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REPEATABILITY CYCLES OF RIVER DISCHARGES: CAN WE IDENTIFY DISCHARGE PATTERNS? A CASE STUDY OF THE SOUTH MORAVA RIVER (SERBIA)

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Abstract: Water scarcity, unequal access to water resources, and the impact of climate change on water availability are among the major global environmental concerns. As dynamic and vulnerable water subjects, rivers are constantly exposed to the pressure of natural conditions variability (primarily climatic) and direct anthropogenic influences. Therefore, it is necessary to investigate river regime dynamics over longer periods to adapt the water management sector, and human demands to any observed variations in river discharge. Observing the periodicity or cyclicity of the occurrence of certain discharge values is an important topic of modern physical geography and hydrology research. Statistics and hydrologic modelling provide great opportunities for observing cyclicality and forecasting future trends. The aim of this paper is to indicate the importance of specific statistical methods of autocorrelation and spectral analysis to study the repeatability of mean annual and maximum discharges. The South Morava River in Serbia (HS: Mojsinje, Korvingrad, Grdelica) has been selected as a case study. The obtained results (period: 1924-2021) indicated the significant cyclicity of mean annual discharges, especially pronounced at the upstream hydrological station Grdelica (3.5-year cycle) and downstream hydrological station Mojsinje (19.5-year cycle). These cyclicities are mostly influenced by variations in the amount of precipitation received from the upper part of the river basin ($R > 0.6$). In contrast, no regular cycles of maximum annual discharge values were determined in the studied period. The obtained results can be important for future detailed geographic and hydrologic studies as well as for the development of strategies and plans in the field of water management, environmental protection, spatial planning, prevention of floods and droughts, etc.

Keywords: river discharge, time-series methods, spectral analysis, cyclicality, South Morava River, Serbia

1. INTRODUCTION

At the beginning of the 21st century, the world is facing different environmental problems, many of which are related to scarcity, unfavourable geographic distribution, and specific dynamics of water resources. Climate change and direct anthropogenic impacts affect the global hydrologic cycle and the availability of groundwater and surface water (Majone et al., 2022; Karam et al., 2023), indirectly increasing socioeconomic and environmental vulnerability. Integrated and sustainable development and water management require an understanding of the impact of these processes on water resource variability (Zhao & Boll, 2022). Changes in the water regime are mostly influenced by variations in the values of the main meteorological elements, particularly precipitation, and temperature (IPCC, 2022). Therefore, research on the effects of climate change on hydrological systems is important from a variety of scientific and practical perspectives, particularly when it comes to understanding the frequency and level of extreme hydrological events like floods and droughts (Duong et al., 2014).

According to the latest IPCC report (IPCC, 2023), Europe has been characterized by regionally varying changes in temperature and precipitation, focusing on southern Europe, which is described by an increase in annual temperature, and different seasonal trends for precipitation. Climate projections show a significant increase in temperature extremes, meteorological droughts, and heavy precipitation events (Beniston et al., 2007). Blöschl et al., (2019) indicated that a decrease in precipitation and an increase in evaporation lead to a decrease of flood waves in the area of large and medium river basins in southern Europe. Extreme discharge values, on the contrary, tend to occur more often, which has resulted in frequent flash floods in smaller river basins, with a negative impact on society and their activities. Additionally, it's necessary to highlight the growing effects of anthropogenic activity in river basins, including direct river regulations (Chen et al., 2023), land use changes, deforestation, and anthropogenic pressure. Quantifying the effects of natural compared to direct anthropogenic causes of discharge variability is thus one of the key challenges of contemporary hydrologic studies.

The most significant feature that is variable at different spatial and temporal scales is river discharge; the temporal domain includes short-term (hourly, daily, monthly and, yearly) and long-term (perennial) variability, while the spatial domain includes variability between rivers and along the same river course. Complex geographic factors, such as geologic, orographic, climatic, biogeographic, and anthropogenic processes, affect the spatial-temporal variability of river discharge (Hansford et al., 2020; Chen et al., 2023). Therefore, it is important to comprehend past, current, and future trends in a particular river basin, identifying the discharge variability at various scales.

Various statistical techniques and mathematical models have been used in contemporary scientific research that deals with hydrological analysis and trends. Even though the determination of discharge cycles has been extensively studied, the determined increase of catastrophic hydrological events opens up new research areas and presents opportunities to use particular techniques for their understanding (Kochanek & Markiewicz, 2022).

The main objective of this research is to determine the repeatability of river discharge cycles in order to ascertain their significance for future discharge variability prediction. In this context, statistical methods of autocorrelation and spectral analysis were applied. As fundamental parameters, mean annual and maximum annual discharge data were used. The South Morava River in Serbia was chosen as a case study for the implementation of the aforementioned statistical techniques since it has a sufficiently long time series of reliable and adequate data (a period of 98 years). The discussion focused on how the variability of the primary climate element (total and maximum precipitation) is related to the results obtained from hydrological analysis.

The main outcomes of this study include (a) the creation of a comprehensive database of meteorological and hydrological data; (b) the results of trend analysis and correlation with rivers with similar characteristics; (c) the application of non-standard statistical methods in hydrological research to ascertain the periodicity of cycles; and (d) the outcomes of the correlation between hydrological and precipitation data. The results can be used as a basis for comprehensive research and widespread implementation of this methodology to quantify and assess the influence of numerous factors on observed changes in the hydrological regime. The findings are important for future geographic and hydrologic studies as well as for the development of strategies and plans in the field of water management, environmental protection, prevention of floods and droughts, etc.

2. MATERIALS AND METHODS

The methodological procedure is composed of multiple parts, including the basic segment (definition of the spatial and temporal aspects, data collection, and data processing), the application of general statistical methods in hydrological analyses (trend analysis), the application of specific methods to determine discharge repeatability cycles, and methods for determining precipitation/discharge relations. For a more comprehensive overview, a flow chart was created (Figure 1).

2.1. Spatial component and data acquisition

The availability of appropriate empirical data as well as the unique geographical and hydrological characteristics of the river basin had played an essential role in determining the spatial and temporal aspects of the study. Application of time series methods requires the availability of data in longer time series (at least 50 years) (Dettling, 2020). Accordingly, the South Morava River is selected as a case study in this research, because it satisfies the requirements mentioned.

The South Morava River Basin (15,838 km^2) is located mostly in Serbia (14,372.5 km^2), with lesser parts in the Republic of Bulgaria (1,096 km^2) and North Macedonia (369.5 km^2) (Figure 2) (Langović et al., 2022). Its area covers 16% of the territory of the Republic of Serbia and represents one of the most important rivers. The South Morava River originates at an altitude of 392 meters at the confluence point of the Binačka Morava and Preševska Moravica rivers in the town of Bujanovac. Near the town of Stalać, it meets the West Morava River to form the Great Morava River, one of the most significant tributaries of the Danube River in the Balkans. Most of the South Morava River Basin is mountainous (77% is higher than 500 m), with the highest points just above 2,100 m (Figure 2). The South Morava River (295 km) has 157 tributaries (Dukić & Gavrilović, 2014), the most important of which are the right tributaries Nišava and Vlasina and the left Toplica. The Nišava River discharges approximately 36 m^3/s of water to the South Morava River, Vlasina River 7.56 m^3/s, and Toplica River 9.48 m^3/s (which is approximately 56% of the total annual discharge of the main river – 91.7 m^3/s near the confluence).

According to the current hydrological station network (RHSS, 2021), there are six active hydrological stations (HS) on the South Morava River main course. However, over history, there have been significant changes in their number, location, and method of recording hydrological features. The history of water level observation and measurement in the South Morava River Basin began in 1923, while systematic measurement and documentation of river discharge began in the mid-20th century. During the whole period, three representative stations were constantly in operation, which is the reason they were selected for further analysis - HS Mojsinje (1), HS Korvingrad (2), and HS Grdelica (3) (Figure 2).

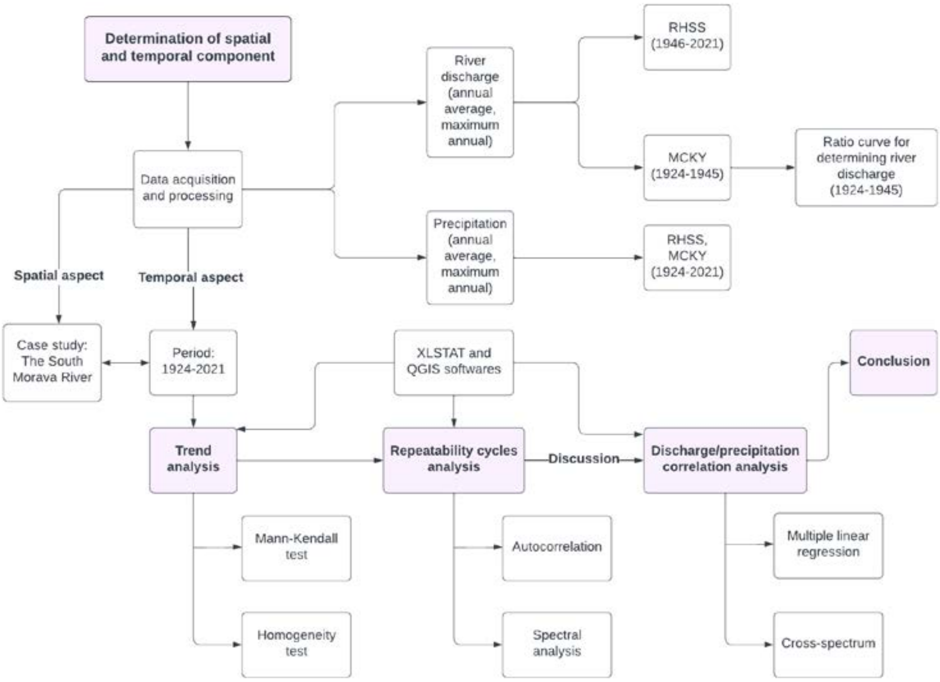

Figure 1. Methodology flow chart

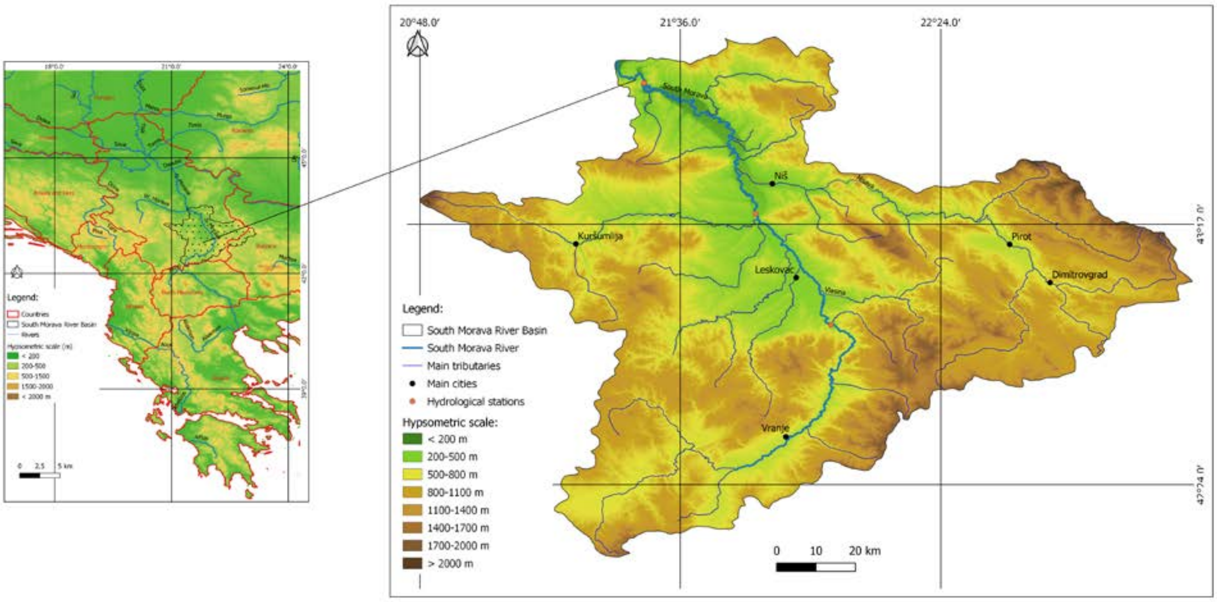

Figure 2. The South Morava River Basin (1- HS Mojsinje, 2 - HS Korvingrad, 3 - HS Grdelica)

The analysis of mean annual and maximum annual discharge data for the period 1946–2021 (RHSS, 1946-2021), represented the initial phase of research. The second part included the water level data collection in the period 1924-1945, which was published in special reports (MCKY, 1924-1945). During the same time period, sporadic discharge measurements were conducted in addition to the daily water level data. Based on the aforementioned data, the consumption curve (ratio curve) was created (Ramirez et al., 2018; Negatu et al., 2022), and a comprehensive analysis was carried out. By using this technique, the corresponding river discharge for each recorded water level at all three hydrological stations was determined. The values of the South Morava River's daily, monthly, yearly, maximum, and minimum discharges for the period 1924-1945 were thus quantified for the first time. This research phase was the most challenging and time-consuming part of the methodological procedure.

2.2. Trend analysis

The fundamental phase in any complex hydrologic analysis is the evaluation of trends in data time series. These methods are referred to as time series analysis methods. Several scientific papers (Langović et al., 2017; Zaghloul et al., 2022) addressed the topic, using various techniques. The Mann-Kendall test (Chen et al., 2021; Abdelaziz et al., 2023), was used to identify the type and value of the trend in mean annual and maximum annual river discharges. It is based on the null hypothesis that shows that there is no trend in the data, i.e., the measurements acquired over time are independent and identically distributed. The results of the Mann-Kendall test indicate the trend characteristics (decreasing, stationary, or increasing) as well as the trend significance at the given significance level. The Sen Estimate test enables estimating an average increase/decrease value of the annual or maximum discharge.

The homogeneity test, which aims to assess the homogeneity of a particular time series, is another significant statistical test. The Pettitte test is a nonparametric test that detects and identifies the presence of a shift in a time series (Arikan & Kahya, 2019; Pastrana et al., 2022; Amichiatchi et al., 2023). It can be used to determine the "breaking point" or the year of change. The XLSTAT 2023 statistical program was used to perform both tests.

2.3. Specific time-series analysis methods

Autocorrelation, often known as serial correlation, is a valuable statistical tool that can be used in hydrological studies. The primary purpose of autocorrelation is to identify the relationship between variables and time lags (Box et al., 2008) or to determine the repetition of some parts of a time series with a given time lag. The results of applied autocorrelation indicate whether time series values are stationary or seasonal (Zamani et al., 2016). During the autocorrelation, a time sequence correlates with itself, shifting it by one lag in each succeeding step. Furthermore, results indicate how each piece of data influences subsequent ones (Larsen et al., 2019). The simplified autocorrelation equation (1) is given:

$$\mathrm{p}_k = \frac{\sum_{i=k+1}^{T}(r_i-\bar{r})(r_{i-k}-\bar{r})}{\sum_{i=1}^{T}(r_i-\bar{r})^2} \quad (1)$$

where the above component (nominator) indicates the covariance between data and lag and the below portion (denominator) represents the sum of squared standard deviations of data (Salkind, 2006) (r_i is i observation of the time series, $\bar{r}$ the average value of the time series, and k is the time lag). The autocorrelation function (pk) is symmetric around 0 (Davis, 1986); this stage is known as "dominant zero" and denotes coincidence in time series data, while prominent peaks (-1 to +1) indicate the presence of periodicities. The calculated coefficient for different lags is presented in the form of autocorrelograms (Caren & Pavlić, 2021).

Spectral analysis belongs to a time-series statistical method that denotes a set of statistical techniques based on Fourier analysis of time series (Mcleod & Hipel, 1999; Babirath et al., 2020). It can be applied to any time sequence with a natural periodicity or that contains harmonic signals incorporated in noise (Chen et al., 2021). It can be applied in a variety of physical geography studies, particularly those focusing on climatology (Michele & Bernardara, 2005; Tsai et al., 2018), hydrology, and paleogeography (Sánchez-Morales et al., 2023) as an explanatory and valuable method for comprehending the dynamics of a particular process.

The concept of using spectral analysis in hydrological research is predicated on the opportunities the technique offers, particularly the capacity to recognize river discharge and water level cycles. Despite many possibilities this method has not been used at a sufficient level in hydrology. The lack of empirically adequate, accurate, and continuous hydrological data is the most frequent cause of this. However, certain scientific papers that applied spectral analysis in hydrologic research can be identified (Kite, 1989; Lall & Mann, 1995; Pisarenko et al., 2005: Timuhins, et al., 2010; Malik et al., 2019; Jiang et al., 2020; James & Bondell, 2022; Abdelaziz et al., 2023). Spectral analysis was first developed as a data compression method for geographical research in the 1980s. Kite (1989) examined linear trends, cycles, and autoregressions between water levels and climate variables using spectral analysis. In order to predict future trends, Lall & Mann (1995) investigated fluctuations of the Great Salt Lake's water level using this method. James & Bondell (2022), using spectral analysis assessed cycles of river discharges in Australia.

The spectral analysis transforms a time series of data into a frequency domain by simultaneously converting time into waves that have different amplitudes, phases, and periods (Adamowski et al., 2013; Denić-Jukić et al., 2020). Thus, it is possible to measure and localize the strength of periodic (sinusoidal) component waves. The importance of spectral analysis can be observed in the decomposition of a complex time series (composed of cyclic elements) into several basic functional sinusoids with specific wavelengths. Assessing the strength of the periodic component at each potential frequency is the analysis' ultimate goal (Houser et al., 2022). To depict spectral analysis the continuous forward Fourier Transform and its inverse form can be used. According to the equation (2), the value of the function f(jω) is (Wearing, 2010; Lei, 2011; Adamowski et al., 2013; Cuff, 2017):

$$f(j\omega) = \int_{-\infty}^{\infty} f(t) * e^{-j\omega t}\, dt \quad (2)$$

where ∫ is an integral over any period, f(t) is a time domain function (f), -j is an imaginary unit and dt stands for frequency domain. The inverse transformation (3) can be used to compute the time-domain function f(t) from the frequency domain F(jω):

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(j\omega) * e^{j\omega t}\, d\omega. \quad (3)$$

The spectrograms are graphs composed of a sinusoidal wave of different frequencies, and are used to display the results. A primary purpose of spectrograms is to show if time series data are random or periodic; if there are peaks that are highlighted, the data are not random (Pekarova et al., 2019). The statistical software XLSTAT 2023 was used to conduct the spectral analysis. Fisher's Kappa and Bartlett's Kolmogorov-Smirnov statistical tests (Bartlett, 1966) were computed as well to see whether the time series of data could be considered to have white noise. The white noise tests determine if the variables are equally distributed as well as autonomously distributed with a mean of zero (Moffat & Akpan, 2019).

Multiple linear regression and cross-spectral analysis methods were used to determine the relationship between hydrological and meteorological parameters. Multiple regression analysis is used to measure the relationship between two or more variables to predict the further behaviour of the dependent variable concerning the independent or explanatory variable (Jung et al., 2017; Zaghloul et al., 2022). Correlation matrices were used for graphic and numeric results presentation. Cross-spectral analysis is a technique used to determine the relationship between two variables in the frequency domain. It includes analysing the cross-spectrum or correlation between frequencies of two parameters (Torre et al., 2018). Therefore, it is possible to determine the degree of coherence between repeatability of hydrological cycles in relation to climatological results.

3. RESULTS AND DISCUSSION

The initial results include the statistical analysis of river discharge trends and the identification of time series homogeneity. Therefore, the Mann-Kendall and Pettitte tests were performed. As input data, the mean annual and maximum annual river discharge of the South Morava River for the period 1924-2021 were used.

The results of the non-parametric Mann-Kendall test (Table 1) revealed a dominant decreasing trend of annual and maximum discharge values at the HS Mojsinje and HS Korvingrad and an increasing trend at HS Grdelica. The only significant trend was registered at HS Korvingrad with a -0.214 m^3/s

Table 1. Results of the Mann-Kendall and Pettitte homogeneity tests

Mann-Kendall test						Pettitte test		
HS	Parameter (m^3/s)	Kendall's tau (τb)	p-value	Trend	Sen's estimator	ά - value	p-value	Breaking point (year)
Mojsinje	Q_{an}	-0.052	0.525	d	-0.088	0.05	0.112	1982
	Q_{max}	-0.084	0.279	d	-1.529	0.05	0.101	1983
Korvingrad	Q_{an}	-0.183	0.026*	d	-0.214	0.05	0.007*	1981
	Q_{max}	-0.183	0.025*	d	-2.250	0.05	0.011*	1965
Grdelica	Q_{an}	0.13	0.096	i	0.061	0.05	0.077	1953
	Q_{max}	0.006	0.947	i	0.038	0.05	0.106	1950

[*] Q_{an} – mean annnual discharge; Q_{max} – maximum annual discharge; d – decreasing trend; i – increasing trend

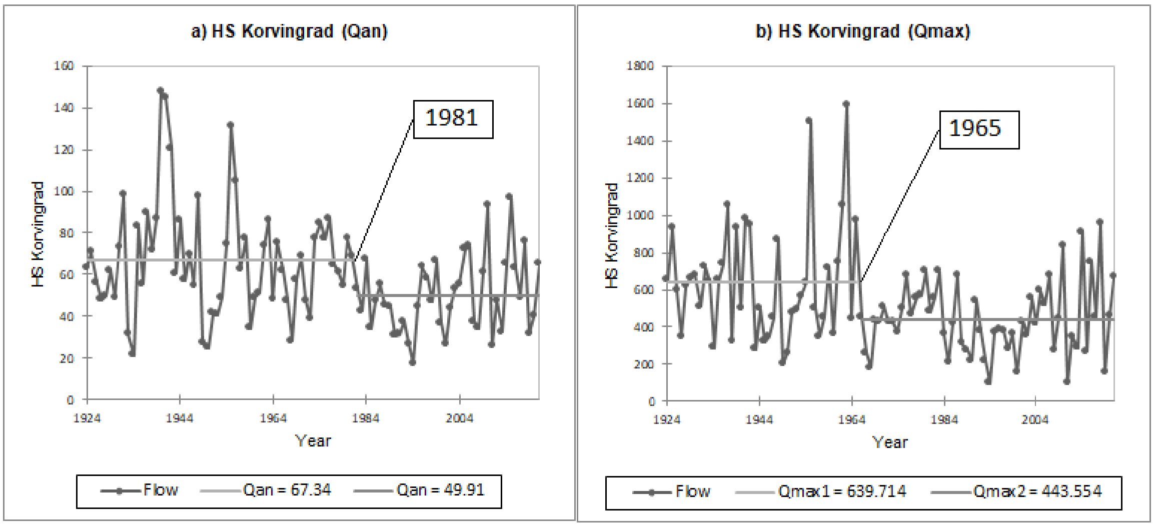

Figure 3. Results of homogeneity test: mean annual (a) and maximum annual (b) discharge at HS Korvingrad

average decrease in annual river discharge, and a -3,75 m^3/s average decrease in maximum river discharge (moderate decreasing statistical trend). Previous research showed that most rivers of the Balkan Peninsula have dominantly decreasing trends in discharge values over the past 60 years (Kovačević-Majkić & Urošev, 2014; Zakwan et al., 2021), with rivers in the South Morava River Basin being particularly highlighted (Langović, 2019).

The homogeneity test results at HS Korvingrad (Figure 3) revealed a significant change in the mean annual and maximum discharge values. For mean annual values, a significant change occurred in 1981, considering that the level of significance is lower than 0.05 (p-value is 0.007), while for maximum discharges, the change occurred earlier, in 1965 (p-value is 0.011). Therefore, for the HS Korvingrad, the null hypothesis of homogeneity has been rejected. In Figure 3, the HS Korvingrad time series inhomogeneity is depicted more clearly. Examining the variations in the trends of monthly and seasonal discharge is important to provide a more thorough explanation of the factors that led to the stated change in annual discharge value at the HS Korvingrad. A statistically significant reduction in seasonal discharge is observed throughout the summer (Z= -2.64, significance level of 0.01) and spring (Z= -1.74, significance level of 0.1), which is mostly responsible for the previously observed decreasing trend in annual discharge values.

To identify the traces of cyclicity in the provided time series, the statistical approach of autocorrelation was applied in the following part. In Figure 4, autocorrelograms illustrate the autocorrelation coefficient of mean annual and maximum annual discharge values within a 95% confidence interval (the computed value of the autocorrelation coefficient is 0.21). After examining the autocorrelation results, it can be determined that the mean annual discharge time series had no established significance. Therefore, the obtained results can be defined as random. Nonetheless, even in that instance, repeatable segments can be identified, even if they have no statistical significance.

At HS Mojsinje and Kurvingrad (Figure 4 a, b), certain patterns can be observed - the outer third of the period (the first and final 30 years) is characterized by predominantly positive autocorrelation in contrast to the centre portion of the period, where negative correlation predominates. Dissimilar them, on the most upstream profile of HS Grdelica (Figure 4c), change cycles of positive and negative autocorrelation values can be clearly distinguished twice. Based on these results, it may be concluded that it is impossible to identify additional dynamics of the indicator values, i.e., adjacent observations (periods) do not "cooperate," resulting the case of "no autocorrelation". However, the presence of several distinct peaks on the HS Mojsinje and HS Grdelica that are statistically very close to the specified confidence interval (such as the one marked with lag 7) may be confirmed. This is not a guarantee that the observed condition demonstrates data dependence in the time series. According to the statistics, for a 95% confidence interval, random fluctuations should cause 1/20 of the period to be statistically significant.

Analysis of the maximum annual discharge values resulted in more significant outcomes, with all three stations determining significant autocorrelation values. This fact purely highlights the significance of examining maximum discharges in hydrological studies. At HS Mojsinje (Figure 4d), significant autocorrelation can be observed at lag 2 and almost significant at lag 7. The autocorrelation coefficient at

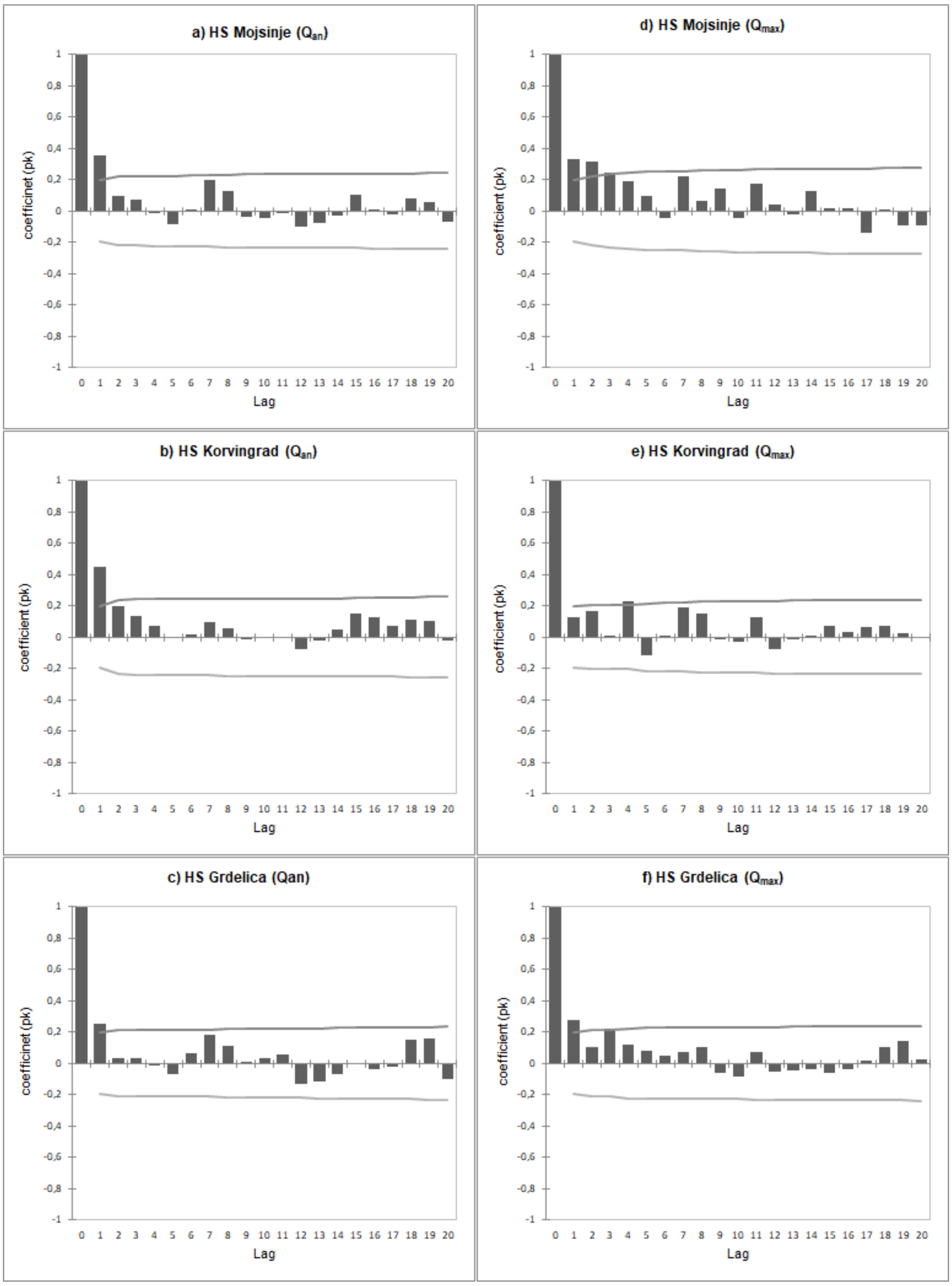

Figure 4. Results of autocorrelation

lag 2 is equal to 0.314, which is considered to be a moderately significant autocorrelation. At HS Korvingrad (Figure 4e), a significant autocorrelation was registered at lag 4 (coefficient value of 0.225), while at HS Grdelica (Figure 4f), the value of the coefficient was 0.223 (at lag 3). Therefore, the autocorrelation models shown in Figure 4 have been described as sinusoidal autocorrelation models. Considering the determined deviations from the confidence interval, an attempt was made to determine the cyclicity more accurately using the spectral analysis.

The spectral analysis method was used as the primary technique for determining the periodicity of the occurrence of certain river discharges (annual and maximum). The results are graphically represented in Figure 5 on six spectrograms. The frequency (F) in each spectrogram ranges from 0 to 3.142, indicating the duration of the analysed time series (periods from 1 to 98 years). Analysis of higher frequency values was not required because periodicity and repeatability of time series were not expected in that domain. Analysing the spectrograms of the mean annual discharge values, certain anomalies can be detected. Several distinctive peaks can be singled out at HS Moisinje (Figure 5a), three of which can be categorized as principal (frequency, 0.321, 0.064, and 0.769). Peak 0.321 (ps = 8560.1) has the highest amplitude, which corresponds to a periodicity of 19.6 years; the other two peaks correspond to periodicities of 98 years (0.064) and 8.16 years (0.769).

The obtained results demonstrate that in the 98 years, dominant mean annual discharge cycles at HS Mojsinje will be projected every 20 years. At the other two sites, there is one principal peak that corresponds to a periodicity of 98 years (f = 0.064) at HS Korvingrad (Figure 5b) and 3.63 years (f = 1.73) at HS Grdelica (Figure 5c). The analysis of the obtained results suggests that at HS Korvingrad exists higher deviations between peaks of the mean annual discharges (or exist one distinctive peak with smallest frequency), which implies that no cyclicity or repeatability of the time series has been established in the defined period. In contrast, at HS Grdelica, the periodicity of the mean annual discharges was determined every 3-4 years.

Analysis of the spectrogram of maximum annual discharge values also revealed significant results. Principal peaks corresponding to periods of 98 years were registered at all three investigated stations (Figure d,e,f). This condition is impacted by the fact that the maximum annual discharges reached extraordinarily high values just once over the whole research period. One secondary peak (f = 2.945) can be distinguished at HS Korvingrad, occurring every 2.13 years, and two secondary peaks (f = 0.256 and 1.731), occurring every 24.5 and 3.63 years, respectively, at HS Grdelica.

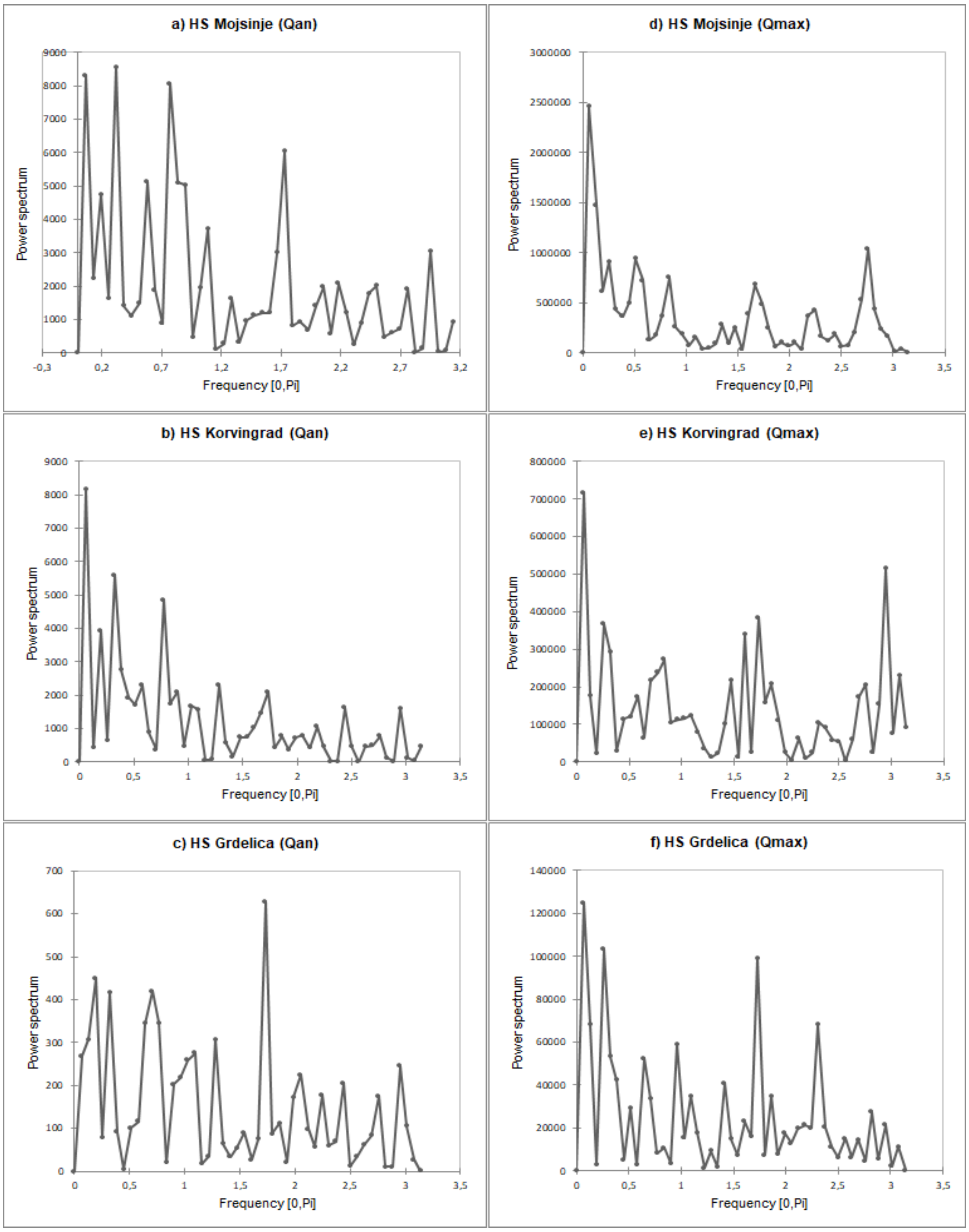

Figure 5. Results of spectral analysis

Other parts of all analysed spectrograms do not have distinct dominant peaks, which means that repeatability regularities are of secondary importance. "Harmonic spectrum" refers to the multiple series of lower amplitudes that are visible on all graphs. They are characterized by high-intensity oscillations and the impossibility of determining certain temporal regularities of repeatability. A group of connected lower peaks can also indicate a macro-component, that is, lower values of the average annual or maximum discharge can be repeated cyclically for a certain period. For example, at HS Korvingrad, when analysing the maximum discharges, two series of low values can be observed, which repeat cyclically every 30 years.

Results of the white noise test (Table 2) showed the existence of differences between stations and indicators. Mean annual discharge values at HS Mojsinje, and Grdelica are significantly different from white noise (significance level < 0.05). These time series can be described as random with unequal intensity at most frequencies. Small p-values cause us to reject the null hypothesis that the series is white noise. Similar results were obtained with the maximum annual discharges of HS Mojsinje and Grdelica, where Bartlett's Kolomogorov-Smirnov value is higher than the critical value (0.307 or 0.212), which rejects the null hypothesis of the existence of white noise. The only time series that has white noise outlines or the one in which the variables are identically distributed around the mean of zero is the maximum annual discharge values at HS Korvingrad (BKS = 0.155, with p-value 0.184).

Table 2. Results of white-noise tests

HS	Parameter (m^3/s)	Fisher's kappa k.	p-value	Bartlett's Kolmogorov-Smirnov k.	p-value
Mojsinje	Q_{an}	4.136	0.553	0.238	0.001
	Q_{max}	6.688	0.041	0.307	0.000
Korvingrad	Q_{an}	6.394	0.057	0.334	≤0.0001
	Q_{max}	5.027	0.247	0.155	0.184
Grdelica	Q_{an}	4.129	0.556	0.196	0.043
	Q_{max}	4.847	0.295	0.212	0.022

An important segment after identifying the repeating cycles of mean annual and maximum annual discharges in a long time series is the determination of the connection with the most important cause variable - precipitation. Data on the mean annual and maximum annual amount of precipitation in the South Morava River Basin in the period 1924-2021 were used for this purpose. The objective is to analyse both sets of data and establish the relationship between the average annual and maximum discharges on one hand and the annual and maximum amount of precipitation for the specified period on the other hand. Therefore, multilinear regression and correlation matrices were used to calculate and visualize their dependence. A cross-spectral analysis was conducted to ascertain how the precipitation cycles influence discharge cycles. The precipitation variations analysis was examined using precipitation data from representative rainfall stations for which empirical data are available in the studied period 1924-2021. In fact, 29 meteorological and rainfall stations were considered, while a more detailed analysis was done for the seven most representative meteorological stations in the basin (Niš, Leskovac, Vranje, Dimitrovgrad, Kuršumlija, Pirot, and Vlasina). Stations are dispersed throughout the South Morava River Basin and in various hypsometric zones (from Aleksinac at 168 m to Kukavica at 1,442 m) to examine the variety of influences in the rainfall-discharge system.

The first results of the multiple regression analysis revealed disparities in the conditionality of the independent variable, precipitation, in relation to the dependent variable, discharge. The amount of annual precipitation at each of the seven representative meteorological stations in the South Morava River Basin is moderately or highly correlated with the mean annual river discharge at three hydrological stations (Figure 6). The upstream HS Grdelica demonstrated the highest level of dependence, ranging from 0.42 (MS Vlasina) to 0.62 (MS Vranje), while HS Mojsinje showed the lowest level of dependence, ranging from 0.37 (MS Vlasina) to 0.51 (Vranje). These findings are consistent with the locations of the hydrological stations relative to the river course and the runoff factors in the river basin. For example, the South Morava River's upstream station is the one that is least impacted by anthropogenic factors, meaning that the river discharge is more closely correlated with the amount of precipitation. Given the length of the time series, which covers approximately 100 years, and the very

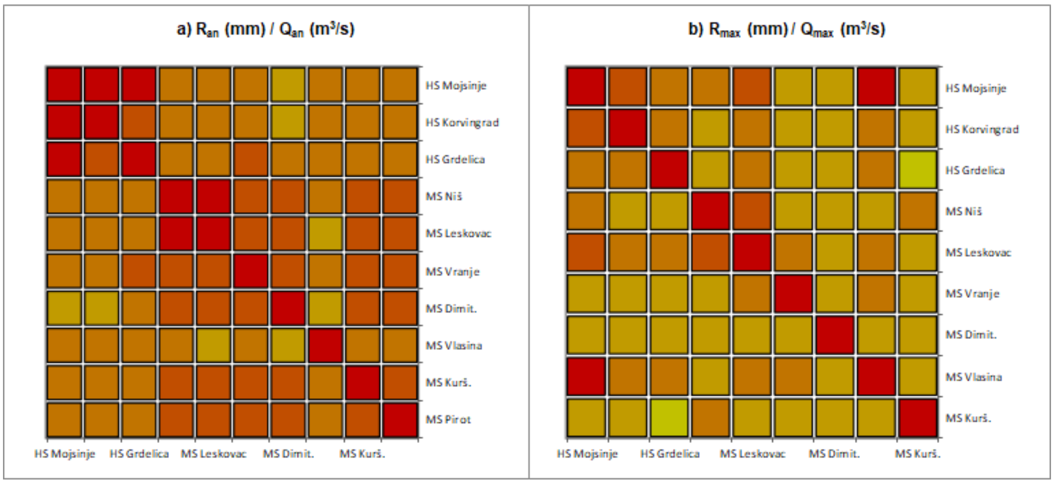

Figure 6. Correlation matrix of annual discharge/precipitation (a) and maximum discharge/precipitation (b)

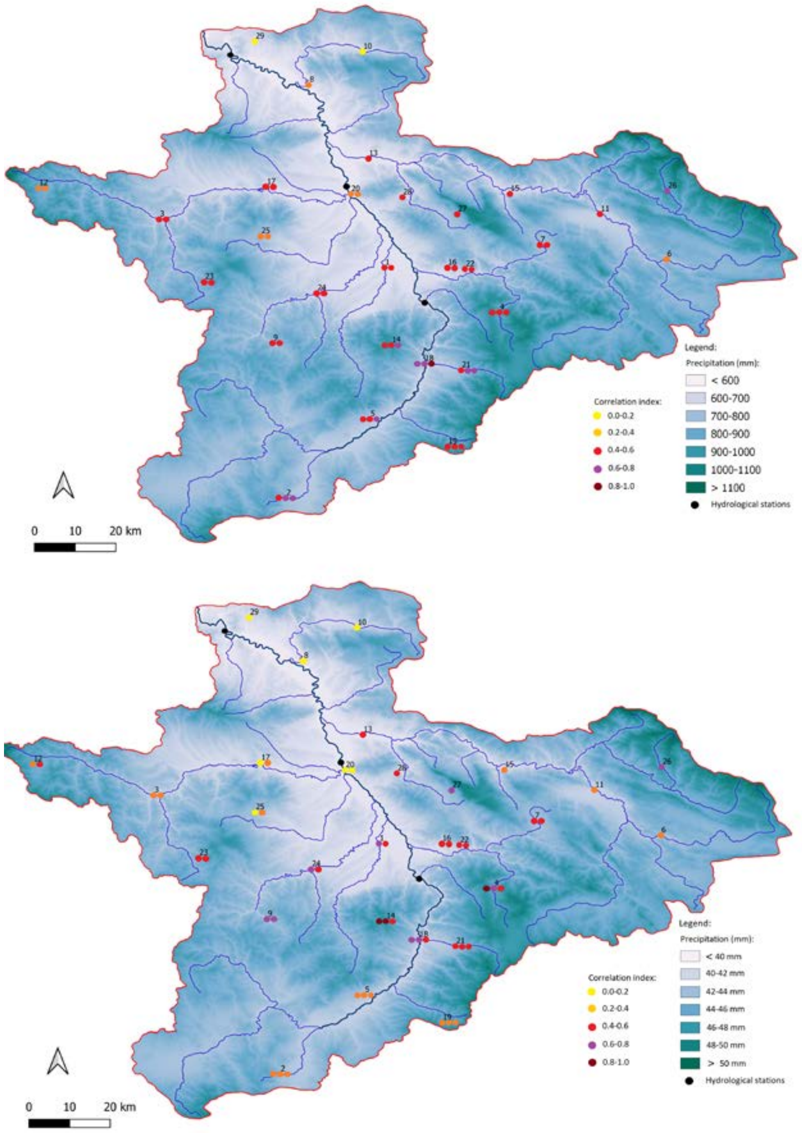

Figure 7. Precipitation maps of the South Morava River Basin (1924-2021) with correlation index (a) mean annual discharge/ precipitation (above), and (b) maximum annual discharge/precipitation (bellow)

[*] 1. Leskovac, 2. Preševo, 3. Kuršumlija, 4. Vlasina, 5. Vranje, 6. Dimitrovgrad, 7. Babušnica, 8. Aleksinac, 9. Sijarinska banja, 10. Sokobanja, 11. Pirot, 12. Blaževo, 13. Niš, 14. Kukavica, 15. Bela Palanka, 16. Vlasotince, 17. Prokuplje, 18. Vladičin Han, 19. Stari Glog, 20. Klisura, 21. Surdulica, 22. Kruševica, 23. Ivan Kula, 24. Lebane, 25. Žitni Potok, 26. Dojkinci, 27. Kaletinac, 28. Grkinja, 29. Ražanj; [**] the first point on the maps represents the correlation index between certain meteorological stations and HS Mojsinje, the second HS Korvingrad, and the third one HS Grdelica.

dynamic environmental, social, and economic conditions which are characteristics of this river basin, the obtained dependency can be considered quite important. The maximum annual discharges on all three stations are also moderately correlated in relation to precipitation. Correlation is noticeably less strong in the case of maximum discharges. Besides high daily precipitation, the snow cover melting is another crucial component that particularly influences maximum river discharges.

By combining the obtained statistical results and GIS software (Qgis), spatial dimension is given. Therefore Figure 7 depicts precipitation maps of the South Morava River Basin with separated zones of total annual precipitation and average maximum annual precipitation in the period 1924-2021. The results showed a high degree of dependence between upstream meteorological stations (Vladičin Han - from 0.65 to 0.89 depending on hydrological stations; Surdulica from 0.58 to 0.78). In contrast, the stations along the lower and middle part of the South Morava River showed low depending values according to discharge values (Ražanj - 0.15; Sokobanja - 0.19, Aleksinac - 0.25, all three compared to HS Mojsinje).

In contrast to the total amount of precipitation, in the case of the maximum annual precipitation, there are greater deviations in the rainfall/discharge system, which indicates a much more significant effect of other factors that influence river discharge. It is important to highlight the high dependence at the highest stations in the South Morava Basin: Dojkinci/HS Mojsinje - 0.78, Vlasina/HS Mojsinje - 0.90, Vlasina/HS Korvingrad - 0.65, Kukavica/HS Mojsinje - 0.90, Kukavica /HS Korvingrad – 0.85).

The final segment involved the application of cross-spectral analysis to determine if there is a correlation between discharge and precipitation cycles. Thus, Figure 8 depicts only stations where a higher correlation dependence was previously determined. Based on the previous analysis, it can be concluded that annual precipitation detected on MS Vranje has influenced moderate and high regression on discharge variations on all three examined stations. Cross-spectrum analysis results indicated that a cycle of annual precipitation occurs every 3.5 years (level of significance ≤ 0.05) which affects the occurrence of simultaneous water cycles on HS Grdelica which was previously proven. The observed climatic-hydrologic oscillation (3-5 years) is not a permanent characteristic of all stations. If we observe the same precipitation time series and compare it with values conducted on HS Mojsinje, we can perceive that there is no complete

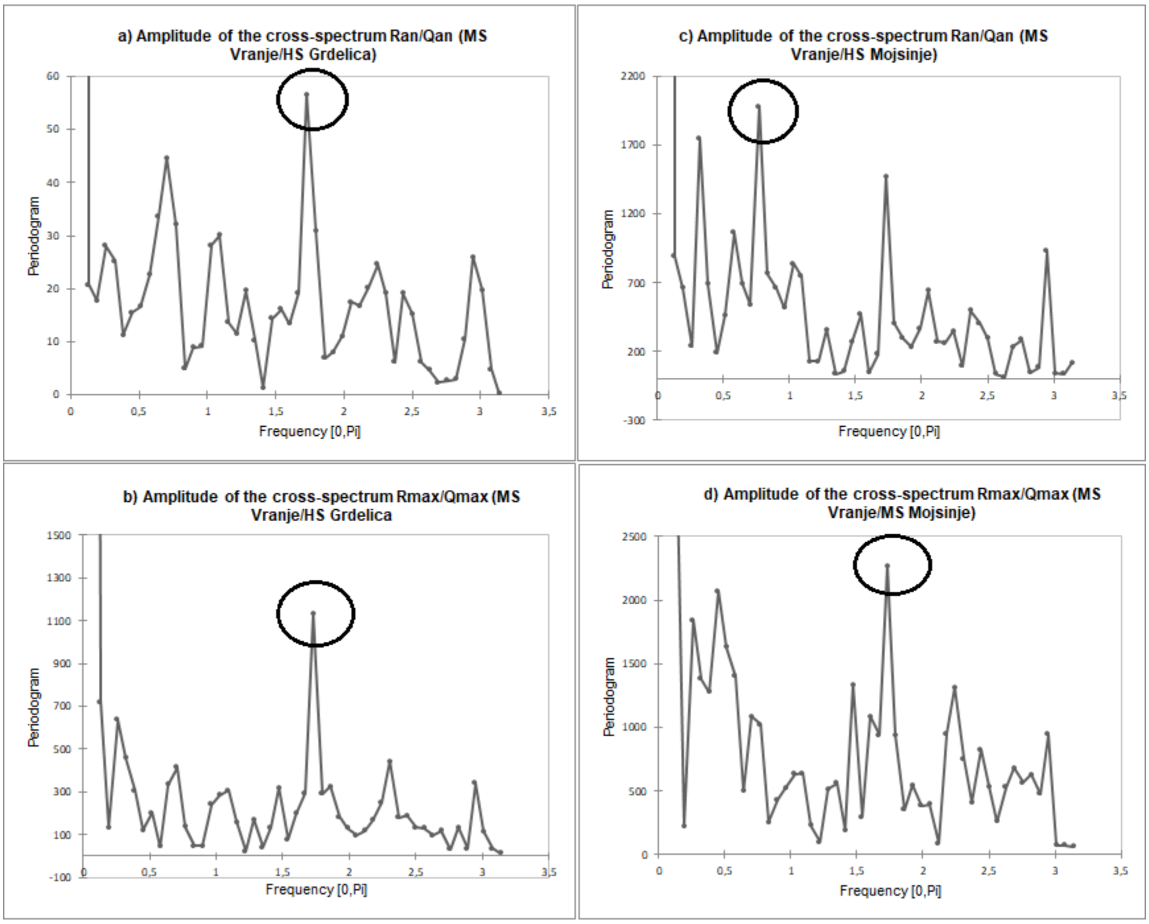

Figure 8. Examples of cross-spectrum spectrograms

concurrence of the precipitation/discharge cycle. The maximum value at HS Mojsinje (primary peak) responded to a cycle of 19.6 years, while the secondary peak in precipitation had a repeatability of 20 years. It leads to the conclusion that, in addition to precipitation, other factors were important in the formation of the mean annual discharge. The third strongest peak registered on the spectrogram of HS Mojsinje (f = 0.769, cycle 8.15 years) corresponds to the highest precipitation peak, as shown by the results of the cross-spectral analysis (Figure 8b). It can be concluded that every eight years, on average, significant annual discharge waves occur, which are caused by simultaneous cycles in the amount of precipitation on MS Vranje. Similar results are obtained by cross-spectrum analysis of maximum river discharges (Figure c, d).

The finalized results of all analyses can be quite significant from a variety of perspectives. Particularly significant is the identified cyclicity of the average annual discharges at HS Grdelica. The average annual discharge tends to fluctuate in regular cycles every three to four years. This cyclicity indicates a rather regular water regime throughout the past century. This does not preclude the possibility of maximum-minimum wateriness variations. The year 2015 was 48% more watery than the research period's average year (Q_{2015} = 46.2 m^3/s compared to Q_{an} = 23.78 m^3/s), however similar annual discharges also occurred in 1955 (46.1 m3/s), 2010 (43.4 m^3/s), etc. The same applies to drier years, such as those with discharges of 7.78 m^3/s in 1934, 8.03 m^3/s in 1933, 9.17 m^3/s in 1994, etc. The HS Grdelica example shows that there isn't a singular maximum or minimum extreme that happened just once throughout the entire 100-year cycle.

In contrast, HS Korvingrad is characterised a cyclicity of 98 years, meaning that the cycles won't repeat throughout the research period (the duration of the time series as a whole is one cycle). The insufficient length of the time series affected the impossibility of determing cyclical patterns. Using the wettest and driest years as an example, we can observe the emergence of an extremely high maximum (a discharge value of 147 m^3/s was recorded in 1940, compared to an average of 60.23 m^3/s, which is 59% higher value) and a clearly defined minimum (a discharge value of 17.55 m^3/s, which is even 71% lower than the average). Such extremes undoubtedly contributed to the difficulty in differentiating cyclicity forms. At HS Mojsinje, the repeatability cycle is 19.6 years, meaning that four to five regular cycles could be identified during the observational period.

According to earlier studies (Stojković et al., 2014; Walega & Mlynski, 2017; Pekarova et al., 2021), major rivers in Europe had characteristic discharge cycles in the 100+ year long time series. They demonstrated that major European rivers experience mean annual discharge cycles every 14 to 20 years and that these variations are influenced by the NAO. Its impact on river discharges in the Danube River Basin is particularly evident. On some hydrological stations in the Danube River Basin (such as HS Bratislava on the Danube River or HS Sremska Mitrovica on the Sava River) shorter discharge cycles were recorded, such as the one registered at HS Grdelica (3-4 years), for example. These brief cycles are likely related to either local characteristics or the impact of ENSO (Pekarova et al., 2003).

What's even more significant are the interpretations of the maximum discharges cycle, which are registered in 98 years for all three hydrological stations. The highest value of the maximum annual discharge was recorded in 1955 at HS Mojsinje (2,088 m^3/s), in 1963 at HS Korvingrad (1,590 m^3/s), and in 1974 at HS Grdelica (552 m^3/s). The extreme values on each of the three stations were 3.2 times higher than the average maximum discharge throughout the whole period. The inability to identify the shorter cyclical components was influenced by the increased extremity of the maximum discharges that occurred in a specific portion of the time series. All three stations experienced a particularly watery period in the 1950s, but they did not cycle again for the following 60 years. The main characteristic of the maximum discharges in recent years is the sudden occurrence and high intensity, which disturbs the eventual cyclicity. This phenomenon is consistent with numerous analyses of the impact of climate change in the context of increasing extremes of discharges in small river basins in Europe.

4. CONCLUSION

Modern hydrologic research focuses a high priority on studying the periodicity or cyclicity of the occurrence of specific discharge values for several reasons (1) overview of a river basin wateriness, determination of dominant trends, homogeneity of discharge data; (2) determination of hydrologic cycles and their frequencies; (3) correlation of these indicators with the fundamental variables that affect the occurrence of discharge variations; and (4) forecasting future tendencies of discharge variations. Thus, it is important to use statistical techniques in hydrological research, particularly time-series analysis methods.

The purpose of this study is to highlight the significance of using spectral analysis and autocorrelation statistical techniques when analysing hydrologic data. Due to its geographic and hydrologic specificities, data availability, and importance in the Danube River system, the South Morava River was used as a case study. The acquired results point to the occurrence of specific discharge cycles with periodicities ranging from 3 to 98 years and differing from station to station. This suggests that certain stations only experienced one unique extreme hydrological event during the studied period, which corresponded to 100-year or even 500-year high water. On the other hand, discharge on the upstream station exhibits a high degree of repeatability. The analysis also revealed a strong relationship between variations in the amount of precipitation recorded at upper meteorological stations and the South Morava River discharge. The results on the congruence of the cycles of precipitation amount compared to discharge serve as proof of this.

Preformed analysis and obtained results can be an important inception point for future research on this topic, but also significant knowledge for scientific institutions and companies in the water management sector, climate change, and variability area, etc. Future studies will include a detailed analysis of the cyclicity of seasonal discharges to forge a stronger connection with the variables influencing it. In order to observe similar cyclical patterns, it is also required to conduct research on similar river courses on the territory of Serbia and the Balkan Peninsula.

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