DETERMINATION OF DISCHARGE CYCLES OF THE SOUTH MORAVA RIVER (SERBIA)

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ABSTRACT

Possibilities of using water resources, their quality and availability in the world represent one of the most complex and very current scientific and practical topic in numerous research of the last decades. The studies on the variability and fluctuations of river discharge values are especially important due to emphasized vulnerability of rivers to climate changes. Accordingly, the aim of this paper is to determine the existence of possible cycles in changes of the values of annual and seasonal river discharges of the South Morava River in Serbia. In addition to determine the trend of changes in the values of the indicator for the period 1946-2020, statistical procedures of autocorrelation and spectral analysis, for studying the possible repetition of the time series of particular cycle, were applied. The results indicated the existence of a certain cyclicity, which was correlated with the most important factor, variation of the precipitation amount. The obtained results present the base for further research that would include examining the repeatability of extreme values, as a particularly important for forecasting the occurrence and frequency of flood and drought waves.

Keywords: river discharge, cycles, South Morava River, trend

INTRODUCTION

Research and analysis of fluctuations of the hydrological parameter values has a distinct scientific and practical significance, especially for the necessity of forecasting and understanding flood and drought waves [1]. The increasing occurrence of catastrophic floods on one side, and extremely dry periods on the other [2], confirms the requirement for more thorough research into the causes and regularity of their occurrence. The variability of the climatic element's values (precipitation and temperature) has been most often singled out as the main factor [3]. However, it is necessary to emphasize the increasingly intensive anthropogenic activities in river basins including river regulation, water use and anthropopressure [4]. One of the main challenges in this type of studies is the inability to quantify the impact of natural in relation to anthropogenic causes of discharge variations.

The values of river discharges are differently variable on certain spatial-temporal scales - on small scales, the river turbulence affects scholastic fluctuations, and on larger scales (daily to annual) fluctuations of discharge values are the result of complex nonlinear interactions between precipitation, topography, and geography [5]. Knowing the mentioned fluctuations of discharges is especially important for determine certain seasonal or annual cycles in a time series of data [6]. In that context, several scientific articles [7], [8], [9], [10] treated this topic by using various methods and techniques.

Smith et al. [11] identified certain variability of river discharges, using the method of wavelet transformation over the values of daily discharges. Chang & Yeh [12] used spectral analysis to determine the correlation between precipitation on the one and runoff on the other side, defining the basin as a "block box" with an input indicator (precipitation) and an output indicator (runoff). A similar study was conducted by Roshani et al. [9] who determined the existence of a certain water cycle of the Rudhan River (Iran), especially during the summer and autumn seasons. Some research used the same methodology to investigate the correlation between water level changes and climate changes [13], [14].
In order to determine the discharge cycles and their repetition, the first step include trend analysis and registration of changes of the hydrological parameter. However, it is important to notice that trend analysis can often lead to a wrong conclusion due to the non-stationarity of a time series, i.e., due to the existence of perennial watery and drought cycles in the series. The aim of this paper is to investigate the existence of possible cycles in the values of the mean annual and seasonal river discharges of the South Morava River (Serbia) as well as to observe the time intervals of their repetition. For that purpose, statistical methods of autocorrelation and spectral analysis were applied. In addition, general statistical trend tests (Mann-Kendall and Pettitte test) were used to observe the trend in the time series.

MATERIALS AND METHODS

Study area

Due to specific water regime, basin characteristics and river morphodynamic, the South Morava River represent adequate example for investigating the variability of river discharges. The South Morava River begins at the confluence (near Bujanovac) of the rivers Binačka Morava and Preševska Moravica at an altitude of 392 m. Near Stalać (145 m a.s.l.) West Morava River (left side tributary) and South Morava River (right side tributary) form the Great Morava River. According to data from 2019 the total length of the South Morava River is 235.5. Its river valley has composite feature in south to north direction, which indicate appearance of several gorges and valleys. The South Morava River Basin covers an area of 15,469 km2, with smaller parts in the territories of Bulgaria and Northern Macedonia [15], [16].
On the South Morava River six active hydrological stations has been registered. On each of them, the most important hydrological parameters are measured. For the analysis of the mean and seasonal discharge variations, data from four active hydrological stations were used, for which empirical data for a 75-year period (1946-2020) exists. Data were obtained from the Hydrological Yearbooks of RHSS [17] for the following stations: Mojsinje (1), Kurvingrad (2), Grdelica (3), and Vladičin Han (4) (Fig. 1). The first two stations are located in the lower course of the South Morava River, downstream (Mojsinje – 16.4 river km) and upstream (Kurvingrad – 105.7 rkm) from the confluence of its largest right tributary Nišava River, while the other two are located in the middle course (Grdelica – 155 rkm, Vladičin Han – 187.6 rkm).

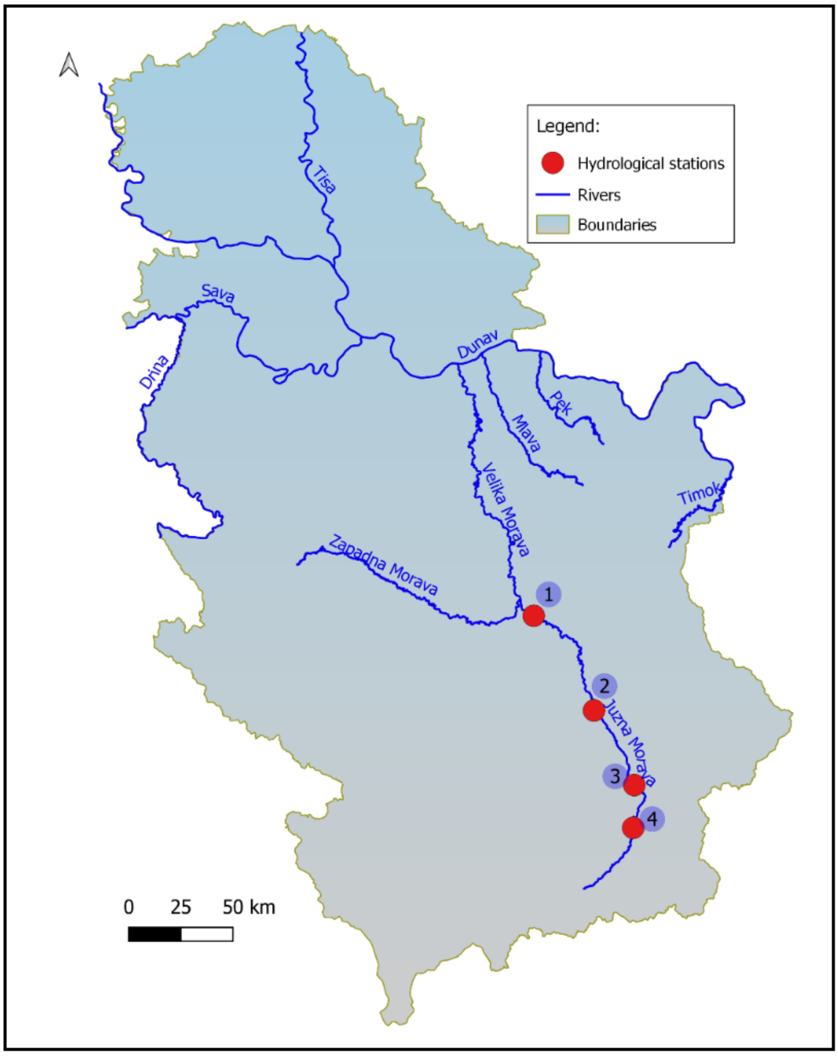

Figure 1. Geographical position of the South Morava River and four hydrological stations in Serbia

Methodology

Numerous techniques and methods have been used in academic literature in order to determine the trend changes of hydrological parameters and the occurrence of cycles of a certain discharge. For the purpose of this article, several statistical and quantitative methods, processed in different statistical programs, were used. Before the existence of certain discharge repetition was determined, trends of river discharges were analyzed by using Mann-Kendall and homogeneity tests, which are applied in many meteorological and hydrological analyzes [18], [19], [20], [16], [21].

Autocorrelation is a statistical method also known as "serial correlation". This technique is important in procedures of observing the repetition of a part of a data series (time series) with a certain time lag. One sequence correlates with itself, so that in each subsequent step, it is shifted by one time lag. The autocorrelation function is symmetric about zero [22]. Dominant "zero" autocorrelation means coincidence in time series data - while periodicities are observed if there are pronounced peaks. The aim of applied autocorrelation is to show whether there is a stationary or seasonal value of the indicator in the time series [23].

Spectral analysis encompasses many useful methods based on Fourier time series analysis. The analysis is useful in examining data within time series, and therefore can be applied in various hydrological research as well as in the fields of paleogeography, climatology, meteorology, oceanology, geophysics, etc. [7]. Many authors used this procedure for many decades, but Kite [24] who analyzed the temporal sequence of water levels and river discharges, examined linear trends, periodicities, autoregression, and possible correlation with climate variability, and Lall & Mann [25] who investigated changes of the Great Salt Lake water level [26] can be considered as pioneers in using mentioned technique in the hydrological research. The main goal of spectral analysis is to transform the time domain (time series of data) into a frequency domain. It can be described as the decomposition of a time series into sinusoids (sine waves) of different amplitudes, phases and periods [27]. By summing all these sinusoids, initial time series would be obtained. Walega et al. [28] state that the significance of spectral analysis is that it "breaks" a complex time series (consisting of cyclic elements) into several basic functional sinusoids with specific wavelengths. Use of spectral analysis could enable describing the frequencies of time series and observing the presence of high frequency variations and cyclicity. The ultimate goal of the analysis is to assess the strength of the periodic component of all possible frequencies

RESULTS AND DISCUSSION

Determination of the existence of a certain trend in time series provide an adequate basis for identification of the cyclical repetition of a period with similar discharges. The non-parametric Mann-Kendall test was used to identify the trend of mean annual and seasonal discharge. Out of four investigated hydrological stations of the South Morava River, the decreasing trend of average annual discharge was recorded at 100% of the analyzed profiles. A decreasing trend that is not statistically significant was observed in 75% of profiles (3 stations). The other 25%, i.e., one station, is characterized by a statistically significant decreasing trend. The test results indicated that at the level of mean annual values, the discharge has a dominant decreasing trend, which is in correlation with most rivers in Serbia [19]. The average reduction rate varies from 0.014 m3/s/year on the Grdelica HS, to 0.14 m3/s/year on the Kurvingrad HS. On the Mojsinje HS, the level of significance is 0.1, which indicates existence of moderate significant decreasing trend (Z = 1.73) (Tab. 1).

Analyze of the seasonal trend of discharge values showed certain differences in the characteristics of the observed trend. However, a common feature for all seasonal trends is that there are no significant changes in the values. The main characteristic of winter seasonal discharges is decreasing trend (from -0.59 on the most upstream station of Vladičin Han, to -1.45 on the most downstream station of Mojsinje) in the limit of significance. In spring, seasonal discharges indicated certain differences depending on the profile - decreasing trend on the downstream profiles of Mojsinje and Kurvingrad (average -0.022 m3/s/year), and increasing trend on the upstream profiles of Grdelica and Vladičin Han (average 0.09 m3/s/year). On three HS in the period 1946-2020 a decreasing trend was recorded in summer season with an average value of -0.52 m3/s. A stagnant or mildly increasing trend on the largest number of profiles was noticed during the autumn (HS Kurvingrad, Z = 0.32).

Table 1. The results of the MK and homogeneity test for the period 1946-2020

HS	Period	Qsr (m^3/s)	Z	α	Year of change
Mojsinje	Spring	162.9	-0.87	-	1988
	Summer	55.59	-0.82	-	1983
	Autumn	39.06	0.05	-	1971
	Winter	107.7	-1.45	-	1981
	Annual	91.69	-1.73	+	1981
Kurvingrad	Spring	99.28	-0.51	-	1982
	Summer	32.53	-0.53	-	1983
	Autumn	23.93	0.32	-	1969
	Winter	59.78	-1.51	-	1981
	Annual	55.85	-1.45	-	1984
Grdelica	Spring	41.91	0.28	-	1953
	Summer	14.13	0.88	-	1963
	Autumn	11.98	0.03	-	1969
	Winter	30.72	-1.02	-	1986
	Annual	24.69	-0.28	-	1984
Vladičin Han	Spring	31.29	0.23	-	1953
	Summer	10.55	-0.22	-	1983
	Autumn	9.45	-0.31	-	1981
	Winter	24.21	-0.59	-	1984
	Annual	18.87	-0.44	-	1984

+ - significance of 0.1; - significance higher than 0.1 i.e., does not indicate any significance in this parameter change

Results of homogeneity test showed that, in the period of 75 years, an all stations a point of change of annual discharge occurred in the period 1981-1986 (Tab. 1) (on HS Mojsinje, from 103.95 m3/s before year of 1981 to 80.7 m3/s after). When it comes to the seasonal discharges, certain disparities regarding the point of change can be observed. Winter discharges are completely coincided with the period determined by annual values. The biggest differences regarding the point of change of seasonal discharges can be noted on the HS Grdelica, where slightly increasing trend was registered, mostly after the 1950s and 1960s (spring, summer and autumn).

The statistical method of autocorrelation was applied by using the same input data on four representative hydrological stations of the South Morava River. In Fig. 2 value of the correlation coefficient for the discharge data and their dynamics in the domain of the 95% confidence interval (black line) are presented (the value of the autocorrelation coefficient is 0.25). The deviation of the correlation value from the mentioned interval indicates that the coefficients are statistically significant, i.e., that the sequence with a certain shift (lag) correlate well with itself. In that case, the base for determination of the possible occurrence of cyclicality i.e., repeatability of a time series after a certain period, can be recorded.

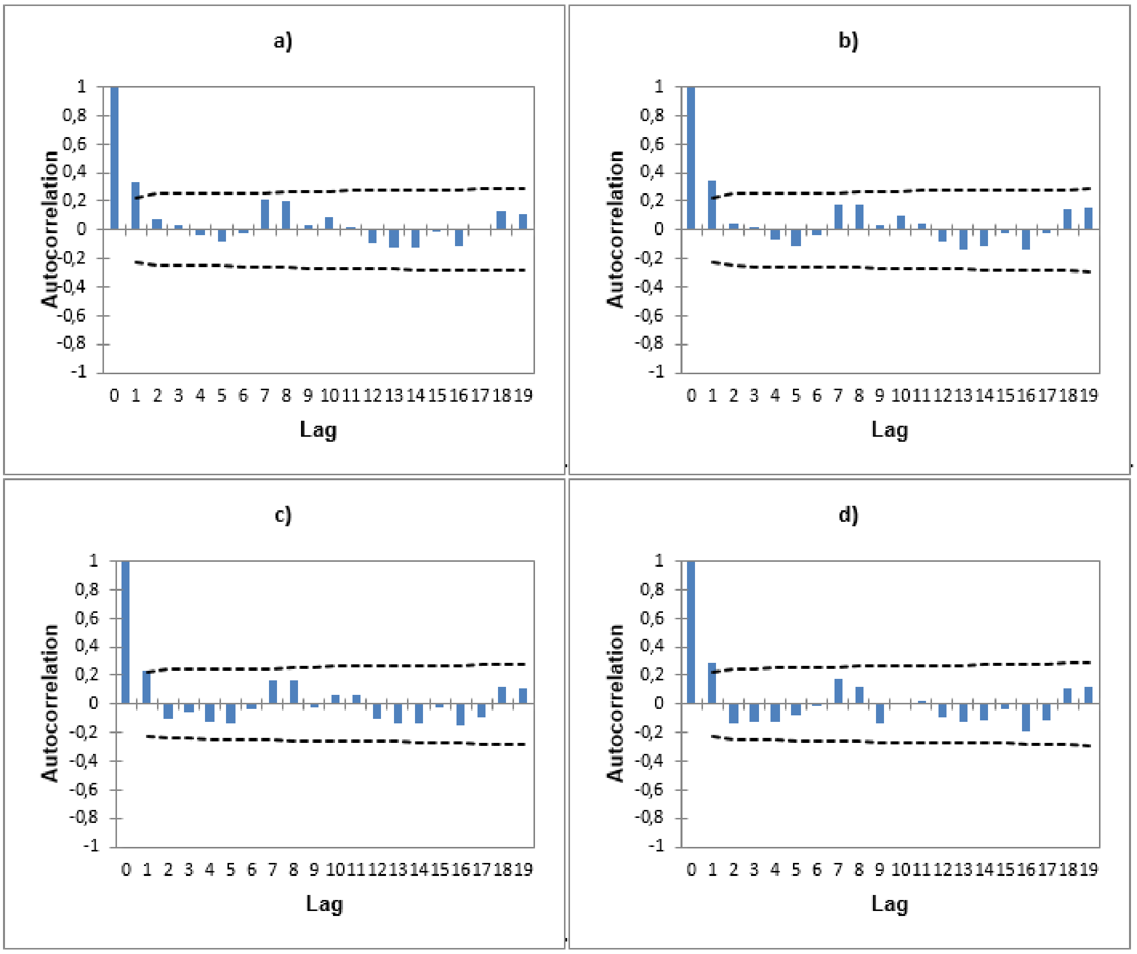

Figure 2. Autocorrelation of mean annual discharge values for the period 1946-2020 - a) Mojsinje, b) Kurvingrad, c) Grdelica, d) Vladičin Han

The graphs presented in Fig. 2 shows that none of significant autocorrelation between the data of mean annual discharge values was registered. Accordingly, obtained results can be described as random and mutually independent. It is also possible to determine the indications of a certain cyclicity within the analyzed sequence, which will be more relevant explained by using another method. Taking into account the fact that the period by definition starts with value 1, it can be noted that almost the entire autocorrelation is within the 95% confidence interval. On the stations of Mojsinje and Kurvingrad, it can be observed obvious pattern that the first 38-year period is characterized by an almost positive correlation, and the second period by an almost negative one. On the other two profiles, it is noticed the dominance of a negative correlation or one that has a value close to zero. Based on these findings it can be concluded that isn't possible to identify further dynamics of the values of indicator, i.e., adjacent observations (periods) do not "cooperate", so this case is called the case of "no autocorrelation".
However, it can be evidenced the existence of two peaks (marked with 7.5 and 8) on the HS Mojsinje (Fig. 2a) statistically close to defined confidence interval. Nevertheless, the obtained situation does not imply that there is a dependency of data in a time series. For a defined 95% confidence interval, it can be expected that about 1/20 of the period be statistically significant due to random fluctuations. In order to reject the suspicion of the existence of random fluctuations in the observed series of data, in Fig. 3 correlograms of seasonal discharges on the HS Mojsinje are presented. The results on the graphs lead to

conclusion that a deviation from the confidence interval exists on the autumn water discharges (value of 0.281, at lag 17) which represents "mildly significant autocorrelation". The types of autocorrelation charts presented on the Fig. 3 are called sinusoidal autocorrelation models.

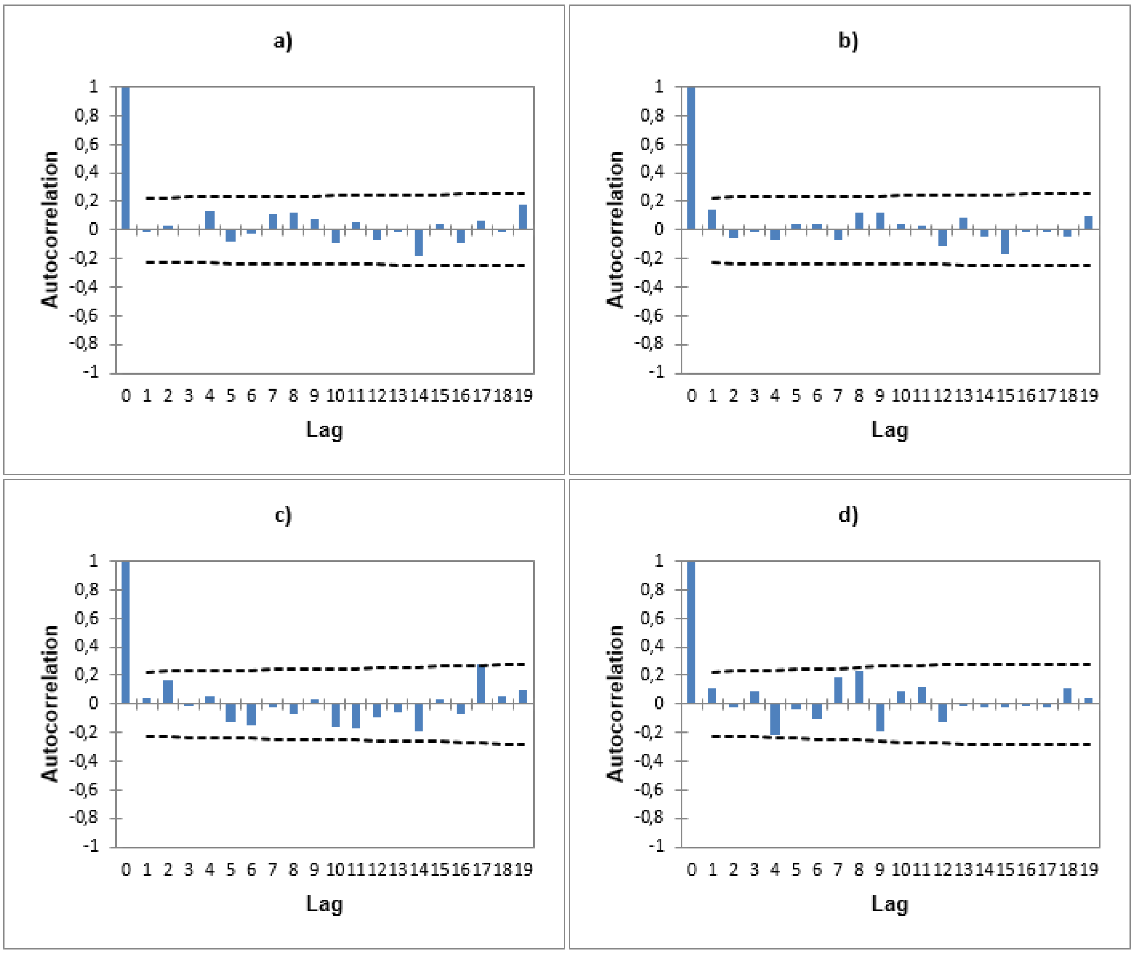

Figure 3. Autocorrelation of seasonal discharge values for the period 1946-2020 on the Mojsinje HS - a) spring, b) summer, c) autumn, d) winter.

The idea of using spectral analysis in hydrological research is based on the possibilities that procedure offers, primarily the ability to identify cycles in a particular time series. Data of the annual and seasonal discharges were used again for the spectral analysis. The graphical results of the spectral analysis are shown in Fig. 4, i.e., on four spectrograms. At all examined stations, the frequency (F) ranges from 0.01 to 0.5, which corresponds to periods from 2 to 100 years (1/F). There was no need to analyze frequencies higher than 0.5, because maximums are not expected in that frequency range, i.e., the occurrence of periodicity is not expected.
Several distinct peaks are clearly visible on all spectrograms on Fig. 4 – one or two primary and several secondary. On the Mojsinje HS (Fig. 4a), the dominant peak has the frequency of 0.097 which responds to a periodicity of 10.2 years. The next peak is distinguished by frequency of 0.27 which corresponds to a periodicity of 3.67 years. The third peak (frequency of 0.11) will repeat its maximum every nine years. In the rest of the observed spectrum, the dominant peaks are not noticeable. The results of spectral analysis indicate repeatability trend of the maximum value of the mean annual discharge

approximately every 10 years, while the other regularities of repeatability are of secondary importance. Similar results were recorded on the upstream profile of Kurvingrad (Fig. 4b). A certain difference was noticed on the last two profiles. On the Grdelica HS (Fig. 4c) two maximum peaks (power = >5), frequencies of 0.117 and 0.27 and periodicity of 8.5 and 7.1 years and two secondary peaks with a repetition of 11,1 and 6 year were recorded. The most downstream profile of Vladičin Han (Fig 4d) is characterized by two distinct peaks - one primary with a frequency of 0.28 (3.5 years) and secondary with 0.15 (6.6 years).
Low frequencies visible on presented graphs are known as "a harmonic spectrum" and are characterized by large periods of oscillation that affect the change of perennial discharge values. Group of significant low-frequency spectrum harmonics constitutes a macro-periodic component. This means that the set of continuous lower discharge values can be repeated cyclically for a certain period of time. By analyzing Fig. 4c (HS Grdelica), one can observe a whole series of low-frequency oscillations that are repeated three times over the observed time period of 75 years.

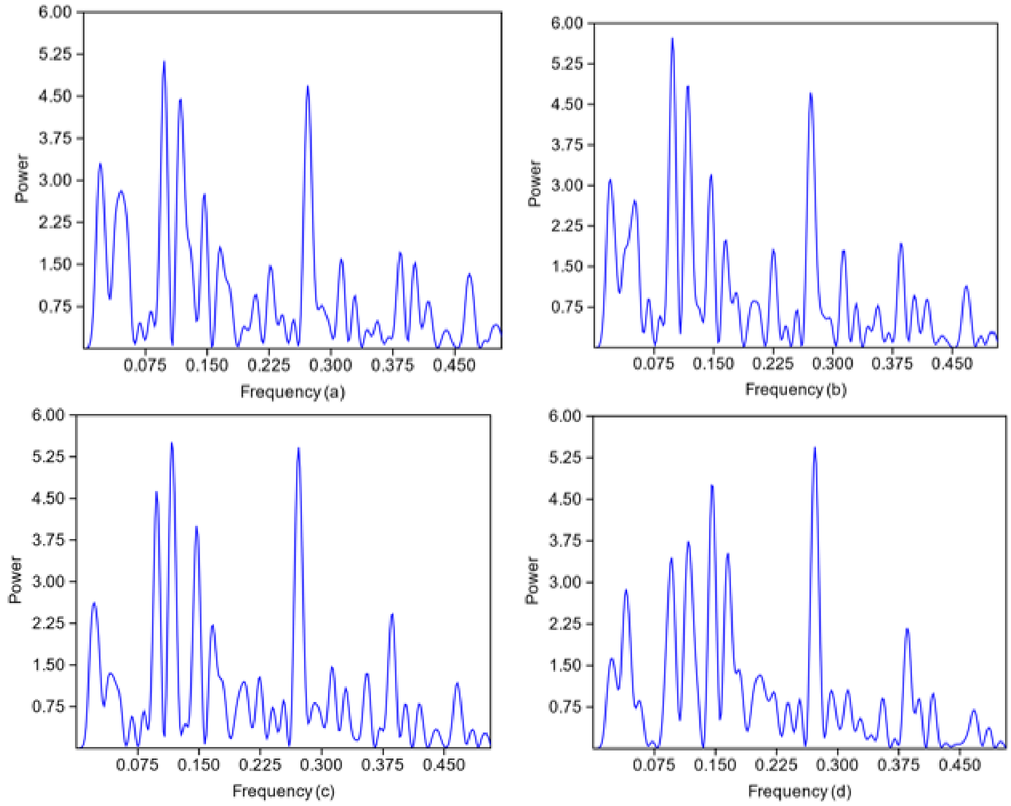

Figure. 4. Spectrograms of mean annual discharges for the period 1946-2020 - a) Mojsinje, b) Kurvingrad c) Grdelica, d)Vladičin Han

Four spectrograms of seasonal discharges of the representative HS Mojsinje, are presented on Fig 5, and by analyzing them certain regularities can be distinguished. During the warmer period of the year (Fig 5a,b), one dominant (frequency 0.458 and periodicity of 2.1 years in spring, i.e. frequencies 0.221 and periodicity of 4.5 years in summer) and one secondary peak can be distinguished. Winter discharges (Fig. 5d) are specified by one maximum peak, frequency 0.27 and periodicity of 3.6 years, as well as two secondary peaks of similar power. Based on the performed spectral analysis of autumn discharges, the existence of two peaks of similar power (3.5), frequencies of 0.04

(25 years) and 0.09 (11 years) can be noticed. By comparing the obtained spectrograms, it can be concluded that the occurrence of discharges of a certain value is uneven during the investigated period, while in the autumn and winter, regularities or cycles of higher or lower river discharges that change properly can be distinguished (especially during winter).

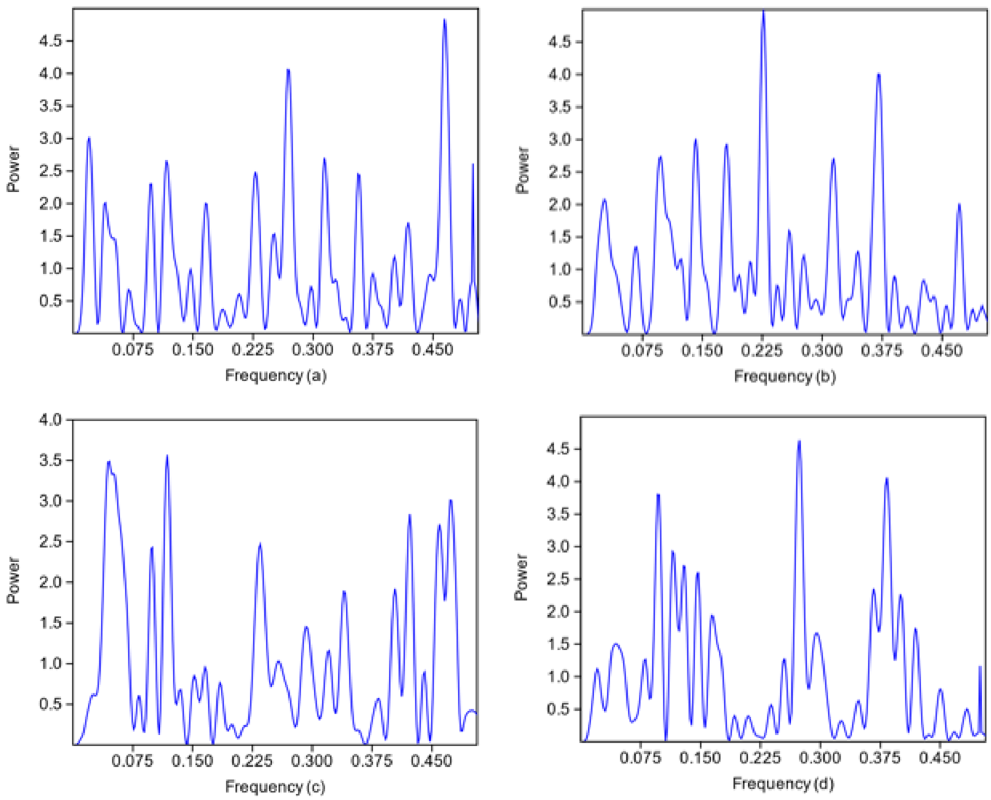

Figure. 5. Spectrograms of seasonal discharges for the period 1946-2020 on the Mojsinje HS - a) spring, b) summer c) autumn, d) winter.

The results of all the applied statistical procedures enabled comprehensively understanding of studied topic. Given that the only significant decreasing trend was registered at the Mojsinje station, as well as indications of the cyclicality occurrence, this station can be emphasized as representative for further discussion. The primary hypothesis indicates that the changes of river discharges on the Mojsinje HS are conditioned by changes in the amount of precipitation, as well as changes of the discharge values of the largest tributary of South Morava River (Nišava River).

Detailed examination has indicated that a significant decreasing change in river discharges on the Mojsinje HS in the period 1946-2020 occurred during the middle of the observed interval, i.e., within the second third of the 75-year period (1971-1996). In that time sequence, a pronounced significant decreasing trend in the discharge values was recorded (MK test results, Z = - 3.71, at the level of significance 0.001). In accordance with the formulated hypothesis, changes in the amount of precipitation were singled out as a main factor. Consequently, MK test was conducted over the precipitation amount data for the period 1971-1996 (required data were obtained from Meteorological Yearbook of HRSS [29] for nearest meteorological station of Aleksinac). The study shows existence of a decreasing trend (Z= - 0.86). For further explanation regression analysis (with independent variable - precipitation and dependent variable - annual discharge) was used. It reveals occurrence of strong dependence because regression coefficient had value 0.71. Finally, the use of spectral analysis and autocorrelation (average annual discharge and precipitation – 1971-1996) confirmed the important influence of precipitation variations on changes in river regimes. Comparative analysis of auto-correlograms (Fig. 6) pointed out that both variables range in the 95% confidence interval, as well as those certain regularities can be identified i.e., that negative changes in precipitation are accompanied by negative changes in discharge. The intensity and dynamic of these changes are not equal in the observed period, which implies that other factors have a special impact on discharge modifications, especially due to geographical position of the HS Mojsinje (most downstream station on the South Morava River and most affected by different anthropogenic activities). The results of spectral analysis revealed the occurrence of a periodicity (13.1 years) of the highest values of annual precipitation and discharge, but unlike the precipitation spectrum, several other smaller peaks clearly stand out in the discharge spectrum. Secondary peaks that are not proportional are greatly influenced by other physical-geographical and especially anthropogenic factors (accumulation construction in the South Morava River Basin, river regulations, water use, etc.).

In accordance with the achieved decreasing trend of discharge values on the Mojsinje HS, are the results obtained by other researchers [30], [16]. Langović [16] determined occurrence of decreasing trend at three HS on the Nišava River and its tributaries Temska and Jerma (pronounced and moderate significancy). Such dynamic of discharges in the last 50 years in the Nisava River Basin inevitably stands out as an important factor of regime variations of the downstream part of the South Morava River, given that Nišava River annually provides amount of 27.3 m3/s of water to South Morava (33% of the mean annual discharge at the Mojsinje HS).

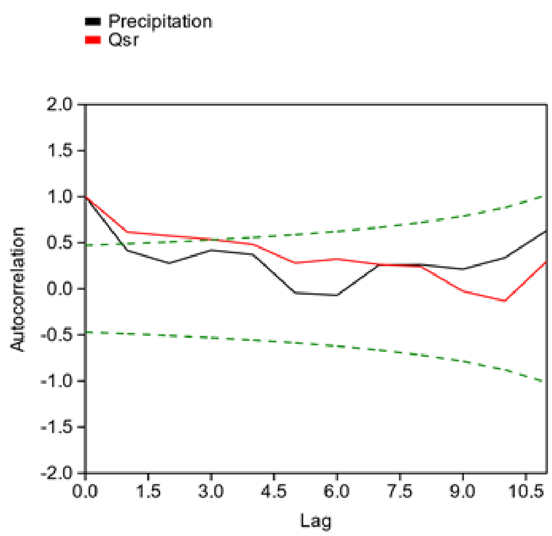

Figure. 6. Comparative autocorrelation of mean annual discharge values and precipitation for the period 1971-1996

CONCLUSION

The possibilities of using statistical programs, techniques and procedures in hydrological research are significant. Considering the current interests of hydrological studies, in addition to the quantification of hydrological phenomena and the use of mathematical and statistical methods to determine the state and prospects of their further development, it is

necessary to use the results in an applicable way. The study of changes in the series of hydrological data in longer time series, and the observation of trends are significant for understanding the river regimes. Using non-parametric tests, it was determined that all stations are characterized by a slightly decreasing trend of discharges, which is in accordance with most rivers in southern Serbia (only on the HS Mojsinje with significance for the period 1946-2020). Based on the applied spectral analysis and autocorrelation, the time (periodicity) of the occurrence of certain discharges was noted. The most downstream HS Mojsinje was singled out and its data were specially analyzed due to occurrence of autumn discharge autocreation. Finally, the analysis of causes that led to the specific river discharge variations of the South Morava River was performed, corelating it to the precipitation factor. Changes of river discharges are proportional to variations in the amount of precipitation, which is proven by calculated regression coefficient (0.71) and determined autocorrelation, but based on results of spectral analysis, the influence of other factors, primarily anthropogenic, is also emphasized.
According to the findings, it can be concluded that the knowledge of variations of annual and seasonal discharge is important as it demonstrates the state of river regimes. The obtained data can serve as a relevant basis for further scientific research in context of detailed investigation of relations between variations in discharge and the dynamics of other physical-geographical processes characterized for the South Morava River Basin (riverbank erosion, soil erosion, torrents etc.). The length of the series of empirical data of 75 years corresponds approximately to the duration of mostly two cycles, which is relatively small for obtaining a more reliable regularities of repetition. Therefore, in the future, it is necessary to repeat the entire procedure after fulfilling the next period norm of 80 years. Also, future research must include a statistical analysis of changes in extreme values and daily discharges.

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