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ANNUAL AND SEASONAL VARIATIONS OF RIVER DISCHARGES IN THE SOUTH MORAVA RIVER BASIN (REPUBLIC OF SERBIA)

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Abstract

Understanding the current status of wateriness, which include studying the variability of different hydrological parameters over a long period of time, represents a significant process for determining the availability and quantity of water resources, especially at the local and regional level. First, it is necessary to identify certain paternity and frequency in a long time series of hydrological parameters. Secondly, it is important to correlate them with variability of some climatological elements on the one hand and anthropogenic influence in other hand, which are the main factors that have influence on the changes in river wateriness. The main objective of this paper is the analysis of seasonal and annual variations of river discharges in the South Morava river basin, for the period of 50 years (1968-2017), and the observation of certain trends (using non-parametric Mann-Kendall test and homogeneity test). Explanation and understanding the potential causes of observed changes, which are significant, is one of the tasks of this research. In this paper are observed data of the mean annual and monthly river discharges from 20 active hydrological stations in the South Morava river basin, for which there are empirical data for the taken period. The results indicate that most rivers in the basin have dominant decreasing trend of the mean annual river discharges (85% of them), but the more significant changes are noticed for the values of the seasonal river discharges.

Keywords: river discharges, trend, South Morava River, wateriness

Indroduction

Utilization of water resources and rivers plays a very important role in many economic and social fields of current humankind. Water is an essential element for natural and artificial environment, which is carried by rivers and provides the life generating-fuel to ecology (Islam & Sikder, 2016). Mostly due to climate change and improper water management, water resources are losing the natural discharge capacity from upper stream (Uddin et al, 2017). Discharges of many rivers in the world has been changing due to change of natural condition (mostly change of climate conditions) and intensive human activities, growth of the population and antrophopressure (Gedefaw et al, 2018). Shi et al. (2019) analyzed changes in river discharges of 40 large rivers in the world in the period 1960-2010 and their results indicated that the discharges have predominantly decreasing trends with a few rivers showing increasing trend. They also concluded that climate changes have been most responsible for these changes, with 75% of influence, and other 25% were direct human impacts. Precisely, determine the percentage share of factor that have influence on annual and seasonal river discharge changing, is one of the most important task, especially for future integrated water management.

Nowadays, the global hydrological cycle has been responding to the observed effects of global warming, which include an increasing atmospheric water vapor content and changing precipitation patterns. The change in precipitation alters the hydrological systems, affecting water resources in both quantity and quality. Variability in rainfall characteristics (type, amount, frequency, intensity and duration) is among the important climate change impacts. Rainfall variability affects water resources sustainability, which includes the availability, management and utilization of water resources. This in turn may affect ecosystems, land productivity, agriculture, food security, water quantity and quality, and human health (EPA, 2014).

Trends of some hydrological parameters are important indicators of the temporal variability of phenomena. By analyzing the time sequence of the discharges, we assess the magnitude and significance of the temporal variability. In recent years, when floods and droughts, due to mentioned influences, have become more frequent, the monitoring and study of hydrological states and events is becoming increasingly topical (Ulaga et al, 2008).

Material and methods

South Morava river basin (in the territory of the Republic of Serbia) has been elected as a study area for this research. Basin covers 15,469 km^2 surface area, of which 14,372.5 km^2 is within the borders of the Republic of Serbia and the rest, 1,056.5 km^2, belongs to Republic of Bulgaria (basins of the Nišava and Visočica source branches and the middle course of the Jerma river) and Northern Macedonia (upper part of the Binačka Morava river). The South Morava River originates from rivers Binačka Morava and Preševska Moravica, which connect near the town Bujanovac at 392 m above sea level in the Republic of Serbia. Its total length from that place to Stalać (where is forming Great Morava River) is 246 km. If the river Binačka Morava is adopted as the main source of the South Morava River, then its total length is 295.5 km. River South Morava receives 157 tributaries - streams, small rivers and rivers - 75 left and 82 right. Most of them fly dry (Gavrilović & Dukić, 2014). Significant tributaries are: Veternica (75 km), Jablanica (84.5 km), Pusta reka (71 km) and Toplica (136 km) rivers on the left, and Vlasina (70 km), Nišava (218 km) and Sokobanjska Moravica (60.4 km) rivers on the right.

In the South Morava River basin (within the borders of the Republic of Serbia), 35 hydrological stations has been registered. In each of them, the most important hydrological parameters are measured. For the analysis of the mean and seasonal values of the river discharges and their trends, data from 20 active hydrological profiles were used, in the territory covered by the studied area, for which there are empirical data for a 50-year period (1968-2017). Data were obtained from the Hydrological Yearbooks of RHS of Serbia for the following stations: Vladičin Han (1), Grdelica (2), Korvingrad (3) and Mojsinje (4) (South Morava), Svodje (5) (Lužnica), Svođe (6) and Vlasotince (7) (Vlasina), Leskovac (Veternica) (8), Pečenjevce (Jablanica) (9), Pukovac (Pusta Reka) (10), Dimitrovgrad (11), Pirot (12), Bela Palanka (13) and Niš (14) (Nišava), Donja Selova (15), Pepeljevac (16) and Doljevac (17) (Toplica), Trnski Odorovci (18) (Jerma), Staničenje (19) (Temska) and Žučkovac (20) (Sokobanjska

Moravica) (Fig. 1) (Tab. 1).

Tab. 1. Geographical characteristics of the main hydrological stations in the South Morava river basin

	Hydr. station	River	Reference height (m)	Basin area (km^2)	Distance from confluence (km)
1.	Vladičin Han	South Morava	321.98	3,052	187.5
2.	Grdelica		251.63	3,782	155
3.	Korvingrad		188.09	9,396	105.7
4.	Mojsinje		136.28	15,390	16.4
5.	Svođe (L)	Lužnica	310.22	318	1.15
6.	Svođe (V)	Vlasina	305.07	350	26.5
7.	Vlasotince	Vlasina	254.39	879	10.5
8.	Leskovac	Veternica	224.18	500	11
9.	Pečenjevce	Jablanica	205.82	891	3
10.	Pukovac	Pusta Reka	195.23	561	4.7
11.	Dimitrovgrad	Nišava	440.40	482	138
12.	Pirot		364.27	1,745	107.5
13.	Bela Palanka		283.15	3,087	67.5
14.	Niš		187.88	3.870	17.5
15.	Donja Selova	Toplica	445.45	353	90
16.	Pepeljevac		329.9	986	69.5
17.	Doljevac		190.41	2052	2.5
18.	Trnski Odorovci	Jerma	552.58	557	22
19.	Staničenje	Temska	335.44	818	1
20.	Žučkovac	Moravica	260.98	394	32.5

(Source: Republic Hydrometeorological Service of Serbia)

In order to determine the existence of a trend in annual and seasonal river discharge values, in this paper it is used non-parametric statistical method – Mann–Kendall test and homogeneity test. The non-parametric Mann-Kendall test is commonly used to detect monotonic trends in series of environmental data, climate data or hydrological data (Sun et al., 2016). The purpose of the Mann-Kendall test (Kendall, 1962) is to statistically assess if there is a monotonic increasing or decreasing trend of the variable of interest over time. Main benefit of this test is that the using data not conform to any particular distribution. No assumption, the strength of the trend depends on the magnitude, sample size, and variations of data series. If the Z value (level of significance) is bigger than 1.96 (what corresponds to the significance level of 0.05), we can conclude that the monotony trend exists in the time series and otherwise (Langović et al., 2017). The Sen Estimate test (B) allows us to estimate the curves of the linear trend and its results represents an average increase/decrease value of the hydrological parameter.

Today, several statistical methods exists, to determine homogenity of the data in time series, but one of the mostly used method for a meteorological and hydrological data is Pettitt test. Null hypothesis indicates that annual and seasonal data are independent and identically random distributed, while alternative hypothesis assumes that there is a point at which a change in a data series has occurred (Mahmood et al., 2017).

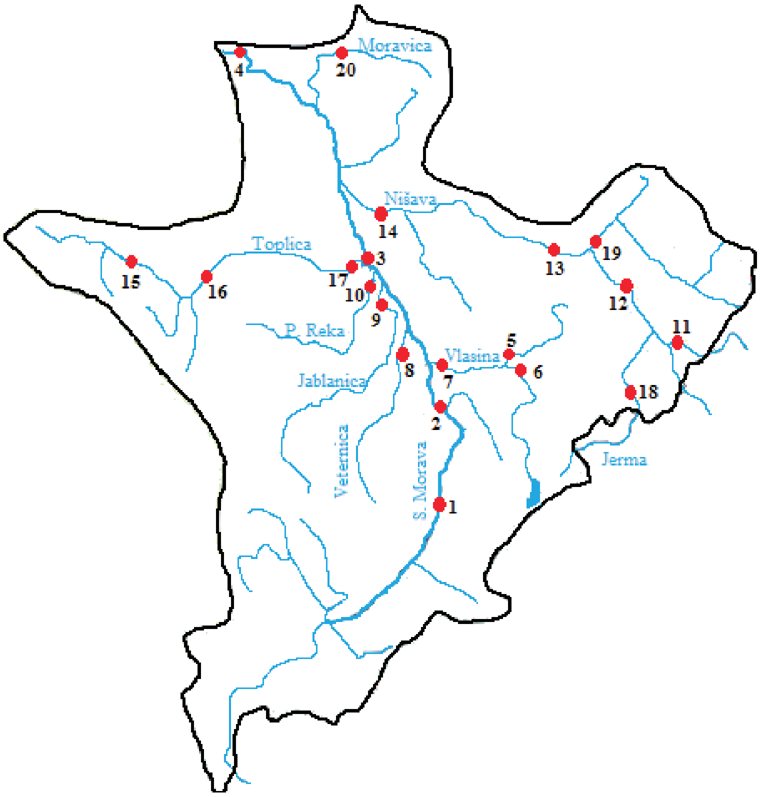

Figure 1: South Morava river basin with registered hydrological stations which data were used in this research

Results and discussion

Mann-Kendall test was used for determine the trend of changes of the mean annual and seasonal river discharges. The results of the test showed that at mean annual level, river discharge has a dominant decreasing trend, which in general is in agreement with the majority of rivers in the Republic of Serbia (Langović et al, 2017).

Of the 20 studied hydrological stations in the South Morava river basin, an increasing trend of mean annual river discharges was recorded at three station (15%), while a decreasing trend was observed in the other 17 hydrological profiles (85%) (Tab. 2). On the main river in the basin - South Morava, in the profiles of Vladičin Han, Grdelica and Korvingrad a slight decreasing trend was noted, while on the Mojsinje profile the trend was slightly more pronounced, but still without statistical significance. The average reduction rate was from 0.02 $m^3/s/$ year on the Vladičin Han profile to 0.17 $m^3/s/$ year on the Mojsinje profile. This analysis found a gradual decrease in the value of mean annual discharges along the South Morava River (from upstream to the downstream hydrological stations), which is in proportion with decreasing trends of its main tributaries. Seasonal trends of discharge of South Morava River are also showing decreasing tendency (except spring season on Grdelica and Vladičin han stations), with no significance and with maximum reduction rate of 0.309 $m^3/s/$ year (summer season – Mojsinje station).

Table 2: Results of Mann-Kendall test for 20 stations in the South Morava river basin (1968-2017)

Station	S	Z	B	α	Station	S	Z	B	α
Vl. Han	Sp	0.37	0.06	-	Dimitrovgrad	Sp	-0.38	-0.006	-
	Su	-1.02	-0.05	-		Su	-1.09	-0.004	-
	Au	0.65	-0.03	-		Au	-0.17	-0.001	-
	Wi	0.25	0.017	-		Wi	-0.43	-0.005	-
	An	-0.28	-0.02	-		An	-0.43	-0.004	-
Grdelica	Sp	0.43	0.069	-	Pirot	Sp	0.62	0.078	-
	Su	-0.59	-0.038	-		Su	0.84	0.030	-
	Au	-0.25	-0.01	-		Au	2.64	0.112	**
	Wi	-0.49	-0.048	-		Wi	2.89	0.018	**
	An	-0.4	-0.035	-		An	1.76	0.081	+
Korvingrad	Sp	-0.11	-0.055	-	B. Palanka	Sp	-2.16	-0.394	*
	Su	-1.05	-0.139	-		Su	-0.94	-0.058	-
	Au	-0.33	-0.048	-		Au	1.37	0.077	-
	Wi	-1.15	-0.243	-		Wi	0.25	0.023	-
	An	-0.97	-0.189	-		An	-1.76	-0.123	+
Mojsinje	Sp	-0.37	-0.2	-	Niš	Sp	-1.30	-0.325	-
	Su	-1.32	-0.309	-		Su	-1.08	-0.110	-
	Au	-0.10	-0.022	-		Au	0.97	0.055	-
	Wi	-0.8	-0.272	-		Wi	-0.4	-0.052	-
	An	-1.17	-0.330	-		An	-1.51	-0.139	-
Svodje (L)	Sp	-0.98	-0.016	-	D. Selova	Sp	1.56	0.033	-
	Su	-0.71	-0.006	-		Su	-0.12	-0.001	-
	Au	-0.66	-0.005	-		Au	-0.32	-0.003	-
	Wi	-1.37	-0.023	-		Wi	-0.55	-0.009	-
	An	-3.04	-0.041	**		An	0.15	0.013	-
Svodje (V)	Sp	-1.54	-0.049	-	Pepeljevac	Sp	1.41	0.033	-
	Su	-2.38	-0.027	*		Su	-0.99	-0.001	-
	Au	-2.25	-0.018	*		Au	-0.77	-0.002	-
	Wi	-2.31	-0.038	*		Wi	0.14	-0.009	-
	An	-1.34	-0.014	-		An	0.64	0.014	-
Vlasotince	Sp	-1.41	-0.075	-	Doljevac	Sp	0.33	0.029	-
	Su	-2.19	-0.060	*		Su	-0.85	-0.015	-
	Au	-1.05	-0.016	-		Au	-0.71	-0.010	-
	Wi	-0.84	-0.035	-		Wi	-1.15	-0.063	-
	An	-1.94	-0.056	+		An	-0.80	-0.028	-
Leskovac	Sp	-0.13	-0.006	-	T. Odorovci	Sp	0.05	0.001	-
	Su	-1.91	-0.014	+		Su	-0.85	-0.018	-
	Au	-0.4	-0.002	-		Au	-0.93	-0.006	-
	Wi	1.96	-0.037	+		Wi	0.67	-0.012	-
	An	-1.67	-0.024	+		An	-0.4	-0.004	-
Pečenjevce	Sp	-0.99	-0.036	-	Staničenje	Sp	-4.32	-0.385	***
	Su	-1.64	-0.011	-		Su	-4.90	-0.123	***
	Au	-0.77	-0.07	-		Au	-1.87	-0.029	+
	Wi	-1.71	-0.043	+		Wi	-3.96	-0.135	***
	An	-2.23	-0.036	*		An	-4.05	-0.192	***

Station	S	Z	B	α	Station	S	Z	B	α
Pukovac	Sp	0.37	0.009	-	Žučkovac	Sp	0.07	0.001	-
	Su	0.59	0.002	-		Su	-0.52	-0.05	-
	Au	0.72	0.002	-		Au	-0.94	-0.004	-
	Wi	-0.27	-0.004	-		Wi	1.10	0.016	-
	An	-0.15	-0.002	-		An	-0.25	-0.002	-

S - season; Z – trend value; S – Sen estimate; α – level of significance (*** - significance of 0.001; ** - significance of 0.01; * - significance of 0.05 i.e. moderate statistical significance; + - significance of 0.1; - significance higher than 0.1 i.e. does not indicate any significance in this parameter change)

In order to determine the consistency between results of obtained trends on hydrological profiles of South Morava River with long-term changes in the mean annual discharges throughout the basin, the trends of its larger tributaries were examined. Slightly decreasing trend, with an average reduction rates from 0.002 m^3/s/year on the Žučkovac profile (Moravica) and Pukovac profile (Pusta Reka) to 0.139 m^3/s/year on the Niš profile (Nišava), was observed on approximately 55% of the profiles in South Morava river basin. All the mentioned registered trend changes in the South Morava river basin do not show significance at any level, i.e. significance is defined with a value $\alpha>0.1$. However, on Svodje (Vlasina) station it was recorded some significant decreasing trends in seasonal discharge – in summer, autumn and winter (an average value of trend is -2.31). On other stations with a slightly and moderate decreasing trend of mean annual river discharge, statistically significant changes of seasonal values were not registered.

Statistically significant decreasing trends of mean annual discharge values were registered in several different hydrological profiles: Leskovac (-1.67), Bela Palanka (-1.76) and Vlasotince profiles (-1.94), which indicates small statistical significance, defined by an α value of 0.1; profile Pečenjevce (-2.23) with moderate statistical significance; profile Svodje (-3.04) with high significance and the Staničenje profile (-4.05) with a pronounced significance of 0.001 (Tab. 2). On mentioned stations, seasonal trends of river flows were also significant. On the profile of Staničenje (Temska), a markedly significant decreasing trend was observed during the spring, summer and winter. The largest decrease in river flow values was registered in the summer (Jun-Aug), where Z had a value of - 4.9 (markedly statistical significance), while in autumn it had - 1.86 (significance level of 0.5). In addition to the Staničenje profile, low statistically significant decreasing trends were observed during the winter months on river Jablanica, with a trend value of -1.71 and during the winter and summer months on river Veternica (-1.94). Moderate statistical significance is noticed in summer season on river Vlasina (Vlasotince – 2.19) and in spring season on river Nišava (Bela Palanka – 2.13). Increasing trends are registered on three stations in basin, with only one significant increasing trend of the mean annual river discharge on the Pirot profile (1.76). On the same profile, during the cold part of the year (autumn and winter), it was noticed moderate increasing trend of seasonal discharges.

The analysis of trends of seasonal discharges at all of the investigated stations (1968-2017) showed that there were no significant changes in most of the examined profiles. Generally speaking, during the spring, on 50% of the profiles, for the period 1968-2017, it was registered an increasing trend of discharge values, in most cases without statistical significance, while 90% stations had decreasing trends during the summer months.

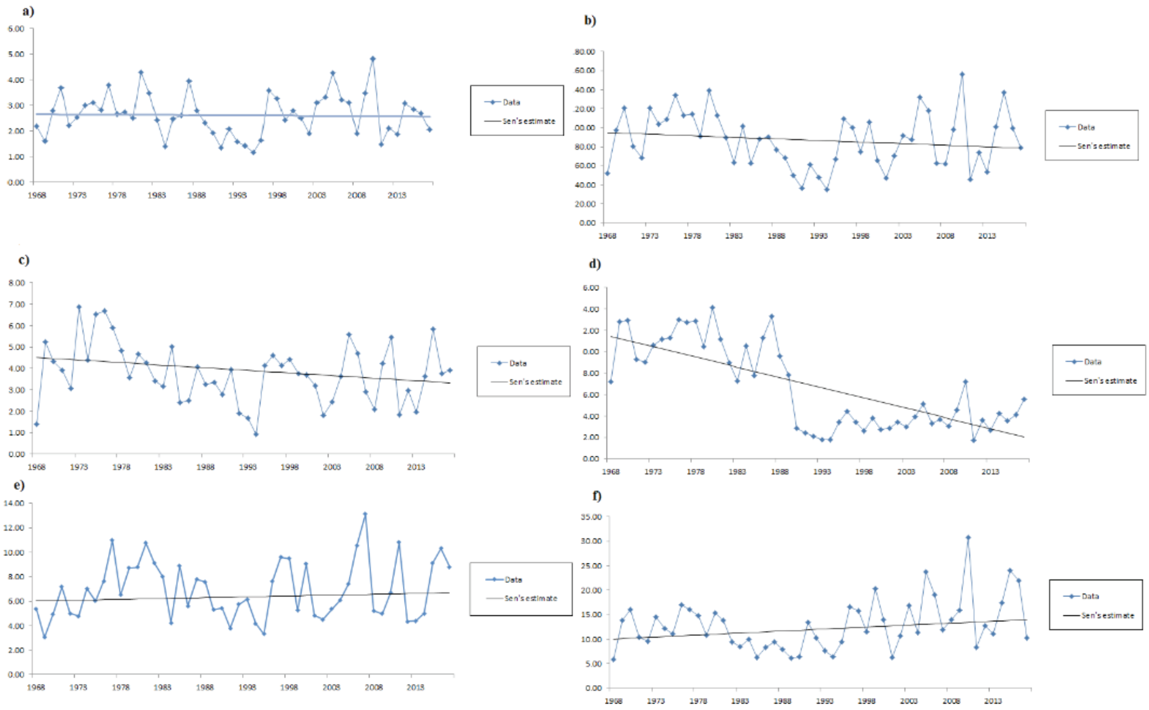

Figure 2: Graphical view of stagnant (a), slightly decreasing (b), moderately decreasing (c), markedly decreasing (d), slightly increasing (e) and moderately increasing (f) types of trends

Based on the obtained values of trend, several graphical types of trends can be determine (Fig. 2): a markedly decreasing, moderately decreasing and a slightly decreasing trend, a stagnant trend, moderately increasing and slightly increasing trend. An almost stagnant trend was registered on the Žučkovac profile (Fig. 2a). The slightly decreasing trend is characteristic for the most of the examined profiles (especially on the course of South Morava river) - Mojsinje profile (Fig. 2b) as an example. A moderately decreasing trend is represented on the Leskovac profile (Fig. 2c). The only one representative of the group of markedly decreasing trends in the mean annual flow rates is the Staničenje profile (Fig. 2d). Slightly increasing trend was registreted on two profiles on the river Toplica, with profile Pepeljevac as an example (Fig. 2e). The group of moderately increasing trends includes only one station - Pirot (Fig. 2e). Group of markedly increasing trends was not registered at any station in the South Morava basin for the observed period.

Results of Pettitte test showed that, in the period of fifty years, on seven profiles it could be determine significant changes and point of changes. On 95% of profiles a point of change occurred in the period 1981-1989 with only one station Pirot with the point of change in 1995 (Tab. 3). On more than a third of the profiles (35%), the breaking point was in 1981, after which, in most cases, there was a decrease in the annual discharges. In addition, 30% of studied profiles have 1984 as a year of change.

On the most profiles, the level of the significance had a value greater than 0.05, which indicates that the changes are not statistically significant, and that the observed time series were almost homogeneous. An average annual discharge values are expectedly distinguished by a decreasing trend and the points of change of that trend have been noticed predominately in the eighties of the last century (Đokić, 2015).

Table 3: Results of the Pettitte test for 20 stations in the South Morava river basin (1968-2017)

	Hydr. station	River	p – level of significance	Q_{ma} (before the point of change)	Q_{ma} (after the point of change)	Point of change (year)
1.	Vladičin Han	South Morava	0.382	18.84		1984
2.	Grdelica		0.204	24.727		1984
3.	Korvingrad		0.027	64.308		1984
4.	Mojsinje		0.018	108.11		1981
5.	Svođe (L)	Lužnica	0.017	3.296	2.396	1986
6.	Svodje (V)	Vlasina	0.001	4.835		1981
7.	Vlasotince		0.001	9.609	6.649	1984
8.	Leskovac	Veternica	0.012	4.947	3.423	1981
9.	Pečenjevce	Jablanica	0.002	4.859	3.280	1987
10.	Pukovac	Pusta Reka	0.367	1.619		1984
11.	Dimitrovgrad	Nišava	0.115	1.947		1981
12.	Pirot		0.009	10.924	15.647	1995
13.	Bela Palanka		0.002	28.402	19.664	1981
14.	Niš		0.006	34.671		1981
15.	Donja Selova	Toplica	0.507	3.344		1987
16.	Pepeljevac		0.856	6.977		1982
17.	Doljevac		0.06	9.463		1982
18.	Trnski Odorovci	Jerma	0.098	3.584		1984
19.	Staničenje	Temska	0.05	10.865	3.463	1989
20.	Žučkovac	Moravica	0.327	2.699		1981

On Fig. 3 are shown representative stations (with significant changes) graphically. On the stations Leskovac (3a), Vlasotince (3d), Pirot (3f) and Bela Palanka (3g), significant changes occurred at the level of significance of 0.1; on three stations occurred negative change (a decreasing trend), and on profile Pirot was noticed positive change (from 10.9 m^3/s before year of 1995, to 15.6 m^3/s after). On the station Pečenjevce (3b) was noticed moderate statistical significance, with year of 1987 as a point of change for decreasing trend. On Svodje station (Lužnica) (3c) declining trend was dominant after the year of 1986, at the level of significance of 0.01. The most significant change occurred on the profile of Staničenje (3e) (level of significance of 0.001), where was, after 1989, noticed enormous decrease in river discharge (from 10.87 m^3/s before, to 3.5 m^3/s after). Considering the fact that the level of significance in these seven examples is less than 0.05, an alternative hypothesis is accepted and it can also be concluded that the observed time series are not homogeneous.

Factors that have determined the quantity of water and its discharge in rivers in the basin of South Morava river, are precipitation, air temperature through evaporation of the water (Burić et al., 2012), terrain slope, a geological composition and pedological cover, vegetation cover and anthropogenic influences. When it comes to interpretation of the results, main question that raises is: Have natural or human factors had more influence on wateriness changing through the period 1968-2018? On the profile Staničenje (Temska) has been recorded the most significant decreasing trend of mean annual and seasonal river discharge (for almost 220% for the studied period). In this case, the main factor is direct anthropogenic influence. From year 1990, a big amount of water from artificial Lake Zavoj (in the upper part of basin of Temska) has been transferred to the river Nišava to assist in production of electricity at hydropower plant “Pirot” (Đokić, 2015). For the same reason, there is noticed statistically increasing trend on the Nišava River, at station Pirot.

Figure 3: Graphical view of trends and points of changes for representative profiles: Veternica (a), Pečenjevce (b), Svodje (c) Vlasotince (d), Staničenje (e), Pirot (d) and Bela Palanka (e)

On the biggest number of other stations, with important changing of river discharges, occurred changes were during the impact of humans (construction of an artificial lakes and hydropower plants, water supply, usage of water for agriculture, industry, etc.). Decreasing trends on some stations are mostly influenced by decreasing in precipitation, which can be concluded from the example of station Niš. Value of trend of mean annual river discharges was -1.51 (which represents a moderate decreasing trend), and value of trend of mean annual precipitation[1] for the same period was similar. Coefficient of correlation between these two variables was around 0.65, which implies that changes of one variable (precipitation) mostly follow variations of another variable (river discharge).

1 Data were used from Meteorological Yearbooks of RHS of Serbia for the period 1968-2017

Conclusion

After all, it can be concluded that the largest number of rivers in South Morava river basin have decreasing trends of mean and seasonal river discharges (85% of them), which is in proportion with the most rivers in the Republic of Serbia. Similar studies in Europe showed that tendency is that rivers in southern part of Europe are characterized by reduction in wateriness. Because of a large surface area, that covers South Morava River basin and local diverse in physical-geographical conditions (geology, orography, climate characteristics, pedology and vegetation) and human impact, there are differentness in the river discharge changing and differentness in their explanations. Understanding the current wateriness represents a very important step for determining the availability and quantity of water resources and good base for future water management in the basin. Obtained data are usefully for future regional and local planning and integrated utilization of water resources. In the next study accent must be on a better explanation of factors that have the most influence on the occurred changes in the basin of South Morava River. In addition, there is a need for more deeply explanation of seasonal and monthly changes, especially from the field of water use for different economic activities.

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