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Characteristics of annual, seasonal and monthly observed climate and hydrologic changes in Serbia in the last seventy years

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ABSTRACT

Observed data and detection of climate and hydrologic changes are of great interest for efficient water resources management. Multiyear temperature (T), precipitation (P) and river discharge (Q) trends across Serbia are presented on an annual, seasonal and monthly basis. The data used in the paper are from 1949 to 2016. The first objective is to present observed multiyear T, P and Q trends in Serbia, on an annual, seasonal and monthly basis. The second objective is to examine how the trends vary among different periods. Three different periods are analyzed: 1949–2006 (58 years), 1959–2016 (58 years), and the entire time span from 1949 to 2016 (68 years). The paper shows the most recent results and discusses whether the earlier registered T, P and Q trends (1949–2006) on all three time scale (annual, seasonal, monthly) exhibit the same pattern or if there are any new phenomena across Serbia in the last 10 years. Additionally, seasonal and monthly trends are compared with observed annual trends. The third objective is to consider what could be expected in general with regard to Serbian river discharges in the next few decades if temperature continues to increase. The fourth objective is to compare the results of this research based only on observed changes, for which regional climate and hydrologic models (RCMs) were not used, with the results obtained for the near future by RCMs in different projects and studies.

Keywords: Climate change; Hydrologic change; Temperature; Precipitation; River discharge; Trends

1. Introduction

Important hydrologic changes are already being observed in Serbia. Pressures on future water supply security are expected, like in many other parts of the world [1–5], given the imminent increase in water demand and a decrease in discharge, to a greater or lesser extent, of all rivers whose catchment areas (C.A.s) are mostly within Serbia [6,7]. Large international rivers (Danube, Sava and Tisa) in the northern part of the country are not the focus of this paper. A temperature and precipitation trend analysis is presented for the whole of Serbia. The period selected for analysis is from 1949 to 2016, which is quite longue and significant, for three reasons:

- Data are available from numerous stations,
- A trend is much less changeable when the data series exceeds approx. 60–70 years, and
- If there is a significant trend in the past 60–70 years, there is also a high probability of a similar trend at least in the near future, e.g. in the next 20–30 years, which is much more the focus of research than the distant future.

All the trend charts shown in the paper were generated using interpolation software "Surfer", based on the data

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recorded at the analyzed monitoring stations, after removing the stochastic component by regional averaging [6,7]. This approach provides better spatial picture of trend changes in the frame of available data. It should be noted that the aim of the research was to arrive at conclusions that are certain enough and important for the water sector.

2. Temperature and precipitation trends in SERBIA

All global and regional climate and hydrologic models (RCMs) predict an increase in temperature and a small decrease in precipitation in Serbia. The average annual temperature increase is expected to range from 2°C to 5°C at the end of 21st century, largely depending on the selected scenario and to a much lesser extent on the analyst [4,8,9]. Annual precipitation predictions are more uncertain, range from current levels (trend ≈ 0) to a small decrease/increase in the near future (of the order of +10%) and significant decrease in the distant future (–25%). Each prediction is sensitive to assumption uncertainties and calculation imperfections. The quality of a prediction, particularly for the near future, grows with increasing validation by observed data and recorded trends [6,10]. To assess past climate trends, 26 temperature stations and 38 precipitation stations were selected [6]. Table 1 shows average monthly and annual temperatures (°C) for all 26 stations, and Table 2 the monthly and annual temperature trends (only averages for the analyzed *T* stations) (°C/100 years), both tables for period 1949–2016. Tables 3 and 4 show the same for precipitation (Table 3 in mm, and Table 4 in %/100 years). Figs. 1 and 3 show the locations of

Table 1
Average monthly temperature (°C) and annual averages (1949–2016)

Number and name of *T* station		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
1.	TS Sombor	–0.5	1.4	5.9	11.5	16.6	20.0	21.5	20.9	16.5	11.1	5.7	1.3	11.0
2.	TS Sremska Mitrovica	–0.2	1.7	6.2	11.7	16.8	19.9	21.4	20.9	16.7	11.4	6.1	1.5	11.2
3.	TS Senta	–0.4	1.5	6.2	12.0	17.1	20.4	22.2	21.6	17.1	11.5	6.0	1.4	11.4
4.	TS Beograd	1.1	2.9	7.3	12.7	17.5	20.8	22.6	22.3	18.0	12.7	7.3	2.8	12.3
5.	TS Zlatibor	–2.5	–1.3	2.1	7.0	11.8	15.2	17.2	17.2	13.3	8.5	3.6	–1.0	7.6
6.	TS Kruševac	–0.2	2.0	6.2	11.7	16.4	19.8	21.5	21.2	16.9	11.5	6.3	1.7	11.3
7.	TS Niš	0.4	2.5	6.7	12.1	16.8	20.3	22.2	22.0	17.6	12.1	6.9	2.2	11.8
8.	TS Požega	–1.9	0.5	4.9	10.0	14.7	18.0	19.7	19.2	15.2	10.0	4.6	–0.2	9.6
9.	TS Pirot	–0.2	1.7	5.8	11.2	15.8	19.2	21.2	20.9	16.7	11.3	6.2	1.6	10.9
10.	TS Vranje	–0.2	2.0	6.1	11.1	15.8	19.3	21.5	21.4	17.1	11.7	6.2	1.5	11.1
11.	TS Zaječar	–0.8	1.1	5.3	11.3	16.4	20.0	21.9	21.2	16.6	10.6	5.3	0.9	10.8
12.	TS Knjaževac	–0.6	1.2	5.4	11.2	16.1	19.6	21.4	20.8	16.3	10.7	5.6	1.3	10.8
13.	TS Veliko Gradište	–0.1	1.6	6.0	11.8	16.7	19.9	21.7	21.2	17.0	11.6	6.3	1.6	11.3
14.	TS Aleksandrovac	–0.1	1.8	5.9	11.2	15.9	19.2	21.2	21.0	16.7	11.4	6.3	1.5	11.0
15.	TS Leskovac	–0.2	2.0	6.2	11.4	16.2	19.7	21.5	21.2	16.8	11.3	6.2	1.6	11.2
16.	TS Prokuplje	–0.2	1.9	6.1	11.3	15.9	19.3	21.3	21.0	16.8	11.4	6.3	1.7	11.1
17.	TS Ćuprija	–0.1	1.7	6.0	11.6	16.4	19.7	21.4	21.1	16.7	11.3	6.3	1.7	11.2
18.	TS Čačak	–0.4	1.6	5.9	11.1	15.9	19.4	21.1	20.7	16.5	11.1	5.6	1.2	10.8
19.	TS Novi Pazar	–1.4	0.7	4.7	9.6	14.1	17.4	19.3	19.1	15.1	10.1	4.9	0.2	9.5
20.	TS Sjenica	–4.2	–2.6	1.4	6.4	11.2	14.4	16.1	15.8	12.0	7.4	2.7	–2.2	6.5
21.	TS Ivanjica	–1.2	0.7	4.6	9.6	14.1	17.4	19.0	18.7	14.8	9.9	5.0	0.3	9.4
22.	TS Jagodina	0.2	2.2	6.6	12.0	17.0	20.3	22.1	21.8	17.4	11.7	6.6	2.0	11.6
23.	TS Čumić	0.6	2.2	6.3	11.5	16.3	19.6	21.6	21.4	17.3	12.2	6.9	2.2	11.5
24.	TS Valjevo	0.3	2.2	6.4	11.4	16.3	19.7	21.5	21.0	16.8	11.5	6.4	2.0	11.3
25.	TS Dragaš	–0.9	–0.2	2.9	7.6	12.3	16.0	18.4	18.2	13.8	9.1	4.6	0.8	8.6
26.	TS Bujanovac	–0.2	2.0	6.1	11.0	15.7	19.3	21.2	21.1	17.0	11.6	6.2	1.4	11.0
Average of 26 stations (°C)		**–0.5**	**1.3**	**5.5**	**10.8**	**15.6**	**19.0**	**20.8**	**20.5**	**16.3**	**10.9**	**5.8**	**1.2**	**10.6**

Table 2
Monthly and annual temperature trends (°C/100 years), average for all 26 *T* stations, 1949–2016

Month		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Temperature (°C/100 years)	Average of 26 stations	3.3	2.6	3.6	1.5	1.8	2.1	2.6	2.5	0.1	0.9	0.2	–1.0	1.7

Table 3
Average monthly and annual precipitation sums (mm), 1949–2016

Number and name of *P* station		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
1.	PS Bezdan	39.5	38.0	35.7	48.2	63.5	75.6	59.9	48.5	47.0	45.3	53.0	48.8	603
2.	PS Sombor	36.5	34.9	33.9	45.5	62.4	75.5	66.3	51.6	47.4	44.8	51.7	47.2	598
3.	PS Palilić	33.5	33.0	32.2	42.4	57.9	73.1	59.3	51.1	44.6	38.6	48.3	45.8	560
4.	PS Senta	37.5	36.7	36.0	42.7	63.2	74.6	55.8	50.7	44.4	41.8	49.4	50.6	583
5.	PS Kikinda	33.0	33.4	33.3	45.0	55.0	73.0	55.8	50.0	43.2	40.1	46.3	46.6	555
6.	PS Zrenjanin	36.4	35.8	35.2	44.3	60.9	80.9	59.3	49.1	45.3	41.1	46.8	49.0	584
7.	PS Jasa Tomić	42.8	39.4	36.2	48.4	66.9	84.6	62.4	52.4	47.6	43.0	49.9	52.5	626
8.	PS Sr. Mitrovica	40.2	36.8	38.8	48.5	63.1	81.5	62.3	52.2	48.2	47.9	53.7	50.5	624
9.	PS Bela Crkva	43.9	41.4	39.7	50.0	75.5	86.9	76.1	56.8	49.6	45.1	49.8	53.0	668
10.	PS Jajinci	47.4	41.8	46.8	56.8	72.4	93.3	67.3	50.5	53.3	48.5	52.6	57.8	688
11.	PS Loznica	59.2	50.8	60.9	65.3	85.5	101.7	81.0	71.9	66.5	62.2	69.0	66.0	840
12.	PS Osečina	64.1	55.7	68.8	73.6	98.9	108.4	81.2	72.6	70.3	66.8	72.4	71.8	905
13.	PS Kosjerić	49.2	46.3	49.3	58.4	86.5	93.0	82.5	66.4	63.5	59.4	62.0	57.8	774
14.	PS Požega	46.8	43.9	49.4	56.6	81.1	84.5	77.7	60.2	62.6	56.8	60.7	53.9	734
15.	PS Ivanjica	54.1	53.4	63.0	70.9	103.1	113.1	90.5	72.6	74.8	63.2	69.9	64.0	893
16.	PS Prijepolje	56.4	56.4	54.6	59.4	82.0	83.3	76.5	60.1	71.5	71.8	78.6	66.8	817
17.	PS Sjenica	46.7	45.0	46.0	51.5	77.4	79.6	67.4	61.8	66.0	65.8	71.5	58.1	737
18.	PS Novi Pazar	41.1	38.1	43.4	46.9	66.7	66.1	59.7	50.2	54.9	51.6	60.3	53.1	632
19.	PS Dragaš	68.1	61.7	63.1	67.5	74.6	72.0	54.1	47.1	69.4	75.7	87.3	73.3	814
20.	PS Smed. Palanka	44.5	40.2	44.8	51.0	67.6	82.9	63.0	51.2	51.1	49.0	50.9	51.2	647
21.	PS Kragujevac	41.3	38.2	44.6	51.8	72.4	78.4	67.3	55.5	50.0	45.6	48.2	47.1	640
22.	PS Rekovac	45.9	41.9	44.6	52.7	72.9	73.2	62.6	50.1	48.1	47.4	51.2	49.4	640
23.	PS Ćuprija	47.3	44.6	44.4	57.6	76.7	78.6	62.6	45.1	52.1	47.7	53.7	54.8	665
24.	PS Aleksandrovac	37.9	34.9	41.1	46.8	72.4	71.4	57.1	46.8	50.2	47.3	51.3	42.1	599
25.	PS Blaževo	51.3	49.4	60.5	68.8	97.6	88.9	74.7	62.1	66.8	65.3	79.6	64.5	830
26.	PS Kuršumlija	44.2	44.6	49.0	52.7	69.8	67.4	59.0	45.4	51.6	54.2	61.6	55.2	655
27.	PS Vel. Gradište	47.5	44.1	43.0	56.5	73.4	83.7	68.5	54.0	53.0	48.1	50.8	55.0	677
28	PS Voluja	49.5	44.2	45.6	60.4	70.2	76.7	66.6	51.1	50.1	51.2	53.9	57.8	677
29.	PS Crni Vrh	50.9	47.8	52.3	70.5	92.3	95.0	74.5	57.5	63.5	64.1	68.5	57.3	794
30.	PS Negotin	48.3	48.8	52.3	57.3	66.1	67.9	50.7	38.3	48.8	56.2	67.7	61.4	664
31.	PS Zaječar	42.5	41.6	44.5	53.8	67.4	64.7	54.0	43.3	43.4	48.9	57.2	52.7	614
32.	PS Knjaževac	43.2	40.1	42.2	50.8	66.9	64.6	55.3	45.1	47.3	47.2	56.7	51.7	611
33.	PS Niš	38.9	38.0	39.6	49.8	62.3	56.9	44.2	43.5	44.3	44.7	53.3	49.8	565
34.	PS Pirot	37.8	37.8	40.5	50.6	68.4	74.9	48.8	43.2	44.6	46.3	55.3	45.1	593
35.	PS Krupac	42.8	41.1	40.9	52.4	66.9	74.9	49.7	42.9	45.3	44.3	56.5	48.8	606
36.	PS Leskovac	44.5	44.0	49.3	55.9	62.7	65.5	46.0	45.8	48.6	50.3	61.1	53.0	627
37.	PS Vranje	41.2	41.3	42.6	51.9	62.7	63.3	49.5	40.8	49.2	56.2	62.9	51.7	613
38.	PS Bujanovac	43.7	45.6	45.0	52.2	62.1	63.4	47.2	38.8	50.4	56.8	63.8	56.8	626
Average of 38 stations (mm)		**45.2**	**42.9**	**45.6**	**54.3**	**72.3**	**78.8**	**63.1**	**52.0**	**53.4**	**52.1**	**58.9**	**54.5**	**673**

Table 4
Monthly precipitation trends and annual averages of all 38 *P* stations (1949–2016)

Month		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation (%/100 years)	Average of 38 stations	8.8	5.5	31.4	7.7	2.3	–15.1	–5.3	9.9	58.9	50.9	–40.9	–24.1	7.5

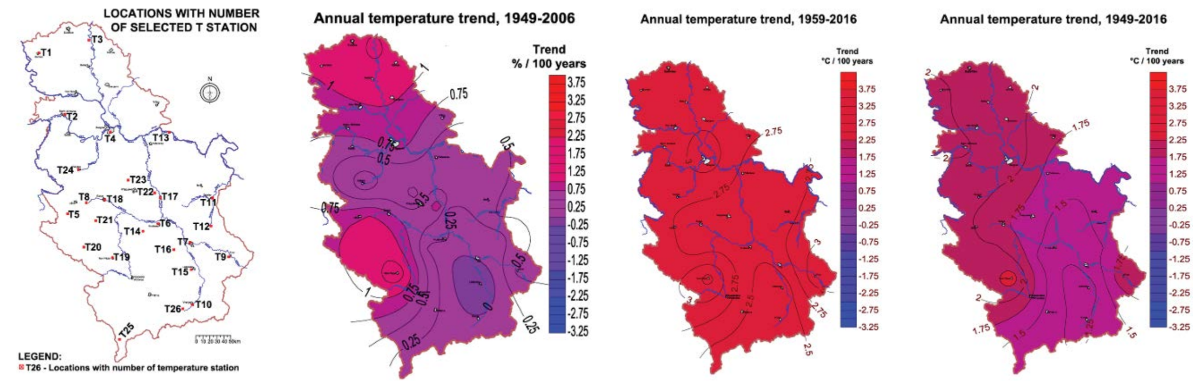

Fig. 1. Locations of selected T stations (far left) and spatial T trend distribution (°C/100 years) for 1949–2006; 1959–2016 and 1949–2016.

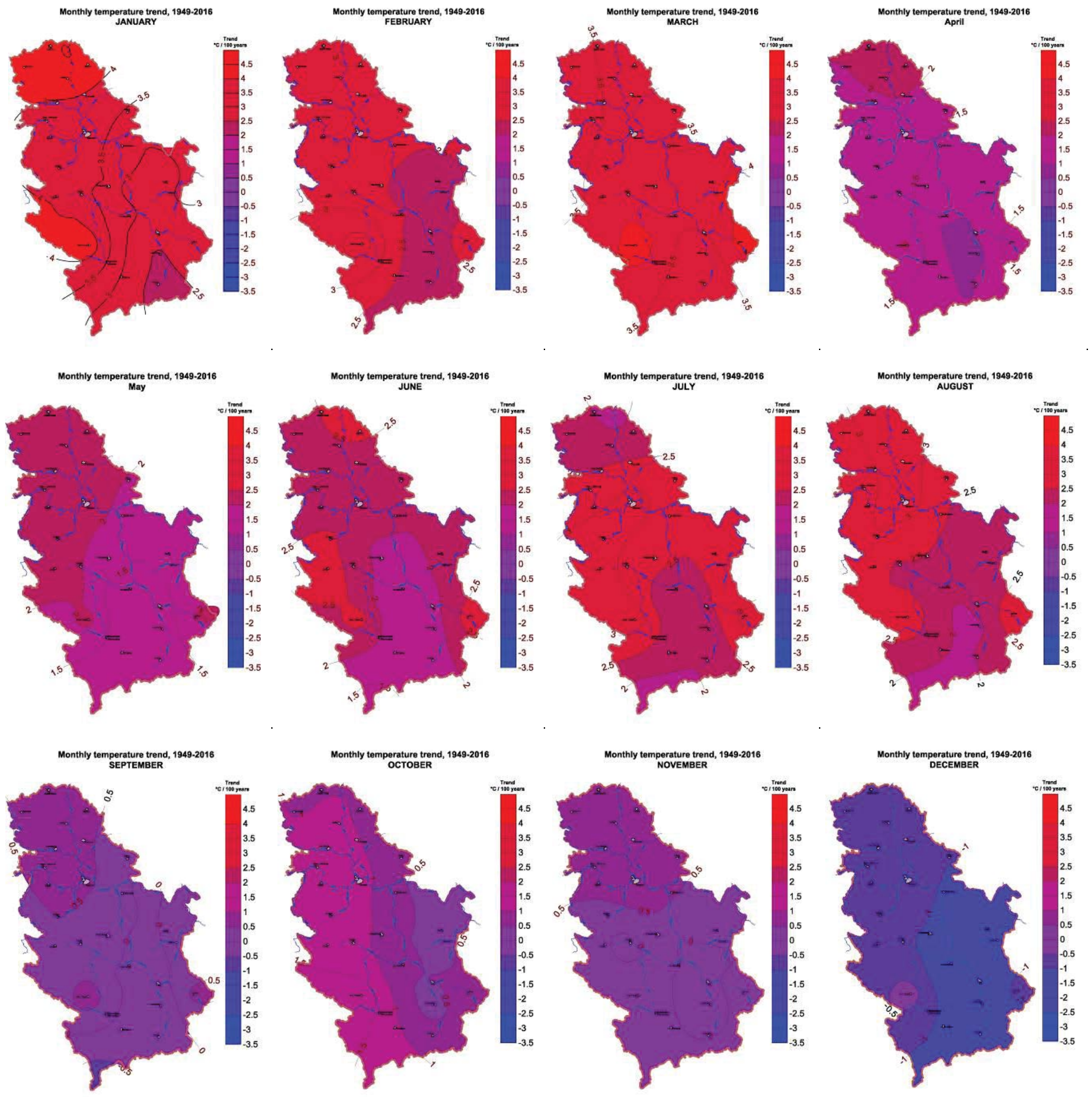

Fig. 2. Spatial monthly T trend distributions (°C/100 years) for 1949–2016.

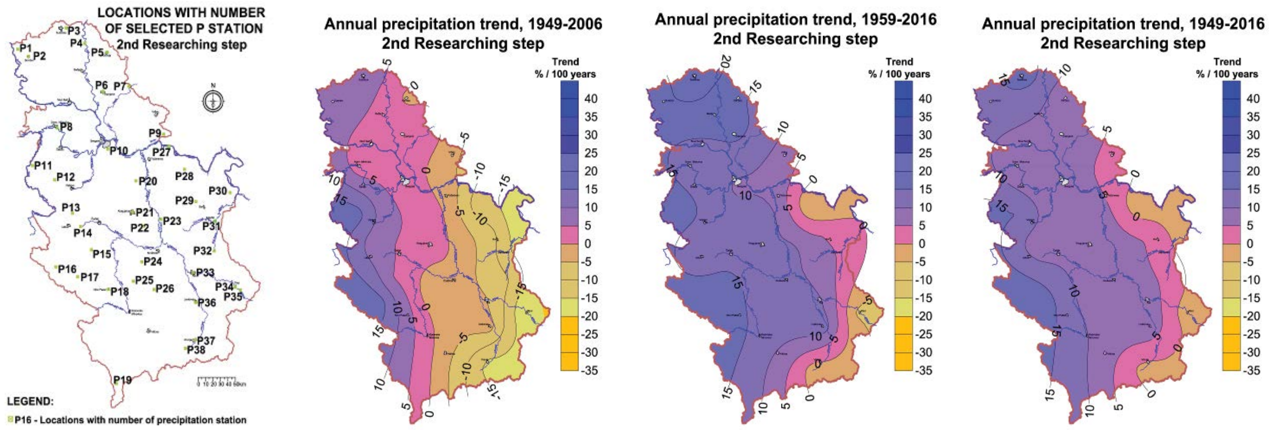

Fig. 3. Locations of selected *P* stations (far left) and spatial *P* trend distributions for 1949–2006; 1959–2016 and 1949–2016.

the selected *T* and *P* stations and the spatial annual *T* and *P* trend distribution for all three analyzed periods: 1949–2006; 1959–2016 and 1949–2016. Figs. 2 and 4 show spatial *T* and *P* trend distribution by month, only for 1949–2016.

Table 5 shows observed average monthly, seasonal and annual temperature trends (°C/100 years) for all 26 stations and, all three periods. The seasons are standard: winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November). Table 6 also shows the average monthly, seasonal and annual trends, but for precipitation (%/100 years), for all 38 stations and, all three periods.

Yearly temperature trends differ quite a lot depending of the selected period. The reason is very high annual values for *T* in the last 10 years. Compared to the first 10 years of the analyzed period (1949–1958), the average *T* in the last 10 years (2007–2016) is 1.1°C higher [6,11]. The observed yearly *P* trends apparently do not differ as much depending of the selected period. They are quite consistent with RCMs [4,8,9]. Seasonal and monthly trends are more debatable for both climate parameters.

Seasonal *T* trends for the longest period with available data (1949–2016) are in line with RCMs – the highest increase in summer and, the lowest in autumn. The other two periods have several debatable seasonal *T* trend values, which could be a consequence of insufficiently long data series (58 years). In addition to July and August, the highest upward monthly temperature trends have been registered in January and March. Negative monthly *T* trends have been registered in November and December, and there has been no significant change in the month September. Other months registered increasing trends, in the range of the annual average.

Seasonal *P* trends show a small decrease in winter, and a sizeable increase in autumn. The distribution of certain monthly precipitation trends is especially questionable: the highest downward trend in the RCMs was almost always predicted for the summer months (often in the order of –50%/100 years), which is inferior to the actual trends in summer. June and July have registered a small decrease in precipitation (in the order of approx. –10%/100 years), while August and particularly September registered significant positive trends. September is at the same time the month with the highest and most consistent positive precipitation trend in all of Serbia. For the water sector, with regard to the low discharge period, is also important that October exhibits significant positive trend as well. November and December are the months which exhibit the highest downward precipitation trend. The months from January to May vary and any conclusion would be highly uncertain.

3. Hydrologic trends in central SERBIA

Serbia is experiencing a downward river discharge trend. Apart from climate change (CC), the hydrologic regime of a river is affected by changes in land use (LU) within the C.A. and changes in the extent and method of human use (HU) of water [12–15]. As a result, some of Serbia's rivers record a considerable decrease in discharge, especially in eastern part of the country. All three components are very important and the degree of significance varies very much from one catchment to another. As noted in Introduction, large international rivers in the north of the country (Danube, Sava, Tisa) were not considered in this paper.

Table 7 shows average monthly and annual river discharge (m^3/s) for all 24 stations, and Table 8 monthly and annual river discharge trends ($m^3/s/100$ years), both tables for the period 1949–2016. Fig. 5 shows the locations of the selected *Q* stations and spatial *Q* trend distributions for all three analyzed periods: 1949–2006; 1959–2016 and 1949–2016.

Contrary to climate parameters, it is difficult to spatially generalize river discharge trends because several factors affect these trends [6,12–16]. Small rivers (C.A. < 100 km^2) are much more stochastic in nature and sensitive to water withdrawal for human consumption, so they were not included in this analysis. Neither were catchments where water is being transferred to another catchment upstream from a given hydrologic station. There are dams and reservoirs upstream from some of the hydrologic stations (stations 1, 5, 6, 7, 8, 9, 11, 15 and 23 in Tables 7 and 8). Contrary to annual trends, the impact of a reservoir on monthly trends is significant, especially in the low-discharge period. An approximate geographic distribution of the downward average annual river discharge trends for central Serbia is shown in Fig. 3, which was compiled based on the trends recorded at 24 selected

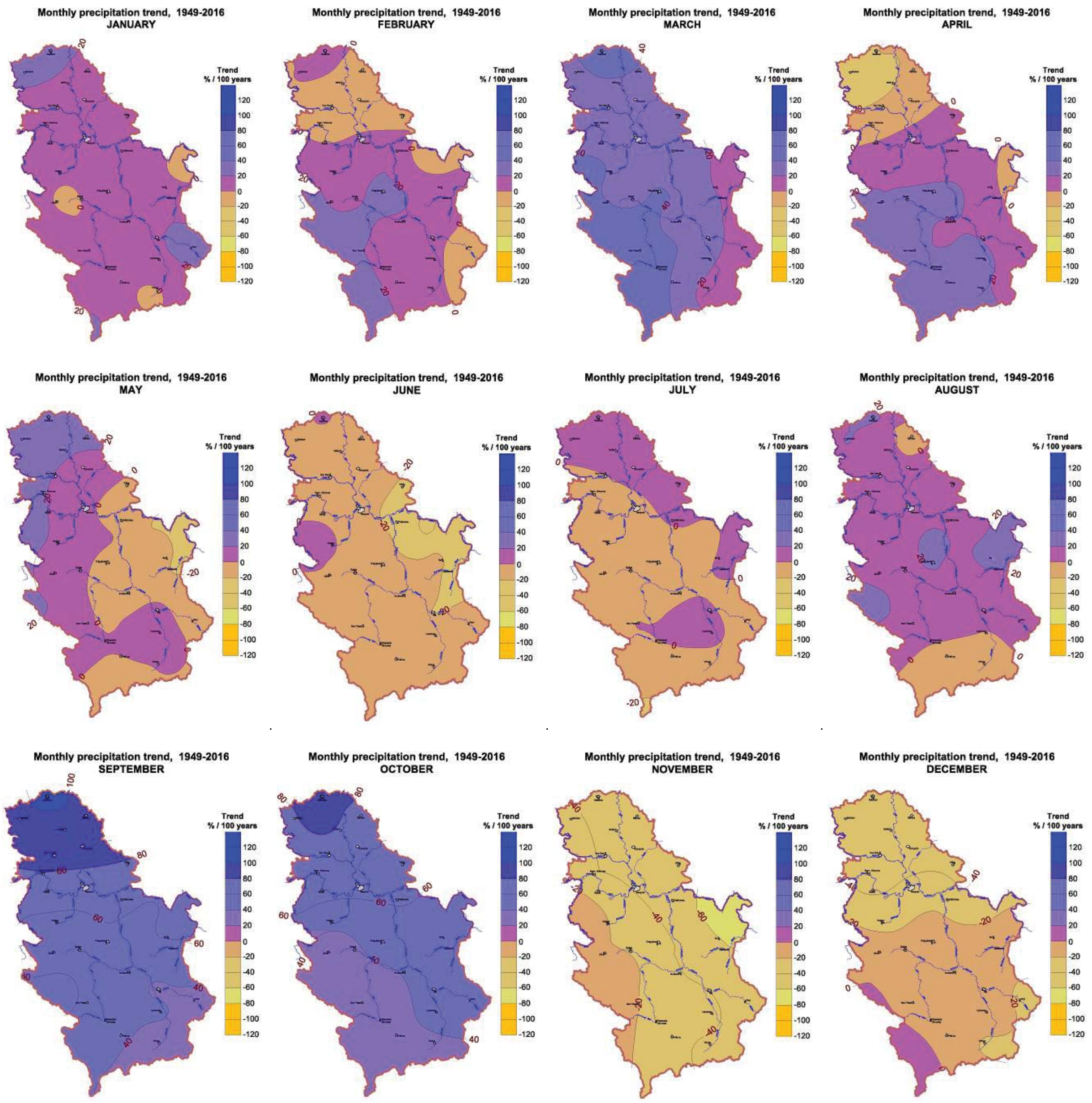

Fig. 4. Spatial monthly *P* trend distributions (%/100 years) for 1949–2016.

Table 5
Monthly, seasonal and annual *T* trends (°C/100 years), average of 26 stations in different periods

Period	*T* data trend	Winter			Spring			Summer			Autumn			Annual
		Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	
1949–2006	Monthly	–2.2	1.9	1.3	3.2	–0.1	1.7	1.1	1.1	0.8	–1.3	1.2	–1.9	0.6
	Seasonal		0.3			1.6			1.0			–0.7		
1959–2016	Monthly	0.5	5.3	2.9	2.6	2.1	2.4	3.7	5.1	4.7	2.0	1.0	0.1	2.7
	Seasonal		2.9			2.4			4.5			1.1		
1949–2016	Monthly	–1.0	3.3	2.6	3.6	1.5	1.8	2.1	2.6	2.5	0.1	0.9	0.2	1.7
	Seasonal	1.7			2.3			2.4			0.4			
Average of 3 periods	Monthly	–0.9	3.5	2.3	3.1	1.2	2.0	2.3	2.9	2.7	0.3	1.1	–0.5	1.7
	Seasonal		1.6			2.1			2.6			0.3		

Table 6
Monthly, seasonal and annual P trends (%/100 years), average of 38 stations in different periods

Period	P data trend	Winter			Spring			Summer			Autumn			Annual
		Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	
1949–2006	Monthly	–19.8	–22.0	–25.5	–13.8	36.0	–46.8	–5.9	8.9	48.6	76.3	9.7	–52.7	–0.6
	Seasonal		–22.4			–8.2			17.2			11.1		
1959–2016	Monthly	–35.9	4.3	23.4	40.6	–1.0	6.6	–25.4	–32.6	9.1	59.3	110.9	–36.7	10.2
	Seasonal		–2.7			15.4			–16.3			44.5		
1949–2016	Monthly	–24.1	8.8	5.5	31.4	7.7	2.3	–15.1	–5.3	9.9	58.9	50.9	–40.9	7.5
	Seasonal		–3.3			13.8			–3.5			23.0		
Average of 3 periods	Monthly	–26.6	–3.0	1.1	19.4	14.2	–12.6	–15.5	–9.7	22.5	64.8	57.1	–43.4	5.7
	Seasonal		–9.5			7.0			–0.9			26.2		

Table 7
Average monthly river discharges (m^3/s) and annual averages (1949–2016)

	River – Hydrologic station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
1	Ibar–Raška	44	59	73	70	54	32	20	15	16	21	33	45	40
2	Lim–Prijepolje	73	77	99	145	139	77	38	23	27	44	78	95	76
3	Moravica–Arilje	9.3	13	20	20	17	12	7.5	4.6	4.3	5.0	6.8	9.3	10.6
4	Studenica–Ušće	5.4	6.8	11	14	12	8.0	5.5	4.0	3.9	4.1	5.1	6.0	7.1
5	Drina–Radalj	377	395	471	614	564	346	197	136	146	237	383	476	362
6	V. Morava–Varvarin	209	299	384	381	299	195	122	81	77	98	140	191	206
7	Z. Morava–Jasika	108	145	188	183	149	100	67	46	44	55	78	102	105
8	J. Morava–Aleksinac	95	136	171	175	128	83	46	29	27	37	55	79	88
9	Nišava–Niš	29	39	51	56	44	30	17	11	11	13	18	26	29
10	Lugomir–Majur	1.7	3.0	4.0	3.5	2.9	1.8	1.0	0.6	0.4	0.6	0.9	1.4	1.8
11	Timok–Tamnič	26	43	63	63	40	22	10	6.0	5.7	8.7	16	24	27
12	B. Timok–Knjaževac	8.1	12.5	16.4	16.1	12.2	7.2	3.6	2.4	2.3	3.0	4.7	7.4	8.0
13	Pek–Kusići	10	14	20	18	11	8.3	4.3	3.1	2.3	3.3	5.0	7.6	9.0
14	Jasenica–D. Šatornja	0.6	0.9	1.2	1.1	0.9	0.7	0.4	0.2	0.2	0.2	0.3	0.5	0.6
15	Veternica–Leskovac	4.6	6.4	8.3	8.3	5.7	3.4	1.8	1.1	1.2	1.5	2.4	3.5	4.0
16	Toplica–D. Selova	3.6	4.3	5.8	6.4	5.0	3.2	2.1	1.5	1.5	1.8	2.6	3.6	3.5
17	Crnica–Paraćin	3.2	4.7	7.2	7.7	5.2	3.4	1.9	1.4	1.0	1.1	1.7	2.9	3.4
18	Jadar–Lešnica	10	13	15	13	11	8.0	4.3	2.5	2.3	3.4	6.7	10	8.3
19	Resava–Svilajnac	4.4	6.7	8.8	10	6.9	5.6	3.1	2.0	1.6	1.6	2.2	3.6	4.7
20	Kamenica–Prijevor	2.5	3.0	3.6	2.7	2.6	2.0	1.4	0.9	1.0	1.2	1.6	2.2	2.0
21	Skrapež–Požega	4.6	7.4	10	7.5	7.2	4.7	3.6	2.1	1.8	2.4	3.5	4.7	5.0
22	Kolubara–Valjevo	4.1	5.5	6.9	5.9	5.7	3.8	2.5	1.6	1.5	1.8	2.7	3.7	3.8
23	V. Morava–Lj. Most	241	336	428	437	343	233	147	97	87	108	151	211	235
24	V. Rzav–Radobuđa	5.8	7.6	11	10	8.6	6.0	4.0	2.6	2.9	3.6	5.2	6.3	6.1

hydrologic stations (Table 8) across central Serbia. It should be noted that within all river discharge trend isolines there are rivers and monitoring stations that often exhibit significant trend variations (both up and down), as a result of the HU factor, and especially if water is transferred upstream from a given hydrologic station.

Table 9 shows observed average monthly, seasonal and annual river discharge trends ($m^3/s/100$ years) for all 24 stations and, all three periods. The seasons are standard: winter (DJF), spring (MAM), summer (JJA), and autumn (SON). Yearly river discharge trends do not differ much depending of the selected period, and they are in the range of (–20 ÷ –25%/100 years). Considering the spatial annual trend distribution, it should be noted that the eastern and south-eastern parts of the country exhibit the highest negative trend (in the range of –40 ÷ –50%/100 years), while the south-west part exhibits trend close to zero (without changes in flow). These Q changes in both part of the country are consequences of observed T and especially P changes, in addition to the HU factor on some rivers (Figs. 1 and 2).

Table 8
Registered 1949–2016 hydrologic trends, monthly and annual (%/100 years)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Average of 24 stations	–1.2	–36.4	16.4	–14.8	–34.1	–40.1	–48.4	–24.8	–0.1	–23.7	–36.6	–45.1	–21.4

Table 9
Monthly, seasonal and annual Q trends (%/100 years), average of 24 stations in different periods

Period	Q data trend	Winter			Spring			Summer			Autumn			Annual
		Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	
1949–2006	Monthly	–53.8	–0.7	–45.5	–13.1	–14.0	–74.8	–21.4	–31.8	–7.4	30.1	–7.0	–55.5	–29.2
	Seasonal		–33.3			–34.0			–20.2			–10.8		
1959–2016	Monthly	–2.5	–4.4	–55.4	24.9	9.0	–39.3	–73.0	–88.9	–17.2	–10.4	16.3	–6.4	–18.6
	Seasonal		–20.8			–1.8			–59.7			–0.2		
1949–2016	Monthly	–45.1	–1.2	–36.4	16.4	–14.8	–34.1	–40.1	–48.4	–24.8	–0.1	–23.7	–36.6	–21.4
	Seasonal		–27.5			–10.8			–37.8			–20.1		
Average of 3 periods	Monthly	–33.8	–2.1	–45.7	9.4	–6.6	–49.4	–44.8	–56.4	–16.5	6.5	–4.8	–32.8	–23.0
	Seasonal		–27.2			–15.5			–39.2			–10.4		

The highest negative seasonal trend is in summer (estimated range –35 ÷ –40%/100 years), followed by winter (–25 ÷ –30%/100 years), and spring and autumn (–10 ÷ –15%/100 years). Two things should be noted regarding the monthly Q trends:

- The highest negative monthly Q trend is in May, June and July (apart from February, where some snow effect is likely present). Significantly smaller water quantities in rivers in late spring and early summer is important information for the water sector, particularly with regard to water use (irrigation and drinking water supply).
- The lower negative trend in the low-discharge months (August to October, range of –20 ÷ +10%/100 years) is a result of an upward P trend during these months and, additionally, often due to the presence of a river reservoir upstream from a given station, which to some extent equalizes annual discharges.

4. Most probable mean flows in central SERBIA in the near future

Based on the above, it is obvious that there is a downward river discharge trend in Serbia. If temperature continues to increase, what is to be expected with regard to hydrologic trends? Will they continue to fall? Will the negative trend increase or decrease? How reliable are the results of RCMs, if hydrologic predictions in different studies result in a broad range of possible annual discharge changes of the same river (extremes of +20% and –40% are noted) [7]?

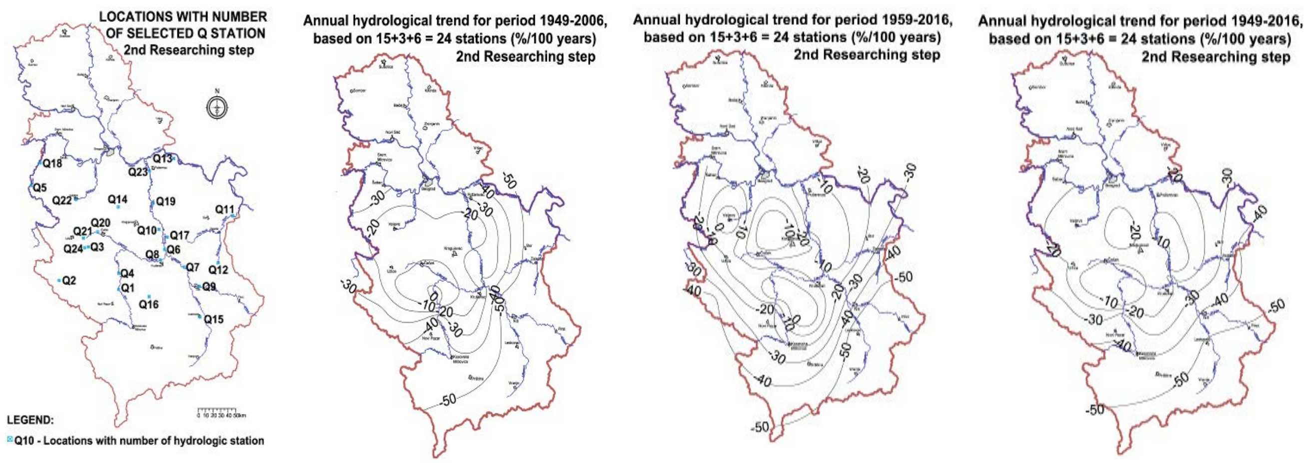

Fig. 5. Locations of selected hydrologic stations (far left) and spatial Q trend distributions for 1949–2006; 1959–2016 and 1949–2016.

One of the best ways to answer these questions is to analyze what has happened in the past to average annual temperature vs. river discharges. The *T* stations which are closest to the center of the C.A. of a hydrologic station were taken as reference stations. The analysis included all 24 *Q* stations and their associated *T* stations. The methodology is described in details in the literature [4,6,7], and results are shown in Fig. 6.

It should be noted that the coefficient of determination is high on all three graphs (on the first and third graphs higher than 0.9), leading to the conclusion that a deviation of the average annual *T* by +1°C has an inversely proportional effect on the average annual *Q* of about 15%. The results differ from C.A. to C.A., but in most cases this variation is not large. If the linear trends are extrapolated to +2°C, the following values are derived for relative river discharges (Table 10).

An important characteristic of this approach is that it takes into account all three changes: CC, LU and HU. Perhaps this methodology could help determine which regional climate-hydrologic model is appropriate for a certain region. In order for it to be applied to individual catchments, it might be useful to produce the same RCMs for a number of catchments and try to arrive at an average for the analyzed region (in this case central Serbia), similar to the correlations shown in Fig. 6 [6,7].

The Intergovernmental Panel on Climate Change (IPCC) and the RCMs that provide a spatial picture of the predicted runoff (river discharge) changes in Europe suggest that a reduction in runoff can be expected in southern Europe (south of around 50°N) and that a decline trend from west to east is likely to happen in southeastern Europe [8,9,17–19]. Some estimate changes in runoff for different increases in temperature and different scenarios. One could say that the direction of the observed annual *Q* changes in Serbia is in line with these studies – a declining trend from the western to the eastern part of Serbia is registered [6,11], but the impact of temperature increase on runoff shown in Fig. 6 is stronger. RCMs that analyzed catchments tended to produce quite different results, depending on the adopted scenario and models, even for the same river [7]. The averages of annual river discharge changes obtained by RCMs are, in most cases, lower than the registered trends.

5. Conclusions

With regard to the analyzed periods, it is important to note that the selection of a period (if the time-series comprise approx. 60 years or more) is not crucial, but still plays an important role in the final results (comparison of pictures in Figs. 1, 3, 5 and 6, and the summary in Table 11). It is apparent Table 11 that the longest period, 68 years (1949–2016), shows trends for all three parameters (*T*, *P* and *Q*) between trends of the other two periods, which could be declared as expected. The most probable trends, relevant to the near future, are likely those between the trends for the 1949–2006 and 1949–2016 periods, but closer to the trends obtained for 1949–2016 [6,11]. The same is valid for the correlation between air temperature and river discharge (Table 10).

An increasing annual temperature trend of approx. 1.7°C/100 years was derived for the period 1949–2016. This was the largest departure from earlier research [7,10], in which the period 1949–2006 was analyzed (reporting an annual T trend of approx. 0.6°C/100 years). A greater trend was always noted in mountainous areas in western Serbia and in the north of the country (even exceeding 2°C/100 years).

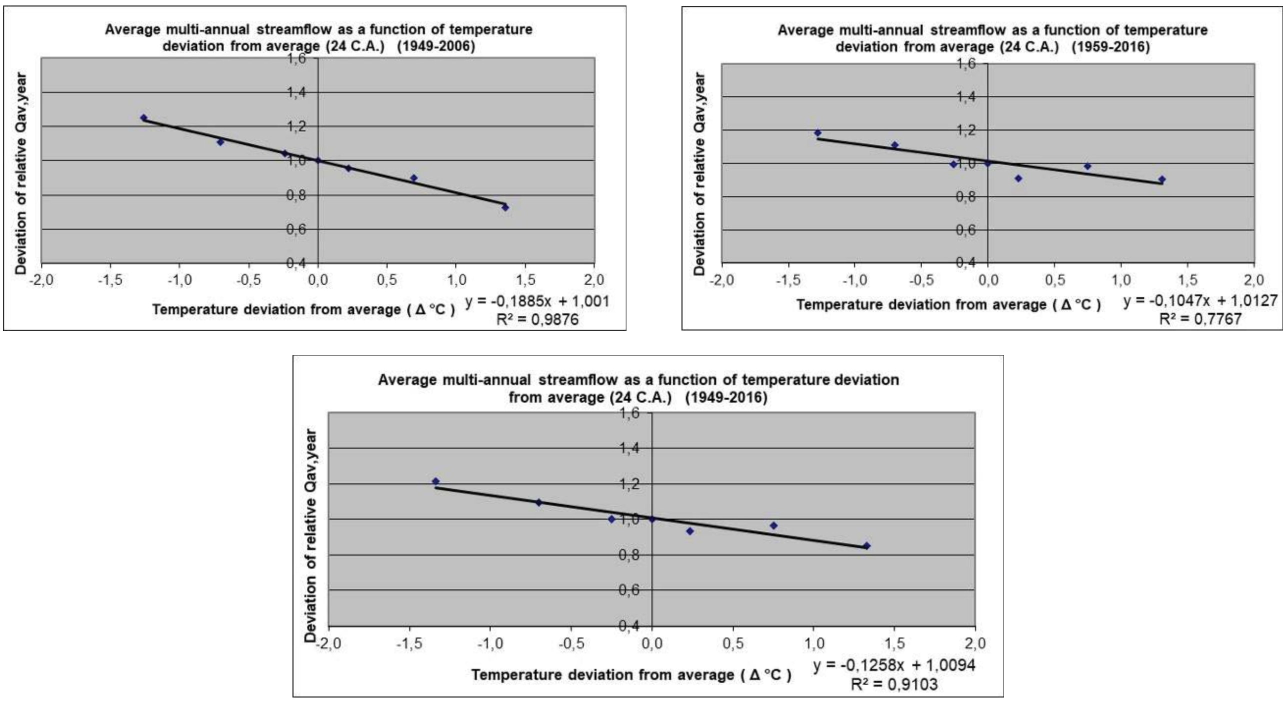

Fig. 6. Average relative annual river discharge, as a function of temperature deviation (all 24 C.A.s), along with the linear trend of dependency, for three analyzed periods (1949–2006; 1959–2016 and 1949–2016).

Table 10
Average relative Q based on linear trends for different increases in average annual T

Relative river discharge (Q_{rel})		ΔT_{av} (°C)	0.5	1.0	1.5	2.0
1949–2006 (linear trend)	a = –0.1885	b = 1.0010	0.91	0.81	0.72	0.62
1959–2016 (linear trend)	a = –0.1047	b = 1.0127	0.96	0.91	0.86	0.80
1949–2016 (linear trend)	a = –0.1258	b = 1.0094	0.95	0.88	0.82	0.76

Table 11
Dependence of average T, P and Q trends and T – Q correlation from the selected period

Analyzed period	Average T trend (°C/100 years)	Average P trend (%/100 years)	Average Q trend (%/100 years)	Average impact of 1°C annual T increase on average annual Q (%)
1949–2006	+0.6	–0.6	–29.2	–18.7
1959–2016	+2.7	+10.2	–18.6	–9.2
1949–2016	+1.7	+7.5	–21.4	–11.6

Southeastern Serbia exhibits the lowest trend in all three analyzed periods.

It should be noted that Serbia recorded much higher annual T in the last 10 years (2007–2016) than the average from earlier periods (which is consistent with the observed T in the world). For the same period (last 10 years), the average annual precipitation in Serbia was also slightly higher than the average from earlier periods. This was not really expected, but can be attributed to natural variations and one very wet year (2014), in which enormous floods were registered in a large part of Serbia [20].

The overall average observed precipitation change in Serbia is relatively small (in the range of +10%/100 years). However, a distinct upward P trend exists in the (south) western and a downward trend in the eastern part of the country. Claims of several RCMs that the greatest monthly reduction in precipitation is to be expected during summer and early autumn (low-discharge months) are in conflict with the observed trends. The greatest increasing monthly P trend has been recorded in August, September and October.

The direction of annual river discharge changes in Serbia is generally in accordance with the forecasts based on the IPCC scenario A1B [8,10], and the observed T and P trends [6,7,10,11]. The recorded average Q trends have decreased by about 20 ÷ 25%/100 years, and depend on a large number of factors. CC is one of these factors, which is present at all monitoring stations, but its significance varies. It is generally dominant in the eastern part of the country, and in the upper parts of the C.A.s [6,12,13], but it is often less significant or even minor elsewhere, especially where human impact is substantial. It should be kept in mind that the above hydrologic results are given in terms of averages and that the Q trend of specific catchments can differ significantly, both up and down, due to differences in human activity, above all.

If forecast regarding the most probable average annual T, P and Q changes in near future (in 20–25 years) in Serbia should be given based on this research, obtained results told us: additionally increase in temperature of about 0.3°C, negligible precipitation changes, and additionally decrease in discharge in Serbian rivers of about 5%.

In general, a lower Q trend was noted in low-discharge months, as a result of an upward P trend during these months, but also often due to the presence of a river reservoir upstream of a given monitoring station, which equalizes annual discharges. This does not mean, however, that a more significant downward trend will not appear during this period if the temperature continues to rise, particularly at stations where there are no upstream river reservoirs.

If the average annual T were to increase by 2°C, based on the correlations established to date between average annual Q and average annual T, one could expect, as the most probable value, approximately 30% less water in rivers whose catchments largely lie within Serbia. Maybe, it is worth using the proposed methodology and trying to find appropriate RCMs for a certain region.

Apart from Serbia, the results of the present study could benefit for the other countries in South East Europe. It is also believed that the results will be of interest to the Mediterranean and other regions where a downward trend of river discharge is expected. Ultimately, the proposed methodology for assessing the impact of average temperature on average river discharge could certainly be applied in many parts of the world, especially in regions where a decreasing precipitation trend is recorded. It could also be used in other regions, but in some cases the results might not be as straightforward.

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