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Present and future mean hydrologic trends in Serbia as a function of climate trends

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ABSTRACT

Past multiyear temperature (T), precipitation (P) and river discharge (Q) trends across Serbia are presented in the paper, both annual and monthly basis. The first objective of the research is to find observed multiyear T, P and Q trends in Serbia, which could be similar to the long-term trends and to assess the correlations between them. The results indicate that the long-term average yearly trends are approximately: temperature increase of 0.6°C/100 years, a slight decrease in precipitation, but with significant differences between western and eastern part of the country, and a decrease in river discharge of 30%/100 years. The second objective, and most important finding is the result of average correlations between air temperature increase and changes in river discharges and precipitation. The conclusion is that all the selected monitoring stations report an inversely proportional correlation between average annual temperatures and annual river discharges. On average, a 1°C increase in annual temperatures roughly corresponds to a 20% reduction in average annual river discharge and a 7% reduction in average annual precipitation. It is shown that an average annual temperature increase of 2°C will likely result in half the river discharge in Serbia, on average. The methodology described in the paper may be very useful for estimating near future (approx. next 30 years) average river discharges in many parts of the world, particularly in regions where a decreasing precipitation trend has been recorded. The third objective and important conclusion is related to low-discharge months (July through October). A considerably lower negative river discharge trend (close to zero) is noted, as a result of an upward precipitation trend during these months, but also in places due to human impact. The fourth objective is to generally compare the results of this research based only on observed changes, in which regional climate and hydrologic models (RCMs) were not used, with the results obtained by RCMs for the near future in different projects and studies by other authors.

Keywords: Climate change; Temperature; Precipitation; River discharges; Trends

1. Introduction

Pressures regarding future water supply security, such as in many parts of the world [1–4], are expected in central and eastern Serbia, given the imminent increase in water demand and decrease in discharge, to a greater or lesser extent, of all rivers in the region [5]. Significant impacts of human activity exist in western and northern Serbia, such that their inclusion and a presentation of the spatial hydrologic trends are less reliable and would require a much lengthier paper. A temperature and precipitation trend analysis is presented for the whole of Serbia. The period selected for analysis is from 1949 to 2006. This period is convenient because it is relatively long (58 years), data are available from numerous monitoring stations, and they exhibit a close similarity to estimated long-term temperature and precipitation trends, and particularly river discharge trends in Serbia [5–7]. The selected long-term trend is that of the past 100 years [5], for two reasons:

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- A trend is much less changeable when the data series exceeds approx. 70 years, and
- If there is a significant trend in the past 100 years, there is also a high probability of a similar trend at least in the near future, for example, next approx. 30 years, which is much more the focus of the research than the distant future.

As such, long time-series data were available from several climatic and hydrologic stations in Serbia [5,7,8].

All the trend charts shown in the paper were generated using software for interpolation purposes "Surfer," based on the data recorded at the analyzed monitoring stations, after removing the stochastic component by regional averaging [5,9]. This approach could not be absolutely precise, of course, but we trust that it gives us the best possible results in the frame of available data. It should be noted that the aim of the research is to arrive at conclusions that are certain enough sure and important for the water sector.

2. Temperature and precipitation trends in Serbia

All global and regional climate models (RCMs) predict an increase in temperature and a decrease in precipitation in Serbia. The average annual temperature increase is expected to range from 2°C to 5°C/100 years, largely depending on the selected scenario and to a much lesser extent on the analyst [3,10–12]. Annual precipitation predictions range from current levels (trend ≈ 0) to –25%/100 years. 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 [6,13]. To assess past climate trends, 26 temperature stations and 34 precipitation stations were selected [5]. The annual average temperature trend in Serbia was found to be about 0.6°C/100 years, while the annual precipitation trend was slightly negative. Monthly temperature and precipitation monthly and annual averages for the period 1949–2006 are shown in Tables 1 and 2, and the locations in Fig. 2. The spatial distribution on an annual basis and for the months of August and September is shown in Fig. 1 [5,7].

It could be said that observed yearly T and P trends are in line with RCMs [3,10,11]. Monthly trends are more debatable.

The highest upward monthly temperature trends in the RCMs have always been predicted for the summer months (June, July, August and September). They are considerably higher than the predicted annual trend in RCMs, while observed trend in September is decreasing. September, along with November and December, was the only month with a distinct negative temperature trend (average –1.4°C/100 years). January, March and May are the months with the highest upward temperature trends.

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 predicted annual trend, while the actual trends in July, August and September were of the order of approx. +40%/100 years. September is at the same time the month with the highest and most consistent positive precipitation trend in all of Serbia. The months from November to February exhibit a downward precipitation trend, August and September an upward precipitation trend, and the other months vary.

3. Past average hydrologic trends in central and eastern Serbia

Serbia, especially its eastern part, experiences 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 catchment area (CA) and changes in the extent and method of human use (HU) of water [14–17]. As a result, some of Serbia's rivers record a considerable decrease in discharge. The discharges of only a small number of rivers have increased, largely due to water transfers from other river basins, which began in the 1970's and 1980's. All three components are very important and the degree of significance varies very much from one catchment to another.

It is well known that contrary to climate parameters, it is difficult to spatially generalize river discharge trends because several factors affect these trends [14,18,19]. Small rivers (CA < 1,000 km^2) are much more stochastic in nature and sensitive to water withdrawal for human consumption, so they are not included in this analysis. The most important factors are:

- The transfer of water, if any, between catchments upstream from a given hydrologic station. This factor is dominant at a number of hydrologic stations and such stations need to be excluded from analysis (otherwise they require comprehensive calculations for which reliable data are generally unavailable), in order to derive relevant results.
- Other human impacts (the presence or absence of river reservoir(s) in the CA, the volume and way of HU of water in a given CA). The degree of significance of this factor ranges from negligible (small volumes of water withdrawn from large rivers) to dominant (large volumes withdrawn from small rivers), within the framework of the recorded trend. A favorable circumstance from a trend analysis perspective is that much more water is used in Serbia for drinking water supply (where relatively accurate data are available), than irrigation (where there are only rough estimates).
- Any LU changes in the CA. LU changes are relatively rare in Serbia but there is a slight arable land shrinkage trend.
- Climate change. CC has had the greatest impact and resulted in the most distinct recorded downward precipitation and river discharge trends in eastern Serbia [5,9]. Conversely, only a minor change has been noted in southwestern Serbia, where many rivers exhibit near-zero trends as a result of an upward precipitation trend, but also an upward evapotranspiration trend due to a slightly higher temperature increase in that region, compared with Serbia's average (Fig. 1).

An approximate geographic distribution of the downward average annual river discharge trends for central and eastern Serbia is shown in Fig. 2. 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 factor B and especially A. Fig. 3 was compiled based on the trends recorded at

Table 1
Monthly temperature trends and annual averages (1949–2006)

No. and name of T station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver
1.	TS Sombor	2.74	1.71	2.71	0.07	2.45	1.54	1.57	1.84	–0.59	1.31	–1.16	–1.76	*1.04*
2.	TS Sremska Mitrovica	2.09	1.54	2.82	–0.09	2.38	1.01	1.02	1.53	–0.86	1.49	–1.25	–1.81	*0.82*
3.	TS Senta	3.04	2.04	2.91	0.40	2.67	1.95	2.02	2.03	–0.39	1.44	–1.06	–1.71	*1.28*
4.	TS Beograd	2.16	1.93	3.31	0.04	2.26	1.13	1.28	1.51	–0.99	1.41	–1.11	–1.86	*0.92*
5.	TS Zlatibor	2.68	1.76	3.32	0.45	2.39	1.73	1.84	1.04	–1.19	1.83	–1.70	–1.99	*1.01*
6.	TS Kruševac	1.67	1.31	3.22	–0.47	1.23	0.64	0.78	0.50	–1.64	0.91	–2.15	–2.69	*0.28*
7.	TS Niš	1.26	0.74	2.99	–0.59	1.01	0.49	0.71	0.22	–1.98	0.70	–2.40	–2.71	*0.04*
8.	TS Požega	2.29	1.70	3.60	0.71	2.54	1.84	1.86	1.23	–0.80	1.66	–2.01	–2.20	*1.03*
9.	TS Pirot	1.62	1.00	3.55	0.19	1.67	1.31	1.29	0.78	–1.23	1.03	–2.25	–2.13	*0.57*
10.	TS Vranje	1.01	0.28	2.82	–0.43	1.08	0.77	0.61	–0.10	–1.85	0.94	–2.23	–2.69	*0.02*
11.	TS Zaječar	2.10	1.39	3.73	–0.25	1.59	1.29	1.23	0.71	–1.51	0.73	–2.26	–2.27	*0.54*
12.	TS Knjaževac	1.66	0.87	3.20	–0.57	1.23	0.78	0.72	0.20	–1.98	0.45	–2.62	–2.51	*0.12*
13.	TS Veliko Gradište	1.52	1.33	2.72	–0.57	1.40	0.59	0.77	0.75	–1.67	0.61	–1.65	–2.63	*0.26*
14.	TS Aleksandrovac	1.64	1.40	3.09	–0.72	0.83	0.35	0.59	0.44	–1.61	1.08	–2.15	–2.70	*0.19*
15.	TS Leskovac	0.98	0.29	2.68	–0.77	0.77	0.41	0.41	–0.23	–2.39	0.24	–2.82	–2.87	*–0.28*
16.	TS Prokuplje	1.15	0.74	2.91	–0.86	0.72	0.26	0.51	0.05	–1.97	0.67	–2.47	–2.80	*–0.09*
17.	TS Ćuprija	1.45	1.08	3.01	–0.69	1.28	0.50	0.72	0.50	–1.70	0.75	–2.15	–2.75	*0.17*
18.	TS Čačak	2.23	1.53	3.32	0.31	2.15	1.40	1.57	1.12	–0.95	1.47	–2.09	–2.07	*0.83*
19.	TS Novi Pazar	3.05	2.58	4.27	0.79	2.30	1.97	2.15	1.36	–0.36	2.23	–1.45	–1.39	*1.46*
20.	TS Sjenica	2.80	1.83	3.45	0.34	1.87	1.60	1.94	0.98	–0.97	1.95	–1.84	–1.42	*1.04*
21.	TS Ivanjica	2.73	2.09	3.82	0.67	2.41	1.78	1.88	1.15	–0.76	1.87	–1.74	–1.63	*1.19*
22.	TS Jagodina	1.47	1.24	3.17	–0.55	1.50	0.70	0.91	0.68	–1.50	0.90	–2.06	–2.70	*0.31*
23.	TS Čumić	2.01	1.67	3.15	–0.42	1.56	0.69	0.92	1.00	–1.12	1.55	–1.67	–2.27	*0.59*
24.	TS Valjevo	2.24	1.52	3.17	0.30	2.48	1.44	1.59	1.53	–0.78	1.65	–1.75	–2.05	*0.94*
25.	TS Dragaš	1.74	0.76	3.21	–0.16	0.82	0.49	0.21	–0.46	–2.33	1.62	–1.59	–2.23	*0.17*
26.	TS Bujanovac	1.10	0.25	2.84	–0.43	1.10	0.78	0.54	–0.23	–1.73	1.16	–2.08	–2.61	*0.06*
Temperature (°C/100 years)	Average of 26 stations	1.9	1.3	3.2	–0.1	1.7	1.1	1.1	0.8	–1.4	1.2	–1.9	–2.2	0.6

19 selected hydrologic stations (Table 3) across Serbia – 16 of them are shown in Fig. 3 and the remaining 3 lie beyond the boundaries of this map, where factor B was assessed as having an acceptable degree of impact, and where factor A was either non-existent or negligible.

4. What characterizes low-discharge trends in Serbia?

The average monthly distribution of the hydrologic trends recorded at 18 stations across Serbia (Fig. 3) are shown in Table 3, along with the only registered long time-series of a karst spring in Serbia. This karst spring is the source of the Mlava River, its capacity is substantial, and it can be considered as river flow. The same results would have been obtained if the flow had been gauged a few kilometers downstream. The reason of including this karst spring in a river discharge analysis lies in the fact that this is the only hydrologic data series in this part of Serbia.

There is a dam and reservoir upstream from some of the hydrologic stations (numbers 1, 5–9 and 11 in Table 3). Contrary to annual trends, impact of reservoir on monthly trends is significant, especially in low-flow period.

Apparently, a much lower trend was noted during the months of low discharge - July to October (–26.8; –7.4; +18.6; –22.1; average app. –10%), primarily as a result of an upward precipitation trend during these months (+11.5; +43.1; +70.9; +6.3; average app. +33%), and additionally, often due to the presence of a river reservoir upstream from a given station, which equalizes annual discharges. An attempt has been made to establish more precise correlations for low-discharge months, but still with no satisfactory outcome. Correlation will be sought in a standard way (hydrology balance) – catchment by catchment, if other important data are available (evapotranspiration, HU of water, operating regimes of hydroelectric power plants, etc.), Hopefully, this will be achieved in the next few years, but it is highly questionable due to frequent lack of such additional data.

5. What is to be expected in the future?

Based on the above, it is obvious that there is a downward average annual 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 discharges of the same river (extremes of +20% and –40% are noted) [7,20]?

Table 2
Monthly precipitation trends and annual averages (1949–2006)

No. and name of P station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver
1.	PS Bezdan	–4.8	–50.8	3.8	–6.9	–39.3	–2.2	29.0	38.7	94.2	58.9	–34.7	–53.6	*2.7*
2.	PS Šid	15.5	–36.1	8.2	17.6	–23.1	17.5	32.1	41.6	90.9	87.9	–10.5	–58.4	*15.3*
3.	PS Horgoš	–12.6	–35.6	15.0	27.2	–49.0	–4.5	48.0	24.5	115.3	41.0	–65.0	–35.8	*5.7*
4.	PS Jaša Tomić	–25.8	–62.6	0.7	49.1	–33.1	1.7	16.8	46.8	103.5	45.7	–64.2	–42.2	*3.0*
5.	PS Prijepolje	–23.7	21.6	–10.6	70.1	–17.9	–16.3	9.3	57.2	102.1	–2.2	12.5	21.3	*18.6*
6.	PS Kuršumlija	–19.1	–20.8	–28.0	41.9	–45.0	–22.1	25.9	33.2	59.0	–48.1	–45.5	–7.2	*–6.3*
7.	PS Leskovac	–12.5	–8.0	–30.3	30.1	–42.3	–8.9	10.5	40.3	48.0	–15.1	–67.6	–11.9	*–5.6*
8.	PS Beoce	–32.3	–5.2	–14.3	56.1	–38.2	–12.6	35.1	50.6	87.4	–20.0	–21.9	5.9	*7.6*
9.	PS Pirot	–7.7	–53.3	–28.7	14.6	–39.4	–18.0	–32.6	45.9	36.2	–31.2	–100.5	–25.3	*–20.0*
10.	PS Vranje	–16.1	–11.2	–31.2	24.9	–41.6	–6.1	2.5	43.9	38.7	–17.2	–77.4	–18.7	*–9.1*
11.	PS Knjaževac	–3.7	–24.5	–15.0	45.7	–39.2	–10.4	–21.3	56.1	57.1	–5.1	–73.0	–32.4	*–5.5*
12.	PS Svrljig	0.9	–22.3	–15.5	40.4	–47.0	–7.6	–3.4	66.2	49.4	–18.5	–65.8	–26.8	*–4.2*
13.	PS Voluja	–21.3	–46.4	0.5	54.1	–54.5	–31.1	–38.5	37.1	44.9	20.5	–67.7	–31.8	*–11.2*
14.	PS Aleksandrovac	–26.5	–22.5	–34.9	40.0	–60.8	–14.8	16.9	37.5	61.3	–43.9	–41.3	–9.5	*–8.2*
15.	PS Vučje	–10.0	–0.9	–26.6	24.4	–48.6	–11.1	10.1	38.6	44.0	–15.1	–67.9	–10.7	*–6.2*
16.	PS Trećak	–23.9	–27.5	-32.1	39.7	–57.2	–21.0	17.2	29.0	54.3	–52.3	–42.5	–12.3	*–10.7*
17.	PS Ćuprija	–15.5	–14.8	–3.0	53.7	–60.6	–1.9	–0.4	43.3	59.4	–3.1	–44.2	–13.3	*0.0*
18.	PS Kosjerić	–22.3	6.6	–19.6	32.2	–45.5	5.1	10.0	34.5	77.1	12.4	–5.2	–4.1	*6.8*
19.	PS Novi Pazar	–32.1	–2.4	–13.4	58.8	–38.1	–18.8	38.7	51.6	89.3	–21.5	–17.5	10.0	*8.7*
20.	PS Brodarevo	–27.1	18.6	–17.6	66.9	–23.7	–12.0	7.0	47.1	107.0	–14.2	10.2	14.6	*14.7*
21.	PS Ivanjica	–43.0	–5.0	–32.6	38.8	–48.0	–16.5	17.2	40.4	86.3	–17.9	–0.3	1.4	*1.7*
22.	PS Vranovina	–33.4	–1.5	–16.3	58.5	–35.3	–14.6	39.2	54.1	91.8	–17.9	–16.6	10.9	*9.9*
23.	PS Rekovac	–27.6	–16.0	–16.7	38.6	–60.9	–0.3	14.3	49.2	79.1	–15.1	–34.1	–11.2	*–0.1*
24.	PS Donja Šatornja	–37.6	–24.5	–25.9	30.7	–62.7	21.0	15.9	47.9	71.6	20.6	–10.9	–7.3	*3.2*
25.	PS Osečina	–14.1	–20.8	–8.0	26.2	–39.5	37.0	29.6	48.2	80.6	55.7	–1.2	–24.9	*14.1*
26.	PS Dragaš	12.1	25.3	21.1	38.4	–50.0	–36.9	9.3	33.1	30.4	–20.1	–43.1	30.6	*4.2*
27.	PS Bujanovac	–28.3	–2.5	–28.4	35.2	–52.8	0.8	11.0	23.5	29.7	–20.6	–83.2	2.7	*–9.4*
28	PS Jajinci	–12.8	–30.7	–11.8	34.3	–56.1	3.0	5.3	54.1	75.9	59.6	–28.1	–27.5	*5.4*
29.	PS Senta	–14.6	–48.7	8.0	26.3	–42.0	–1.7	38.3	25.8	114.7	48.3	–54.1	–41.5	*4.9*
30.	PS Srem. Mitrovica	–12.5	–55.3	–3.6	12.7	–42.4	4.4	16.0	57.9	84.2	77.0	–23.8	–69.9	*3.7*
31.	PS Kriva Reka-Brus	–25.2	–23.0	–33.9	43.3	–53.3	–19.5	19.5	37.1	70.9	–48.6	–40.5	–9.1	*–6.9*
32.	PS Martinci	–6.3	–50.0	0.0	14.2	–37.9	6.7	19.6	56.0	87.1	79.4	–18.5	–64.9	*7.1*
33.	PS Krupac	–5.3	–51.5	–24.7	17.6	–37.0	–16.4	–31.2	53.9	36.2	–27.4	–98.7	–23.0	*–17.3*
34.	PS Bogojevo	–6.8	–44.4	1.5	–7.2	–27.9	3.9	40.1	35.7	83.9	64.9	–31.8	–62.7	*4.1*
Precipitation (%/100 years)	Average of 34 stations	–16.0	–21.7	–12.4	35.7	–43.7	–6.6	11.5	43.1	70.9	6.3	–41.4	–17.9	–0.3

One of the best ways to answer these questions is to analyze what has happened in the past to average annual temperature vs. river discharge levels, and it is also useful to establish the same type of correlation between temperature and precipitation [4,9]. The temperature and precipitation stations which are closest to the center of the CA of a hydrologic station were taken as reference stations. The analysis included all 18 hydrologic stations and their associated meteorological stations.

5.1. Methodology and results

The values of the following parameters were calculated for each CA during the 1949–2006 period:

- Average annual river discharge at a given hydrologic station, relative to the average, Q_{rel};
- Annual precipitation sum recorded at a precipitation station close to the center of the CA, again relative to the average annual sum, P_{rel};
- Difference, ΔT_{av}, between the average annual temperature and the average temperature at that station.

To establish correlations, data were grouped into categories according to deviations of average annual temperatures from the mean values for a given station, at intervals of 0.5°C. Average values were then calculated for each category of temperature deviation, and of the annual discharge and precipitation relative to their mean values, respectively. These data

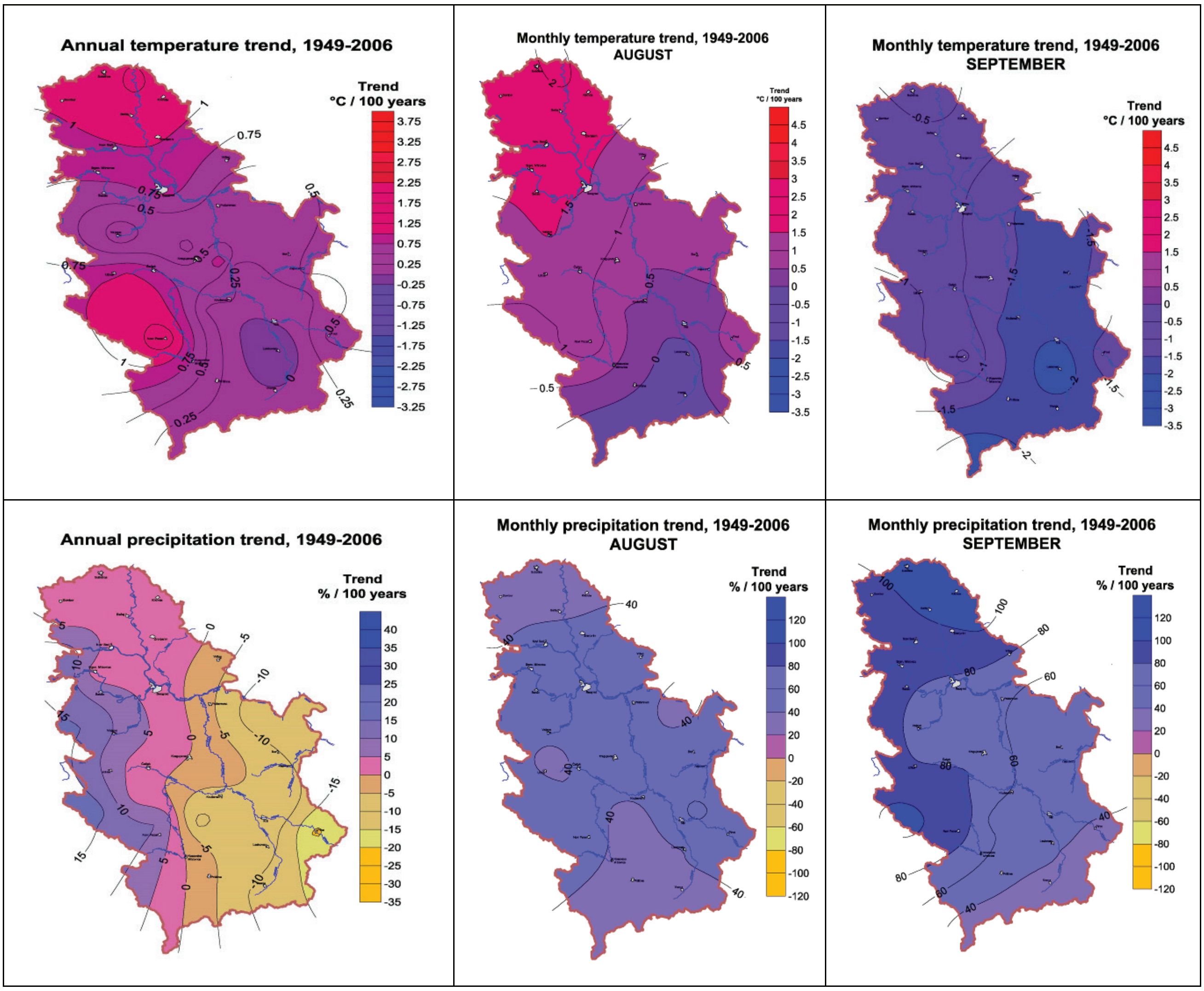

Fig. 1. Recorded annual and monthly T and P trends for August and September in Serbia (1949–2006).

were then used to construct graphs of the correlations between the derived values, displaying also the linear and 3rd degree polynomial fit to the composite data shown and the associated coefficient of determination R^2. Even though each of the studied CAs exhibits specific features, there is no major difference between them: all show the expected trend of an average decline in river discharge with increasing temperature and vice versa. It is, therefore, fully justifiable to synthesize all relevant data into a single data set. This enlarges the data set by 58 members, of each of the analyzed time series, to 58 × 18 = 1,044, and decreases the effect of random, non-standard years, especially in classes that otherwise have few data points. A synthesis of all data (Fig. 4) yielded average values and the derived trends can be considered highly representative for assessing the average temperature impact on river discharges in Serbia.

It should be noted that the coefficient of determination is very high on both graphs, leading to the conclusion that a deviation of the average annual temperature by ±1°C has an inversely proportional effect on the average annual precipitation levels of about 7%, and on the average annual river discharge of about 20%. The results differ from CA to CA, but in most cases this variation is not large. If the linear and 3rd degree polynomial trends are extrapolated to +2°C, the following values are derived for relative river discharge and relative precipitation (Table 4).

An important characteristic of this approach is that it takes into account all three changes: CC, LU and HU. Perhaps, this methodology could help in research which regional climate hydrologic model is appropriate for certain region. In order to be applied to individual catchments, it might be useful to produce the same RCM models for a number of catchments and try to arrive at an average for the analyzed region (in this case central Serbia) that is similar to the values of the correlations given in Fig. 4 [5,9,20].

6. Comparison of hydrologic results with literature sources

Intergovernmental Pannel on Climate Change (IPCC) and those RCMs that provide a spatial picture of predicted runoff (river discharge) changes in Europe tell us that we can expect runoff reduction in southern Europe (south of around 50°N) and that a decline trend from west to east is likely to

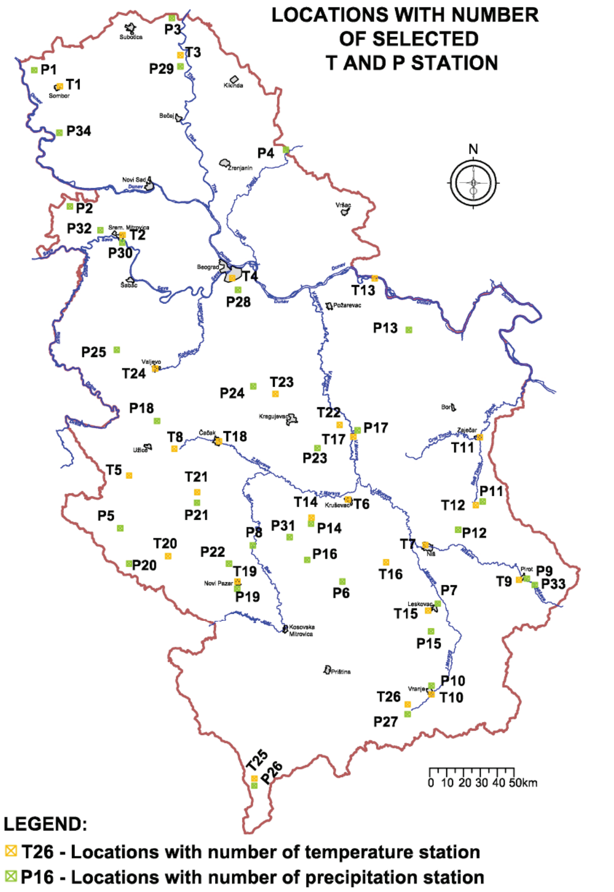

Fig. 2. Locations of selected temperature and precipitation stations.

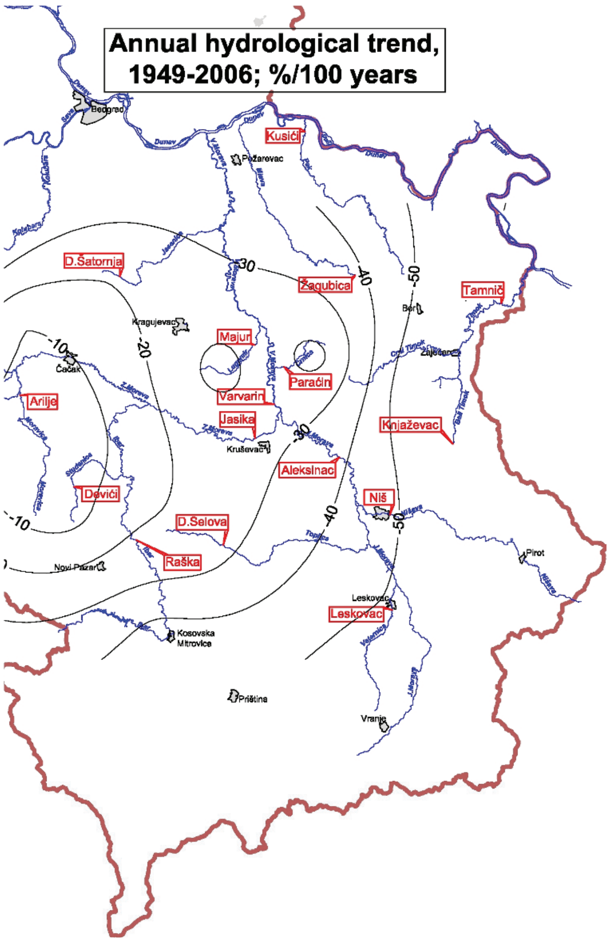

Fig. 3. Isolines of the downward average annual river discharge trend.

happen in southeastern Europe [10,11,21–23]. Some estimate changes in runoff for different increases in temperature and different scenarios. One could say that the direction of the observed yearly discharge changes in Serbia is in line with these studies – a decline trend from western to eastern part of Serbia is registered [5,6], but the impact of temperature increase on runoff, shown in Fig. 4, is significantly stronger. RCMs that are analyzed catchments tend to produce quite different results, depending on the adopted scenario and models, even for the same river [9,20]. The averages of annual river discharge changes obtained by RCMs are, in most cases, lower than the registered trends [20].

Like precipitation, low-flow monthly trends are more debatable. In the majority of cases, RCMs predict a greater (in absolute value) river discharge decline during low-flow periods than the annual average [10,11], whereas observed data tell us the opposite – a lower decline is observed from July to October, compared with annual river discharge trends. This could be explained by the existence of numerous reservoirs in Serbian river basins, which to some extent temporarily equalize discharges.

7. Conclusions

An increasing temperature trend of 0.6°C/100 years was derived from 26 analyzed temperature stations. A greater trend was noted in mountainous areas and in the north of the country (even exceeding 1°C/100 years). Southeastern Serbia exhibits the lowest trend (about 0°C/100 years).

The overall average observed precipitation change in Serbia is slightly negative. A distinct upward trend exists in the (south)western part of the country 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 the summer and early autumn are in conflict with the observed trends. The greatest increasing monthly precipitation trend has been recorded in August and September.

The direction of annual river discharge changes in Serbia is generally in accordance with the forecasts based on the IPCC scenario A1B [10], and the observed temperature and precipitation trends [5,6,9,13].

The recorded average river discharge trends are decreasing by about 30%/100 years, and depend on a large number of factors. Climate change 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, but is often less significant or even minor elsewhere, especially where human impact is substantial. Based on precipitation trend distributions, the greatest negative trend changes were noted in eastern Serbia.

Table 3
Registered 1949–2006 hydrologic trends by month and annual average (%/100 years)

River – Hydrologic station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver
1	Ibar – Raška	7.4	–54.0	–41.0	–44.9	–87.5	–46.6	–3.9	52.4	67.4	–42.8	–82.5	–94.1	*–44.2*
2	Lim – Prijepolje	–17.0	–75.8	–7.8	14.5	–24.2	–55.9	–97.1	–60.1	–6.4	–20.6	–59.7	–66.5	*–33.5*
3	Moravica – Arilje	47.7	–1.7	37.4	37.6	–94.6	0.7	–59.8	–10.6	35.1	30.0	–26.1	9.7	*–0.1*
4	Studenica – Devići	2.1	–84.2	8.6	59.3	6.5	12.3	–17.9	–6.3	13.0	–28.1	–33.4	–54.1	*–1.8*
5	Drina – B. Bašta	–4.8	–29.3	–16.6	–31	–51.3	–57.7	–44.4	–14.1	12.4	14.2	–48.4	–56	*–32.5*
6	V. Morava – Varvarin	–15.4	–64.1	–28.8	–19.3	–67	–22.7	–16.6	21	25	–4.9	–51	–55.2	*–33.0*
7	Z. Morava – Jasika	–58	–83.4	–49	–25	–62.8	–34.6	–43.9	18.6	–34.9	–23.6	–83.9	–81.9	*–51.7*
8	J. Morava – Aleksinac	10	–44.8	2.4	5	–67.2	–19.6	–12	15.5	51.1	–0.5	–40.9	–30.5	*–16.0*
9	Nišava – Niš	–73.7	–86.4	–56.5	–57.1	–80.6	–48.9	–84.2	–1.1	–30.4	6	–76.6	–97.3	*–64.3*
10	Lugomir – Majur	4.2	–26.3	–24.9	–63.1	–78.6	–30.7	110	55.7	35.8	–56.5	–115	–69.0	*–33.8*
11	Timok – Tamnič	–52	–82.4	–110	–60.5	–64.1	–22	–32.3	11.1	–20.9	–29.4	–87.5	–85.2	*–69.1*
12	Beli Timok – Knjaževac	–37.7	–72.4	–50.5	5.5	–78.9	–81	–121	–81.6	–56.5	–90.6	–117	–70.4	*–58.4*
13	Pek – Kusići	–35.2	–38.6	–10.9	–19.3	–71.8	–124	–50.6	–4.5	9.6	3.5	–122	–64.6	*–43.5*
14	Jasenica – D. Šatornja	–4.7	–26.8	–37.2	0.5	–76.6	15.3	59.1	–47.5	23.2	–8.5	–56.2	–37.3	*–20.2*
15	Veternica – Leskovac	–93.7	–96.6	–56.9	–31.4	–72.9	–38.1	–29.1	30.2	142	29.1	–96.5	–101	*–56.4*
16	Toplica – D. Selova	16.5	–56.5	14.3	22	–33.8	6.4	6.9	–23.8	–50.9	–119	–76.5	–86.7	*–22.9*
17	Crnica – Paraćin	52.7	–12.7	14	–24.1	–37.9	–16.8	–29.3	–110	20.3	–21.1	–73	–20.6	*–16.1*
18	Jadar – Zavlaka	35.3	–52.4	24.1	–126	–213	10.1	–16.0	21.4	100	–35.6	–129	–157	*–63.4*
Average of 18 stations		*–12.0*	*–54.9*	*–21.6*	*–19.8*	*–69.8*	*–30.7*	*–26.8*	*–7.4*	*18.6*	*–22.1*	*–76.4*	*–67.7*	*–36.7*
KS Mlava – Žagubica[a]		–31.4	–79.4	32.0	46.4	–26.1	–27.7	–51.7	–14.4	–8.0	–20.2	–86.8	–77.8	–28.8

[a]Karst spring, source of the Mlava River.

Temperature deviation category (°C)	Relative discharge (average)	Relative precipitation (average)	Temperature difference (average)	Number of data points (years)
$\Delta T_{av} < -1.0$°C	1.27	1.09	-1.22	74
$-1.0 < \Delta T_{av} < -0.5$	1.11	1.05	-0.72	148
$-0.5 < \Delta T_{av} < 0.0$	1.04	1.00	-0.24	327
All data for 18 C.A.	1.00	1.00	0.00	1044
$0.0 < \Delta T_{av} < 0.5$	0.96	1.00	0.22	278
$0.5 < \Delta T_{av} < 1.0$	0.90	0.99	0.70	123
$1.0°C < \Delta T_{av}$	0.72	0.88	1.36	94

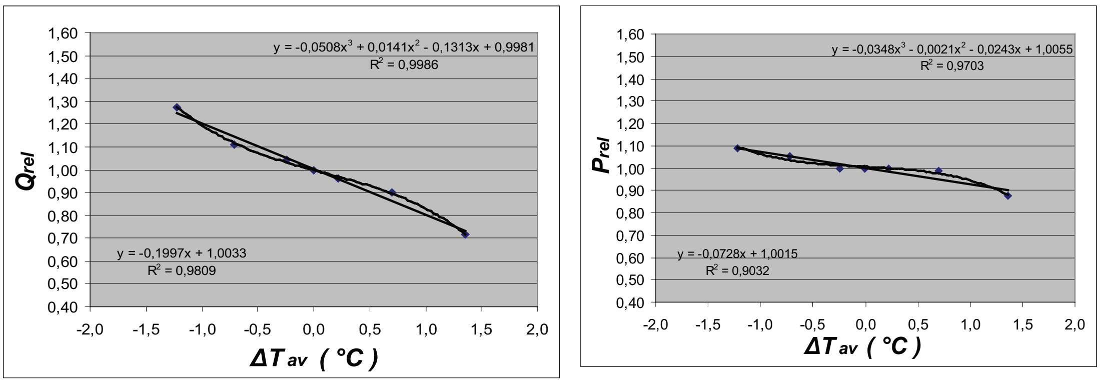

Fig. 4. Average annual river discharge and precipitation, relative to the average, as a function of temperature deviation (all 18 CAs).

In general, during low-discharge months, a considerably lower river discharge trend was noted, as a result of an upward precipitation 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 negative trend will not appear during this period if the temperature continues to rise (especially if the mean annual temperature would be 2°C higher, or more, than the average of the past 60 years, or so), particularly at stations where there are no upstream river reservoirs.

Table 4
Average relative river discharge and precipitation levels based on linear and 3rd degree polynomial trends for different increases in average annual temperatures

	ΔT_{av} (°C) →	0.5	1.0	1.5	2.0
Relative river discharge (Q_{rel})	Linear trend	0.90	0.80	0.70	0.60
	3rd degree polynomial trend	0.93	0.83	0.66	0.39
Relative precipitation (P_{rel})	Linear trend	0.97	0.93	0.89	0.86
	3rd degree polynomial trend	0.99	0.94	0.85	0.67

It should be kept in mind that the above hydrologic results are given in terms of averages, while the river discharge trends for specific catchments can differ significantly, both up and down, due to differences in human activities.

If the average annual temperature were to increase by 2°C, based on the correlations established to date between average annual river discharges and average annual temperatures, one could expect, on average, approximately half the amount of water in rivers whose catchments largely lie within Serbia. It is worth using described methodology and trying to find appropriate RCMs for a certain region.

Who could benefit from the outcomes of this research? Apart from Serbia, it is believed that the presented results will be of interest to the entire region of South East Europe. Further, the results indicate that an in-depth study of all observed data (above all temperature, precipitation and hydrologic data) should be undertaken before a regional model is produced. Ultimately, the proposed methodology for the assessment of average temperature impact on average river discharge and precipitation 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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