the water level and discharge on that same day.

Nonetheless, the Pearson correlation was calculated for the case of lags, meaning that it is possible for a larger amount of precipitation to fall, but for its effects to be noticed only a day, two, or three later. Accordingly, we observe a slight increase in the correlation between precipitation and water level, proportional to the passing days, which is why the highest correlation was recorded on the 3rd day. Furthermore, for discharge, an even greater increase in the impact of precipitation on discharge is observed, where after two days the discharge already has a slightly more significant value on the second day, transitioning from negative to positive value. The highest correlation occurs on the third day, meaning that precipitation had the greatest influence three days after the extreme precipitation amount. Also, the Pearson correlation was calculated by year for the impact of precipitation on water level/discharge (Figure 10).

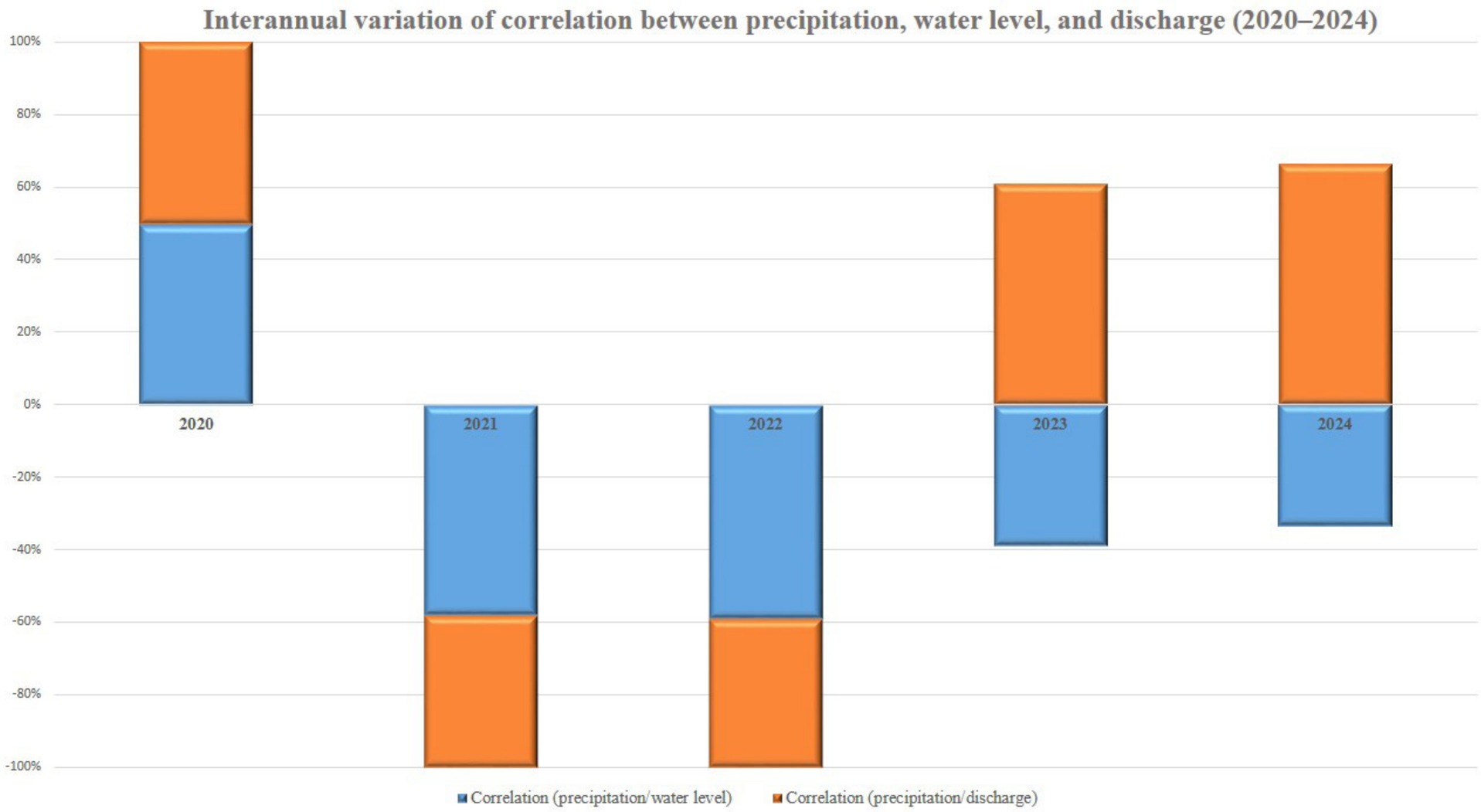

Figure 10. Interannual variation of correlation between precipitation, water level, and discharge (2020–2024)
Source: RHSS, , Hydrological Yearbooks (2020-2024)

The Figure 10. shows the interannual variation of the correlation between precipitation and water level, and precipitation and discharge, in the period from 2020 to 2024. The blue colour represents the correlation values between precipitation and water level, while the orange colour indicates the correlation between precipitation and discharge.

During 2020, positive correlations were observed for both pairs of parameters, indicating that an increase in precipitation was followed by an increase in water level and discharge, consequently. In 2021 and 2022, the correlations became negative, which may indicate a reduced dependence between precipitation and hydrometric parameters, likely due to hydrological, climatic, or anthropogenic influences (e.g., flow regulation, increased evaporation, and changes in infiltration patterns).

In 2023 and 2024, correlations returned to positive values, although weaker than in 2020, indicating a partial restoration of the relationship between precipitation and surface water parameters. This trend suggests that the relationship between atmospheric and hydrometric factors changes over time, probably as a result of the combined influence of climatic oscillations and local hydrological conditions.

Table 3. Descriptive statistics (10th and 90th percentiles) for precipitation, water level, and discharge

	Percentile	Value
Precipitation [mm]	Percentile 10	0.2
	Percentile 90	14.6
Water level [cm]	Percentile 10	76
	Percentile 90	383
Discharge [m^3/s]	Percentile 10	1690
	Percentile 90	3934

Using the 10th and 90th percentiles, sums of precipitation, water level, and discharge were used to define extreme values (Table 3). A total of 57 extreme precipitation events were identified, while water level extremes coincided with these events on only 5 days, and discharge on 7 days. This indicates that only in

some cases were extreme precipitation events followed by corresponding extremes in water level or discharge. However, extreme water levels and discharges were sometimes observed even when precipitation was within normal or low ranges, suggesting contributions from upstream precipitation, snowmelt during winter months, and other hydrological factors.

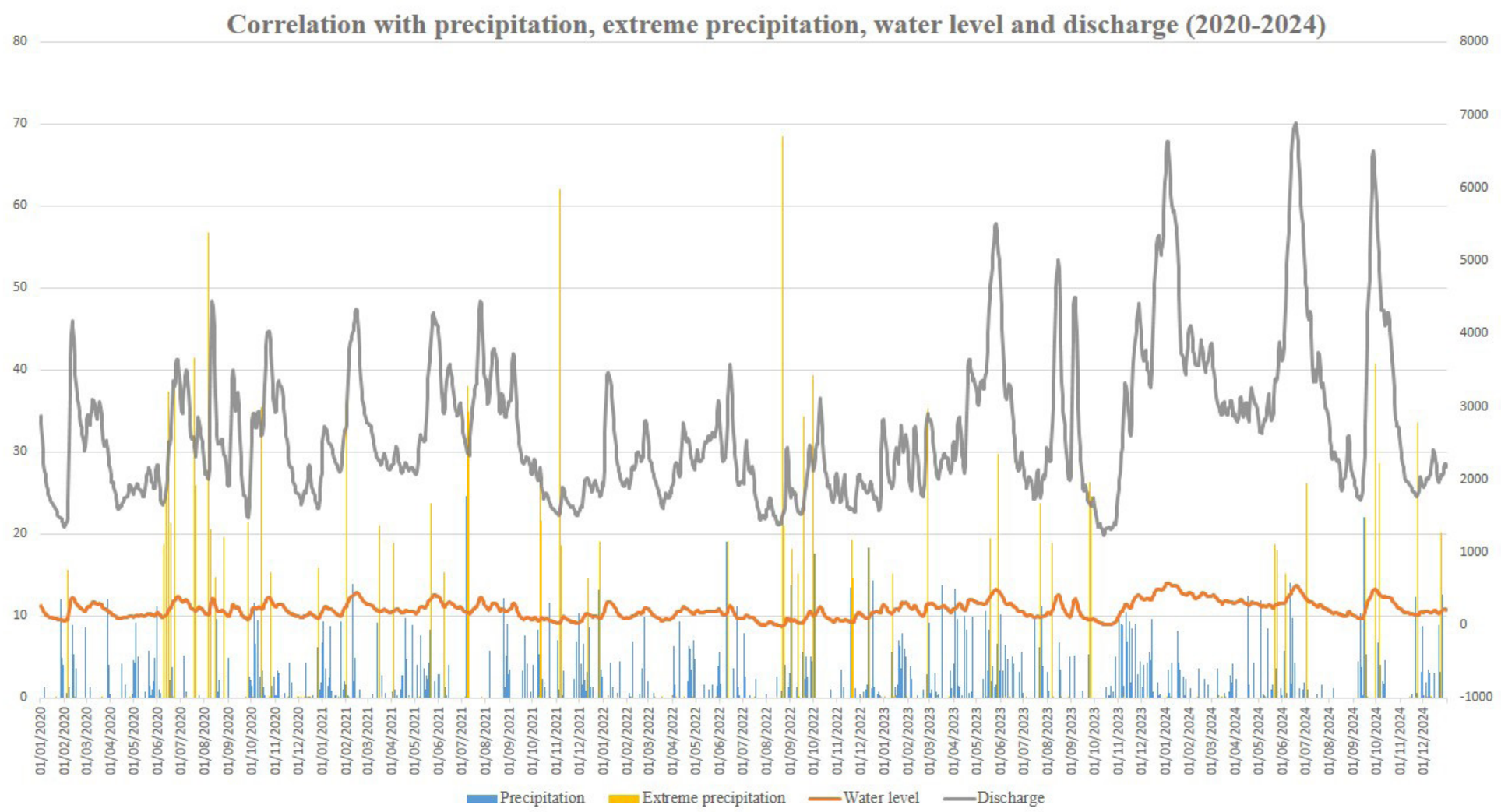

Figure 11. Correlation with precipitation, extreme precipitation, water level and discharge for 2020 to 2024.

Source: RHSS, Meteorological Yearbooks and Hydrological Yearbooks (2020-2024)

In Figure 11, overall relationships between precipitation, extreme precipitation (above the 90th percentile; >14.6 mm), water level, and discharge are presented. Blue bars represent total precipitation for 2020–2024, yellow bars indicate extreme precipitation events, and orange and grey lines represent water level and discharge, respectively.

Seasonal and periodic patterns are visible in the grey discharge line, showing annual cyclical peaks that correspond with expected rainfall and snowmelt cycles. Peaks in discharge generally follow periods of higher precipitation.

Extreme precipitation events (yellow peaks) are often followed, after a short time lag, by rises in water level and increased discharge. Water level remains relatively stable with minor fluctuations, though a slight increase after 2022 may indicate changing hydrological conditions, such as higher average precipitation or reduced drainage capacity. Extreme precipitation events are rare but occur nearly every year, typically followed by a response in discharge, highlighting potential flood risk. The 2023–2024 period appears to represent the most active hydrological cycle, with more pronounced peaks and higher flood risk, whereas 2020–2021 was more stable, with smaller amplitudes and fewer extremes.

The relationship between precipitation and water level shows a temporal lag, which is statistically weak but positive, indicating that precipitation effects on hydrological parameters may manifest after some delay.

DISCUSSION

In this study, an analysis of water level and discharge at the Danube hydrological station in Novi Sad is presented. Data from hydrological and meteorological stations in Novi Sad were used. Precipitation was

used as the main factor for comparison with water level and river discharge.

Observed deviations from the long-term precipitation regime indicate that certain drivers of precipitation distribution have changed in recent years. While the long-term pattern (1949–2024) is characterized by a pronounced increase in precipitation during late spring and summer, the recent period (2020–2024) shows a relative shift toward higher autumn precipitation, particularly in September. This may be related to changes in atmospheric circulation patterns over Central and Southeastern Europe, including an increased frequency of late-summer and early-autumn cyclonic activity. In addition, rising air temperatures can increase atmospheric moisture capacity, which may contribute to more intense precipitation events outside the traditional peak season (May–July).

Mean monthly water levels are slightly higher than long-term averages, however, this cannot be directly attributed to precipitation alone, given the weak relationship observed between precipitation and both water level and discharge. The observed variations are more likely related to a combination of upstream hydrological conditions, including snowmelt processes, tributary contributions and overall basin-scale dynamics. During winter and spring, earlier snowmelt and higher temperatures may have contributed to elevated water levels, while during summer months higher values may occasionally be linked to precipitation in upstream areas. In late summer and autumn, lower water levels are more consistent with reduced precipitation and drought conditions in parts of the upstream basin, rather than direct local precipitation effects.

The generally stable water regime, with a winter maximum, suggests that factors other than local precipitation exert a stronger control on water level dynamics. This pattern likely reflects the influence of delayed hydrological processes, such as snow accumulation and melting. In contrast, the pronounce June peak in discharge indicates the importance seasonal factors, particularly snowmelt and transitional hydrological conditions, followed by stabilization as the regime becomes more consistent. Both water level and discharge are controlled by multiple interacting factors, such as snow and ice melt processes, upstream basin conditions, and inflow from Danube tributaries. However, the results indicate that no strong direct relationship with local precipitation can be identified at the analysed scale.

Statistical analysis was applied using the 10th and 90th percentiles to determine precipitation extremes and their effects on water level and discharge. Additionally, the Pearson correlation coefficient was calculated to assess the statistical significance of precipitation impacts on water level and discharge. The influence of precipitation extremes on the Danube at the Novi Sad hydrological station was also evaluated.

It was noted that the impact of precipitation on water level was smaller than on discharge. Furthermore, the effects of precipitation were also evaluated using lag times of several days, as larger precipitation events may influence river response with delay. An increase in the influence of precipitation was observed for both variables, although the correlation remained negative for water level, while it became positive for discharge with delay. The strongest changes were observed on the third day after precipitation events. Water level increases may be more evident during prolonged periods of intense precipitation or significant snowmelt, whereas short-term rainfall events often do not produce an immediate response, particularly in large river systems such as the Danube.

Differences among years were also observed. Pearson correlation was calculated for each year, showing a positive correlation for water level in 2020, while for discharge positive values were observed in 2020, 2023, and 2024. Years 2020 and 2023 were characterized by higher precipitation totals, whereas 2024 exhibited lower values.

Overall, precipitation in Novi Sad shows low statistical significance in relation to Danube water level and discharge, with slightly negative Pearson coefficients, although higher values are observed in the days following extreme precipitation events. This limited influence may result in short-term increases in water level and discharge, which are sometimes detectable only at an hourly scale, when direct responses become more apparent.

As Pekárová et al. (2019) pointed out, variations in Danube discharge could be influenced not only by in-

creased precipitation associated with climate change but also by human interventions such as river channel modifications aimed at reducing flood risk and accelerating drainage. Additionally, Mitková (2021) observed that water levels are now higher than in the past for the same flood discharges, which may indicate changes in the river channel or surrounding environment, such as river regulation, levee construction, or reduced floodplain extent.

The main limitation of this study is the use of a single hydrological station. Using only one hydrological and meteorological station limits the assessment of precipitation impacts, given the large size of the Danube catchment and the strong influence of upstream hydrological and climatic conditions. Another limitation is the use of daily data, which may not capture short-term responses to extreme precipitation events.

Therefore, future studies should incorporate multiple upstream stations and higher temporal resolution (e.g., hourly data) to better assess precipitation impacts on water level and discharge. Such improvements would provide a more comprehensive understanding of hydrological responses and their variability over time.

CONCLUSION

The temporal analysis of precipitation effects on water level and river discharge at the Novi Sad station on the Danube indicates that the relationship between these variables is complex and weak at the local scale. The results show no clear or consistent evidence that local precipitation directly controls short-term variations in water level and discharge.

During the observed period (2020–2024), changes in precipitation patterns were identified compared to the long-term record (1949–2024), with higher precipitation occurring in summer and autumn months. However, water level and discharge exhibit an opposite seasonal pattern, with higher values during the first half of the year, indicating a weak direct correspondence with local precipitation at the seasonal scale.

Local precipitation in Novi Sad represents one of the contributing factors to the hydrological regime, although its effect is weak and non-linear at the analysed scale. The observed variability is primarily influenced by a combination of basin-scale processes, including snow accumulation and snowmelt in upstream mountainous regions, spatial variability of precipitation across the Danube catchment, and tributary inflows.

In particular, hydrological responses are strongly modulated by snowmelt processes in upstream areas, which can dominate discharge dynamics during certain periods. Earlier onset of snowmelt, driven by rising temperatures, may also alter the timing of runoff contributions. Major tributaries, such as the Drava, Sava, and Tisa, further contribute to discharge variability due to their distinct hydrological regimes. In addition, anthropogenic regulation, including dam operations and hydropower management, influences flow through retention and controlled releases. High summer temperatures may additionally reduce discharge through increased evapotranspiration and prolonged dry periods.

A temporal lag in the response of hydrological parameters to precipitation was observed, although the relationship remains weak. For discharge, statistically significant correlations were detected at lag times of up to three days, suggesting a delayed response to precipitation events, while no significant relationship was found for water level.

Overall, the findings indicate that local precipitation does not represent a primary control on the hydrological regime of the Danube at Novi Sad, but it still contributes to the overall system response, while river dynamics are mainly driven by upstream and basin-scale hydrological processes.

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CONFLICTS OF INTEREST

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