



Impact of Different Factors on Changes in Water Resources Availability

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Abstract

When considering trends in hydrological changes (HC) for one region, two questions arise: (1) Are they simply variations of one parameter (coincidence), or have they been initiated with certain causes; and (2) If they are not random, how do various significant environmental changes impact these trends, and how do they vary across the region. The most important environmental changes which could impact HC are changes in Temperature (T), Precipitation (P), Forest Cover (FC) and Human Use of water (HU). This paper sheds light on these questions for central Serbia (CS) based on a series (analyzed period 1949–2023) for 24 hydrological stations in CS, and 26 T stations and 38 P stations across the whole of Serbia. Estimation of FC changes and changes in HU are based on the available data for three larger regions, which cover the whole of central Serbia (western, central and eastern part). The results indicate that temperature is generally the most significant factor for the observed decrease in HC in central and especially eastern CS (impact slightly greater than 50%), while in the western part of CS, P and T the impacts on HC are about the same (both slightly lower than 50%). Other environmental changes (ΔFC and ΔHU) generally exhibit a lower impact. The methodology offered for evaluating the impact of different factors on HC could also be applied to the other parts of the world where decreasing HC is observed. After presenting the methodology and results, the paper discusses the confidence of the results and cites some results from different Mediterranean and other countries/regions.

Keywords Hydrological Changes · Forest Cover · Precipitation · Temperature · River Flow

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1 Introduction

1.1 Used Abbreviations and Remarks

Here is the list of repeatedly used abbreviations:

Δ	Change;	T	Temperature;	P	Precipitation;
FC	Forest Cover	HU	Human Use of Water;	RF	River Flow
CC	Climate change;	CS	Central Serbia;	HC	Hydrological change
W	West;	C	Central;	E	East
HS	Hydrological station;	TS	Temperature Station;	PS	Precipitation station;
LT	Linear trend;	IF	Input Factor	MLV	Most Likely Value;

Remarks:

- 1) Both words “influence” and “impact” are used in the paper, and they have the same meaning.
- 2) Possible periodicity in RF is not analyzed in the paper (Simić et al. 2017), only the changes which could be considered as a trend. Trend analysis here comprises of analysis of LT.
- 3) The annual changes in River Flow are analyzed, and further the term River Flow change (ΔRF) is used instead of Hydrological change.
- 4) The paper only analyzes changes on an annual basis during the 1949-2023 period.
- 5) Some literature (CC-Waters, (2009)–(2012)) instead of talking about Forest Cover, the term Land Cover or Land Use is applied. The term Land Cover has a wider sense, but in this paper Forest Cover is used and analyzed for two reasons: these changes are dominant on ΔRF inside the changes related to Land Cover and ΔFC have been recorded throughout several periods in the past in Serbia, which allow for the required analysis.

1.2 General Consideration

River flow changes are present in many parts of the world (Tanarhte et al. 2024; Ma et al. 2008; Barajas 2007; Bashabseh and Alzboon 2024). In some areas they are negligible and could be declared as a nature variation, while in other areas they are significant and caused by certain environmental factors.

Important environmental changes which could impact ΔRF in certain regions are Climate changes – Temperature (T) and Precipitation (P) above all, changes in Forest Cover - FC (% of forest), and changes in Human Use of water – HU (types and quantities). These four factors are called Input Factor(s) – IF(s), and together with RF will be called variables. All four types of IF changes being considered are present throughout the world, only the intensity of the changes and the means of manifestation differ. While environmental changes, as we have grouped them (ΔT , ΔP , ΔFC , ΔHU) can be quantified, more or less successfully, it is a much more difficult task to assess how all of them together affect water resources, and especially each of them individually.

Therefore, we attempt to identify a function using the following:

$$\Delta RF = f(IFs) = f(\Delta T, \Delta P, \Delta FC, \Delta HU)$$

The majority of rivers in CS have exhibited a decreasing trend in the last 75 years. The downward trend for many of them is significant. Environmental changes (ΔT , ΔP , ΔFC , ΔHU) in the same period and their impact on ΔRF in central Serbia have been analyzed in the paper using a new methodology, which attempt to mathematically determine the level of influence for each of them. Rivers with heavy human impact and significant redistribution of water between the catchments have been excluded from the analysis from the start.

Mathematical determination of each of the 4 input factors impacting RF is important, because it could be helpful/instructive for decision-makers when adopting which measures should have priority in the adaptation against climate or/and environmental changes in their countries/regions.

The influences of various factors on an annual basis for central Serbia are sought, which is considered utilizing data on changes in the western, central and eastern parts (Fig. 1). It has been determined that on average for the whole CS, ΔT has had the greatest impact on ΔRF , followed by ΔP , and a sum of ΔFC and ΔHU have had the least impact (after excluding rivers with heavy human activities).

1.3 The Goals of the Current Study

The goals of this paper are:

- 1) To show that the increasing temperature trend in Serbia and decreasing trend in domicile rivers of central Serbia are not random.
- 2) To approximately estimate the level of significance of different IFs on observed decreasing RF into three parts of CS.

2 Study Area and Data Sources

The territory of Serbia has a continental climate in the lowland and in the entire northern part, characterized by warm summers and relatively cold winters, while most parts of Central Serbia (CS) have a temperate continental climate. The southwestern part of CS is located on the border of the Mediterranean climate zone and the continental climate zone. CS, above altitudes of 800 m.a.s.l. is characterized by the mountain climate. Serbia covers an area of about 88.000 km², of which Central Serbia covers app. 56.000 km². Available data for 24 HS in CS (more HS have been selected, but several of them have been excluded from the start due to extremely high artificial/human impact), and 26 T and 38 P stations (RHSS, H-books, 1949–2023; RHSS, M-books, 1949–2023) across entire Serbia are included in the analyses for the 75-year period.

For analysis in this paper, the CS is split into three parts: western, central and eastern (Fig. 1). The reasons are changes in analyzed factors that differ in three parts, which is discussed later. Designations of the three types of stations (H, T, P) correspond to Table 1, which presents the average values and recorded linear trend for 1949–2023 for each of them.

The same table shows data and the graph of changes in percent of forest in central Serbia, in the analyzed 1949–2023 period (Stojanović et al. 2015; PC Serbia-forest 2024); Statistical department of RS, (2024)). Some of the points on this graph were calculated based on

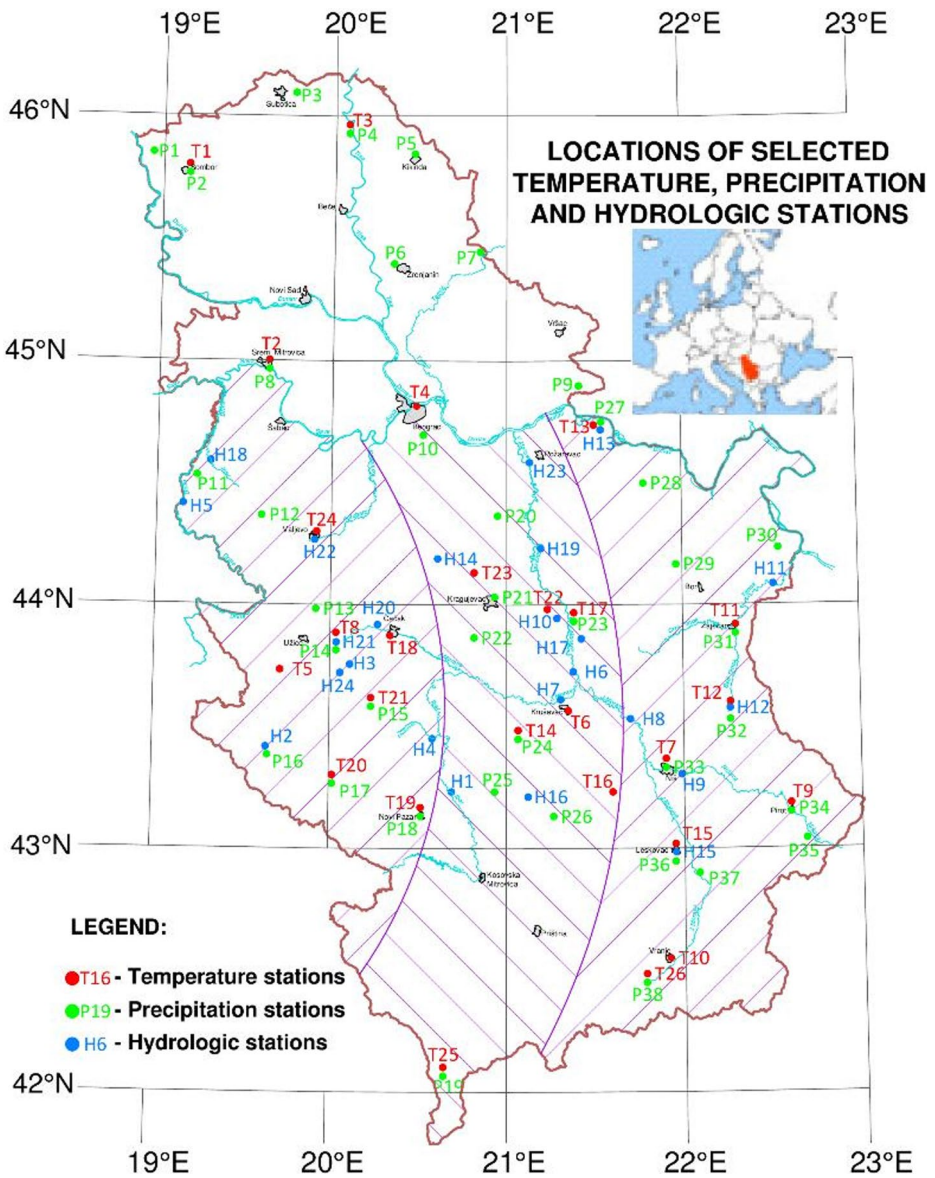


Fig. 1 Analyzed HS, TS and PS and three considered parts of CS (western, central and eastern)

Table 1 Analyzed HS, TS and PS with average values and recorded linear trend, and data and graph of forest cover in central serbia, all for the 1949–2023 period

Hydrological data			Temperature data			Precipitation data		
River – Hydrological station	Q _{aver.} m ³ /s	Trend %/10 y	Temperature station	T _{average} °C	Trend °C/10 y	Precipitation station	P _{average} mm/y	Trend %/10 y
H1 Ibar – Raška	40.2	-2.5	T1 Sombor	11.2	0.27	P1 Bezdán	612	1.3
H2 Lim - Prijepolje	76.5	-2.4	T2 Sr. Mitrovica	11.4	0.27	P2 Sombor	605	1.4
H3 Moravica - Arilje	10.7	0.5	T3 Senta	11.7	0.29	P3 Palić	561	1.6
H4 Studenica - Ušće	7.15	0.6	T4 Beograd	12.6	0.29	P4 Senta	587	1.2
H5 Drina - Radalj	361	-2.2	T5 Zlatibor	7.8	0.25	P5 Kikinda	559	0.8
H6 V.Morava- Varvarin	203	-2.6	T6 Kruševac	11.4	0.21	P6 Zrenjanin	579	1.1
H7 Z.Morava- Jasika	105	-1.1	T7 Niš	12.0	0.20	P7 Jaša Tomić	633	1.1
H8 J.Morava- Aleksinac	87.5	-2.7	T8 Požega	9.7	0.23	P8 Sr. Mitrovica	624	0.6
H9 Nišava- Niš	28.4	-4.0	T9 Pirot	11.3	0.22	P9 Bela Crkva	668	0.6
H10 Lugomir- Majur	1.74	-3.6	T10 Vranje	11.3	0.17	P10 Jajinci	689	0.7
H11 Timok - Tamnič	26.8	-4.5	T11 Zaječar	10.9	0.20	P11 Loznica	848	1.4
H12 B.Timok -Knjaževac	7.77	-4.8	T12 Knjaževac	11.0	0.22	P12 Osečina	908	1.4
H13 Pek - Kusići	8.69	-3.5	T13 Vel. Gradište	11.5	0.23	P13 Kosjerić	782	1.0
H14 Jasenica – D.Šatornja	0.60	-4.8	T14 Aleksandrovac	11.2	0.21	P14 Požega	742	1.0
H15 Veternica- Leskovac	3.94	-4.7	T15 Leskovac	11.3	0.17	P15 Ivanjica	896	1.3
H16 Toplica- D.Selova	3.45	-1.7	T16 Prokuplje	11.2	0.18	P16 Prijepolje	816	1.7
H17 Crnica- Paraćin	3.39	-0.7	T17 Čuprija	11.3	0.22	P17 Sjenica	746	2.0
H18 Jadar- Lešnica	8.15	-4.0	T18 Čačak	11.0	0.23	P18 Novi Pazar	636	1.4
H19 Resava- Svilajnac	4.65	-0.5	T19 Novi Pazar	9.6	0.27	P19 Dragaš	814	1.3
H20 Kamenica- Prijevor	2.02	-1.9	T20 Sjenica	6.7	0.24	P20 Smed. Palanka	654	1.2
H21 Skrapež -Požega	4.88	-2.9	T21 Ivanjica	9.9	0.22	P21 Kragujevac	641	1.0
H22 Kolubara -Valjevo	3.66	-2.8	T22 Jagodina	11.9	0.22	P22 Rekovac	644	0.9
H23 V.Morava–Lj.Most	234	-1.1	T23 Čumić	11.7	0.24	P23 Čuprija	669	1.0
H24 V.Rzav – Radobuda	6.08	-0.5	T24 Valjevo	11.5	0.26	P24 Aleksandrovac	606	1.0
			T25 Dragaš	8.6	0.16	P25 Blaževo	835	1.1
			T26 Bujanovac	12.0	0.17	P26 Kuršumlja	664	1.2
Changes in Forest Cover in whole and in central Serbia (1949-2023)								
%	1949	1963	1979	2000	2009	2017	2023	
whole Serbia	21	23	24	29	30	32	39	
Central Serbia	28	30	32	37	39	41	48	

P27 Vel. Gradište	677	0.5
P28 Voluja	691	0.4
P29 Crni Vrh	791	0.6
P30 Negotin	654	0.1
P31 Zaječar	621	0.6
P32 Knjaževac	614	0.7
P33 Niš	600	1.1
P34 Pirot	595	0.3
P35 Krupac	615	0.4
P36 Leskovac	635	1.3
P37 Vranje	615	0.4
P38 Bujanovac	629	0.4

the Forest Cover for the whole of Serbia and taking into consideration that north part of the country has consistently had a low level of Forest Cover (6÷8%).

3 Methodology

3.1 Increasing Temperature Trend in Serbia and Hydrologically Decreasing Trend in Domicile Rivers of Central Serbia Are not Random

Each series must have a linear trend, positive or negative (in exceptional cases it can be zero – a horizontal line). The question arises as to which LT appears as random (due to the natural variability of an analyzed parameter), and which cannot possibly be random (has important

significance). The methodology is reflected in the starting supposition that certain trends are random, and after calculating the probability of occurrence where the same or steeper trend is recorded, proves that they could not be random.

If we do not have a physical explanation for a phenomenon, then perhaps it would sometimes make sense to consider even probabilities of 1:1,000,000 in the realm of chance. If we have a physical explanation for a given phenomenon, especially if it is relatively clear, then even probabilities of 1:10 are ‘suspicious’, while all probabilities over 1:100, and certainly those over 1:1000, do not make much (any) sense to consider in the realm of chance.

If a trend was a random variable, then it also means that the distribution of values within a given data set is random. So, we need to calculate the probability of achieving such a distribution of mean annual temperatures that for a given time series have achieved a realized trend or steeper. The exact value of the required probability is the number of permutations in which a given series has a trend equal to or steeper than the one achieved, divided by the total possible number of permutations without repetition ($N_{\text{perm.}} = n!$), where in this case n is the number of years of the given series. Since the number of permutations $n!$ grows very quickly, the problem is solved by the method of a sufficiently large sample size that yields reliable results (certainly two significant numbers). This methodology is applying for the T changes in the case of TS Belgrade. The values of the achieved LT for a different series of years and the corresponding probabilities of the occurrence of a trend with a greater slope than the achieved one are given in Sect. 5.1.

Regarding Hydrological changes, in addition to the possibility of applying the same methodology as for T (not covered in this paper), a common method in hydrology is implemented and presented for all HSs. The Mann-Kendall test is a standard and frequently used test. This test is non-parametric and is based on ranking the trend in a time series. Depending on the adopted significance threshold (commonly $\alpha = 0.05$), it is concluded whether a trend exists in the time series or not. In addition to already calculated LT (Table 1), for each of 24 HS the p-value is calculated. HSs are split into 3 classes:

- a. (A) With significant trend – comprise p-value < 0.05 and $|LT| > 1.5\%/10$ years.
- b. (B) With debatable trend – comprise p-value > 0.05 and $|LT| > 1.5\%/10$ years.
- c. (C) With no - significant trend – comprise p-value > 0.05 and $|LT| < 1.5\%/10$ years.

3.2 The Estimation of the Level of Significance of Different IFs on Observed Decreasing RF into Three Parts of CS

The flowchart (methodology) applied for this goal consists of several steps:

Step 1° In the 1° step, it is necessary to determine the changes (LT) of the analyzed variables (RF and four IFs) for the analyzed area (in this case central Serbia).

Step 2 In the 2° step, based on data, characteristic regions are determined - regions inside the analyzed area which have significant differences in LT of the variables.

Step 3 Based on the results of previous steps, it is determined the most likely value (MLV) of the trend change for each of the variables and within which borders they can occur.

Step 4 In the 4° step, 3 equations for RF average LTs as a function of IFs average LTs are set – 3 parts of CS with 3 unknown weight coefficients (which should be calculated).

Step 5 In the 5^o step, the MLVs for weight coefficients are obtained, using in the equation the MLVs of IFs defined in step 3^o.

Step 6 And in the 6^o step, IFs have been varied under the defined borders, to see within what limits their influence on the RF of the analyzed area are possible.

For step 1^o, the methodology is given in this Chap. (3.2), and for step 2^o characteristic regions are already noted in Sect. 3 with the aim of enabling the reader to follow the subject of the paper with greater ease. For the other steps, the methodology is practically contained in the description (title) of the step, and depends on the results of the previous steps; therefore explanations (including results) are given in the Results Chap. (4.2).

Step 1^o - Determining changes (LT) of the analyzed variables (RF and four IFs) for the analyzed area.

For all T (26), P (38) and H (24) stations LT is calculated for the period 1949–2023 (Table 1).

3.2.1 Changes in Climate Variables (T and P)

The T and P trend charts (Fig. 3) were generated using software Surfer, after removing the stochastic component in data by regional averaging (Dimkić, 2016). This approach provides a better spatial picture of trend changes in the frame of available data.

3.2.2 Changes in River Flow

It is more difficult to spatially generalize RF trends (in comparison with T and P trend's mapping) because several factors affect these trends. For the adopted 24 HS in this study the same method was applied as for T and P, except that regional averaging was not made (cannot be acceptable due to nature of data) – Fig. 3.

3.2.3 Changes in Forest Cover and changes in Human Use of water

FC has changed throughout history. Table 1 shows that following WWII FC throughout the whole of Serbia was about 20%, in 1979 about 24 ÷ 25%, in the first decade of XXI century 29 ÷ 30%, in 2017-year 32 ÷ 33%, and in 2023 between 37 and 40%. At the same, time central Serbia exhibits 7–9% greater FC than the average of the whole of Serbia (Table 1). Inside the CS, the greatest increase up to 1990 was in E part. Between 1990 and 2013, forests have increased in the W and a slightly less in the E part of CS (Stojanović et al. 2015). During that entire period (up to 2013) forests in the central part of CS have increased about 1.5 times less than on the W and E parts of CS. During the last ten years forests have increased significantly in all three parts (more significantly in the W and E parts compared to the central part of CS).

HU changes and its impact are probably the most difficult to assess. Previous research (Dimkić 2019) indicates that its impact is particularly large in cases of water transfer from one basin to another. Cities that capture water from one river and then deliver it to another after use (especially if the rivers are small and the cities have a larger population) create a significant negative trend on the first rivers, and mitigate the negative trend on the second,

which often turns positive. For these reasons, all such HS were excluded from the analysis. The impact of HU changes can also be considerable on some small rivers with significant human activities (due to water capture for supplying certain industries or irrigation, or filling of reservoirs). On medium and larger domicile rivers, the impact of this factor is significantly smaller (in the order of $0.1 \div 0.4\%/10$ years), which could grow in the future. It is certain that the influence of the HU factor is greater in the western and especially central part of central Serbia compared to the eastern part, and that it is still significantly smaller than the influence of the FC factor, which is taken into account in the analyses in the Results section.

4 Results

4.1 Increasing Temperature Trend in Serbia and Decreasing Trend in Domicile Rivers of Central Serbia Are not Random

Figure 2 shows the average annual T in Belgrade from the time they were measured (1888) to 2023 – 136 years. The blue line represents recorded data, while the other two lines are the same 136 T data, in strictly decreasing order (orange line) and in strictly increasing order (green line).

The recorded LT is not far from the maximum possible trend. Applying methodology described in part 3.1, the recorded, minimum, and maximum trend for TS Belgrade for different lengths of T series, and the recorded probability of occurrence of the same or steeper trends are as follows:

	Period and number of years in series (the last one is always 2023)								
N_{ser} (No. of years)	136	120	100	80	60	40	30	20	10
Period	1888–2023	1904–2023	1924–2023	1944–2023	1964–2023	1984–2023	1994–2023	2004–2023	2014–2023
Recorded trend ($^{\circ}\text{C}/10$ yrs)	0.19	0.20	0.23	0.29	0.50	0.74	0.79	1.05	0.97

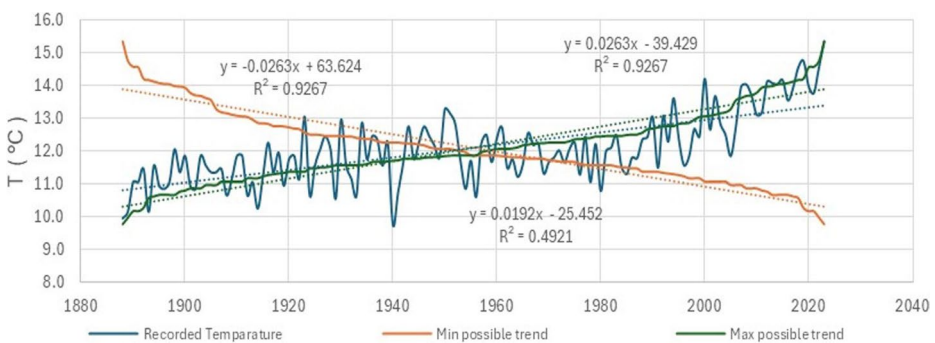


Fig. 2 Recorded average annual T in Belgrade (1888–2023), with the same data in strictly decreasing order (orange line) and in strictly increasing order (green line)

	Period and number of years in series (the last one is always 2023)								
Minimum trend (°C/10 yrs)	-0.26	-0.29	-0.35	-0.43	-0.61	-0.89	-1.04	-1.29	-1.71
Maximum trend (°C/10 yrs)	+0.26	+0.29	+0.35	+0.43	+0.61	+0.89	+1.04	+1.29	+1.71
Probability that trend is the same (as recorded) or steeper	$P < 1:10^9$	$P < 1:10^9$	$P < 1:10^9$	$P < 1:10^9$	$P < 1:10^6$	$P < 1:10^6$	$P < 1:10^6$	$P < 1:10^6$	$P < 1:500$

A smaller series, up to the order of 10–15 years, can only be considered as “random”. For all series of 20 years and more, the probabilities of the recorded LT ($P < 1:10^6$) exclude any coincidence. The probability for longer series (80 years and more), if we wanted to determine it precisely, would quite certainly be (much) smaller than $1:10^9$. The same conclusion would be drawn for any other T-series in Serbia.

Using the same procedure, it is observed that the trend of decreasing flow in many Serbian rivers can hardly be classified as random (regardless of the recorded HS trends that do not have such extremely low probabilities, as is the case with increasing T). The results are not presented here, but rather a common method in hydrology is implemented and presented for HSs - the Mann-Kendall test, which points to a similar conclusion (Table 2).

4.2 The Approximate Level of Significance of Different IFs on Observed Decreasing RF into Three Parts of CS

Step 1° Determining changes (trends) for analyzed factors.

Changes in climate variables (T and P).

Obtained T and P trend charts for the whole of Serbia on an annual level are shown on Fig. 3.

4.2.1 Changes in River Flow

An approximate distribution of the downward average annual RF trends for central Serbia (1949–2023) is shown on Fig. 3. It should be underlined again that within all RF trend isolines there are HS that exhibit significant trend variations (both up and down), because of the HU factor, and especially if water is transferred upstream from a given HS (as noted, these rivers/HS have been excluded prior to the start of the analysis). It can be observed that the greatest RF decreases have been recorded in the South-East of CS. These RF changes are supported with the observed changes at Struma River in the South-West of Bulgaria (Niagolov et al. 2012).

Table 2 Results of the Mann-Kendall test for 24 HS (divided into classes according to criteria in part 3.1)

A. HS with significant trend				B. HS with debatable trend				C. HS with no significant trend			
River – Hydrolo-gical station	trend %/10 yrs	p-value (-)	signif. yes/no*	River – Hydrolo-gical station	trend %/10 yrs	p-value (-)	signif. yes/no*	River – Hydrolo-gical station	trend %/10 yrs	p-value (-)	signif. yes/no*
H9 Nišava-Niš	-4.0	0.019	yes	H2 Lim - Prijepolje	-2.4	0.057	?	H4 Studenica-Ušće	0.6	0.184	no
H14 Jasenica-D.Šatornja	-4.8	0.019	yes	H8 J.Morava-Aleksinac	-2.7	0.167	?	H23 V.Morava-Lj.Most	-1.1	0.525	no
H12 B.Timok-Knjaževac	-4.8	0.020	yes	H6 V.Morava-Varvarin	-2.6	0.191	?	H3 Moravica-Arilje	0.5	0.534	no
H13 Pek - Kusići	-3.5	0.025	yes	H1 Ibar – Raška	-2.5	0.220	?	H7 Z.Morava-Jasika	-1.1	0.677	no
H22 Kolubara-Valjevo	-2.8	0.036	yes	H10 Lugomir- Majur	-3.6	0.268	?	H17 Crnica-Paraćin	-0.7	0.833	no
H18 Jadar-Lešnica	-4.0	0.044	yes	H21 Skrapež-Požega	-2.9	0.332	?	H24 V.Rzav-Radobuda	-0.5	0.931	no
H15 Věternica-Leskovac	-4.7	0.044	yes	H20 Kamenica-Prijedor	-1.9	0.339	?	H19 Resava-Svilajnac	-0.5	0.945	no
H11 Timok-Tamnič	-4.5	0.047	yes	H16 Toplica-D.Selova	-1.7	0.942	?				
H5 Drina-Radalj	-2.2	0.050	yes								

* yes – hydrological trend is significant; ? – hydrological trend is debatable; no – hydrological trend is no significant

4.2.2 Changes in Forest Cover and changes in Human Use of water

Figure 4 shows the state of FC in Serbia in 2017. The picture on the left shows distribution of different types of forests obtained by satellite images at 10×10 m, and the picture on the right shows the percent of land area covered by forests in municipality. The picture inside Table 1 shows an average increase of about 2.3%/10yrs in land area covered by forests in CS during the 1949–2023 period.

Step 2° Determination of the characteristic regions in CS.

As noted in Sect. 3, for the purpose of the analysis in this study, CS is split on western, central and eastern part. The approximate borders of these three parts are shown in Fig. 1. The main reason for this separation is the observed change in trend - especially P and RF (Fig. 3).

Step 3° Based on the results of previous analyses, determination of the most likely values of the trend changes and within what borders they can occur, for each of the variables.

The MLVs of the trend changes for T, P and RF were obtained using interpolation of the iso-lines on Fig. 3 inside each of the three parts of CS. With respect to the given data in 3.2, and Fig. 4, the estimation of the FC for three regions was made and similarly was done for HU factor. The MLVs and the extreme borders inside which could vary, are shown in Table 3.

Step 4° Setting the equations for RF average changes as a function of average IF changes.

An attempt is made to give the dependence of RF changes from average changes (LT) in FC, HU, P and T, through a function of the form:

$$\Delta RF = a_1 \cdot \Delta FC + a_2 \Delta HU + a_3 \cdot \Delta P + a_4 \cdot \Delta T \quad (1)$$

where a_1 , a_2 , a_3 and a_4 are the weighting coefficients required.

Equations with average values of trend changes can be established for three parts of the country which are the western, central and eastern, and we have four coefficients. Therefore, the effects of FC and HU are grouped, and we get the form of the equation:

$$\Delta RF = a_1 \cdot (\Delta FC + \Delta HU) + a_2 \cdot \Delta p + a_3 \cdot \Delta t \quad (2)$$

a_1 , a_2 and a_3 are required.

Step 5° Determining the weight coefficients, based on the MLV of IFs defined in step 3° and obtained influence.

Equations for three parts of CS, based on the MLV of IFs defined in step 3°:

$$\text{Western part of CS} : -1.60 = a_1 \cdot (-2.4 - 0.3) + a_2 \cdot 1.30 + a_3 \cdot (-0.240) \quad (3)$$

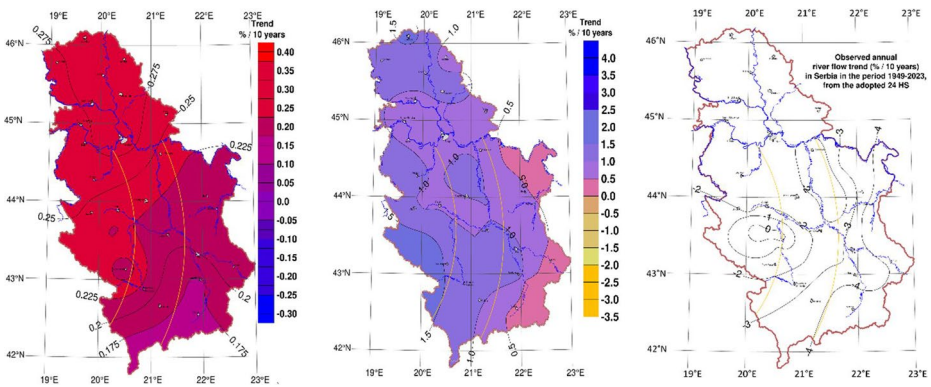


Fig. 3 Annual level of ΔT (°C/10y) and ΔP (%/10y) charts for Serbia (1949–2023), and isolines of $\Delta R F$ in CS (%/10y)

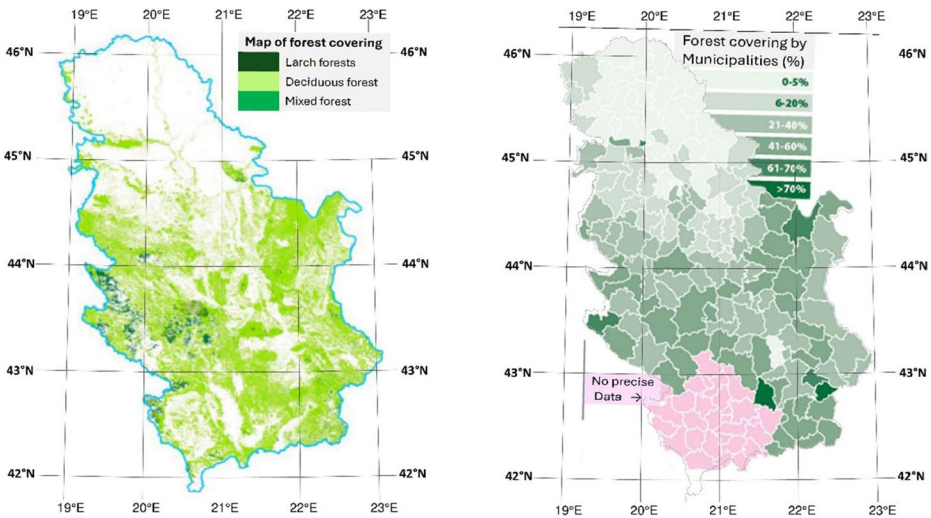


Fig. 4 Forests Cover in 2017

Table 3 The MLVs of trends for variables and their approximately extreme border’s values

Variable	Western part of CS			Central part of CS			Eastern part of CS		
	MLV	min	max	MLV	min	max	MLV	min	max
$\Delta R F$ (%/10 years)	-1.60	-1.45	-1.75	-2.40	-2.25	-2.55	-4.00	-3.8	-4.2
ΔT (°C/10 years)	-0.240	-0.225	-0.255	-0.220	-0.205	-0.235	-0.200	-0.185	-0.215
ΔP (%/10 years)	1.30	1.15	1.45	0.95	0.80	1.10	0.60	0.45	0.75
$\Delta F C$ (%/10 years)	-2.4	-1.8	-3.1	-1.6	-1.2	-2.0	-2.9	-2.5	-3.3
$\Delta H U$ (%/10 years)	-0.3	-0.2	-0.4	-0.4	-0.3	-0.5	-0.1	0.0	-0.2

$$\text{Central part of CS} : -2.40 = a_1 \cdot (-1.6 - 0.4) + a_2 \cdot 0.95 + a_3 \cdot (-0.220) \quad (4)$$

$$\text{Eastern part of CS} : -4.00 = a_1 \cdot (-2.9 - 0.1) + a_2 \cdot 0.60 + a_3 \cdot (-0.200) \quad (5)$$

Solving these equations gives:

$a_1=0.5$; $a_2=4.8$; $a_3=27.3$; By substitution in Eqs. (3, 4 and 5), we get:

$$\text{Western part of CS} : -1.60 = -1.27 + 6.22 - 6.55 \quad (6)$$

$$\text{Central part of C} : -2.40 = -0.94 + 4.55 - 6.01 \quad (7)$$

$$\text{Eastern part of CS} : -4.00 = -1.41 + 2.87 - 5.46 \quad (8)$$

The right side of the equations represents the total influence (100%), therefore the percent of their absolute values represent the influence of each factor for that part of CS (regardless of changes in (FC+HU) and T are in opposite correlation with changes in RF, and changes in P are in positive correlation with changes in RF). So, we get:

Part of CS	Total influence (%)		$\Delta(\text{FC+HU})$ influence (%)		ΔP influence (%)		ΔT influence (%)
Western part:	100	=	9	+	44	+	47
Central part:	100	=	8	+	40	+	52
Eastern part:	100	=	14	+	29	+	56

Forexample, ΔT influence in the Western part: $| -6.55 | \cdot 100\% / (| -1.27 | + | 6.22 | + | -6.55 |) = 47\%$

It should be noted that these percentages of total influence refer to each of the parts of CS and are not fully comparable between the different parts of CS. By example, ΔT influence is (absolutely) greater in the W part, compared to C and E, but due to the influence of other IFs are significant in the W part, the relative contribution of the ΔT influence is lower.

Step 6° Variation of variables with the aim of determining the limits of IFs influence on the RF.

Due to the subject of the analysis (determination of different factors' influence on RF changes) is on "slippery terrain", the methodology is to some extent rough, so the variables must be varied in the aim to determine the limits of IFs' influence on the ΔRF .

The borders of (FC+HU) changes are wider compared to other variables' changes (Table 3); so the following was done: Seven different cases of ($\Delta FC + \Delta HU$) are adopted (in the frame of borders defined in Table 3), and for each of them the MLVs for ΔRF , ΔP and ΔT are applied, and additionally all eight combinations of min and max values for ΔRF , ΔP and ΔT (min-min-min; min-min-max; min-max-min; ...; max-max-max) are defined in the same Table 3. For all cases the impact of IFs (in %) are calculated. Table 4 shows (in %) the MLVs for all 7 cases in addition to the minimum and maximum impacts obtained from 8 analyzed min-max combinations for each of the IFs and for all three parts of CS. The shad-

Table 4 The MLVs and min and max impacts for each of the IFs on ΔRf for all cases and for all three parts of CS $\Delta(FC+HU)$ in (W-C-E) parts (%/10y) \rightarrow

Input factor (IF)	Part of CS	Case 1 (2.0-1.5-2.5)			Case 2 (3.0-1.5-3.0)			Case 3 (3.0-2.0-3.0)			Case 4 (3.0-2.5-3.0)		
		MLV	min	max	MLV	min	max	MLV	min	max	MLV	min	max
$\Delta(FC+\Delta HU)$	Western part	8	6	10	5	4	6	8	7	10	17	14	21
	Central part	7	6	9	3	3	4	7	5	8	18	14	22
	Eastern part	14	11	17	8	6	10	12	9	15	25	20	31
	Western part	44	43	45	45	43	46	45	43	46	44	43	45
	Central part	39	37	41	40	38	42	40	38	42	39	37	41
ΔP	Eastern part	29	24	33	31	26	34	30	26	34	29	24	33
	Western part	48	48	48	50	50	50	47	47	48	38	36	40
	Central part	54	53	54	56	55	58	53	53	54	43	41	44
	Eastern part	57	56	59	62	59	64	58	56	60	46	45	47
	Average MLV (cases 1 ÷ 7) and extreme borders	Case 5 (3.5-2.5-3.5)			Case 6 (3.0-2.2-3.3)			Case 7 (2.8-2.2-2.9)			Average MLV (cases 1 ÷ 7) and extreme borders		
Input factor (IF)	Part of CS	Influence of IF (%)			Influence of IF (%)			Influence of IF (%)			Influence of IF (%)		
		MLV	min	max	MLV	min	max	MLV	min	max	MLV	min	max
$\Delta(FC+\Delta HU)$	Western part	10	8	12	9	7	11	12	10	15	10	4	21
	Central part	8	7	10	8	6	10	12	9	15	9	3	22
	Eastern part	14	11	17	14	11	18	18	15	23	15	6	31
	Western part	45	43	46	44	43	46	44	43	46	44	43	46
	Central part	40	38	42	40	37	42	40	37	42	40	37	42
ΔP	Eastern part	30	25	34	30	25	34	29	25	33	30	24	34
	Western part	46	45	47	47	46	47	43	42	45	46	36	50
	Central part	52	51	52	52	52	53	49	48	49	51	41	58
	Eastern part	56	55	57	56	55	58	52	52	53	55	45	64

owed columns show the average values of MLVs for all three IFs and the absolute minimum and maximum impacts obtained from 7 cases.

5 Discussion

In general, regression analysis can sometimes give results which move us away from correct conclusions. This is particularly the case when the series is not long enough (when it is shorter than 50 or even 60 years). If we adopt 100-year trends for relevant analysis (which are rarely available), the results based on trends with series longer than 60 years do not significantly differ from the relevant values. The period of the last 75 years is quite relevant, especially if analysis is limited to the observed period and near future (next 20–25 years) and does not pretend to estimate values and relations in the distant future.

The results of this case study seem to be logical. The analysis suggests that ΔT is the most significant factor on ΔRF in CS, and that CC (ΔT and ΔP) have generally much greater impact on ΔRF than ($\Delta FC + \Delta HU$). In the W part of CS positive impact of ΔP and negative impact of ΔT on RF is about the same, so the ΔRF is in line with ($\Delta FC + \Delta HU$) impact, which is generally no uniform (could differ significantly from HS to HS from average value of the region). In the C part of CS, the absolute values of ΔP and ($\Delta FC + \Delta HU$) are much lower than in the W part (Table 3), so the relative impact of ΔT is higher – Table 4 (regardless of whether the absolute ΔT is lower than in the W part). In the E part of CS impact of ΔP further decreases and impacts of ΔT and ($\Delta FC + \Delta HU$) on ΔRF increase (Table 4). Results differ depending on the chosen period for analysis, but the 75-year period is respectable and greater differences are not expected, at least in the near future.

The proposed methodology requires careful consideration of all data. The MLVs of all 5 variables are obtained according to the recorded data during the 1949–2023 period. The values obtained for ΔT , ΔP and ΔRF in three parts of CS seem to be quite relevant. Data for the other two variables (ΔFC and ΔHU) are more difficult to determine precisely, and despite persistent efforts to estimate them as correctly as possible, the borders of these two variables in Table 3 should be and are (much) wider (in %). It seems that the values outside of the borders of all 5 variables defined in Table 3 have low probability. According to the approach described, the results presented in the previous paragraph could be stated with relative confidence.

Some authors in other countries have also considered the impact of different factors on ΔRF (or water availability changes in general), but the conclusions they made are usually based only on logical consideration (without mathematical calculations). For example, in Spain (Barajas 2007) water availability has been consistently decreased, and the authors have analyzed all four IFs. All of them have a negative impact on water availability (P has exhibited a generally decreasing trend in Spain). After considering each IF, they have concluded that temperature increase is the most important factor on water availability. The same conclusion has been made by authors from Montenegro (Burić et al. 2025). Even in Poland, increased evaporation (caused by T growing) is a dominant factor of decreasing RF (Bartczak et al. 2024). River basins in Turkey and Vietnam (Durdu 2009; Binh et al. 2025) show that CC has a significant impact on RF, but the greatest influence is related to (potential) Human Use of water (ΔHU). In central Italy (Romano et al. 2022), regardless of negligible P

changes are negligible in the long-term scale, they are very significant in episodes of several (2 to 10) years, and impact increasingly frequent and severe occurrences of droughts.

6 Conclusion

The impacts of four analyzed factors differ in central Serbia, but some general conclusions could be made:

- 1) On average for the whole of CS, ΔT has had the greatest impact on ΔRF (about 50%), followed by ΔP (about 35 ÷ 40%), and (ΔFC and ΔHU) impacts (about 10 ÷ 15%). The approximate borders of these impacts are $\pm (5 \div 7) \%$, and depend on the part of CS.
- 2) Impacts of four IFs differ in the three parts of CS (Western, Central and Eastern). In the W part of CS positive impact of ΔP and negative impact of ΔT are about the same, while in the E part ΔT impact is about two times greater than ΔP (as absolute values).
- 3) Impact of ΔFC is present in all three parts, and its significance is the most important in the E part (exhibiting the greatest increase while other IFs are not too pronounced).
- 4) After excluding HS with visibly high human impact, this factor (ΔHU) does not have significant influence on ΔRF . That is in line with the demographic decreasing trend in Serbia, while in certain countries with strong population growing, this factor is often the most important.

Climate variables are the primary driver of natural river flow, but human activities are often main contributors for significant flow alterations. Analyzed literature worldwide also suggest that ΔT is often the most important factor among the four analyzed, but each of them could be dominant in certain circumstances. In the countries/regions with population growth (examples from the Southern and Eastern Mediterranean part, or Vietnam) ΔHU seems to be the most important factor on water availability changes in the majority cases, while in countries/regions with decreasing population (North Mediterranean and greater parts of Europe) one of two CC parameter (ΔT or ΔP) is usually dominant. Quantitative analysis should be made on a case-by-case basis.

Regardless of whether this applied methodology may appear rough at first glance, it is indicative, and it provides logical results for all three parts of CS. It would be good to verify the suggested methodology in some other parts of the world, particularly where decreasing hydrological trends have been observed on a great majority of rivers within an analyzed region, and where none of the IFs is clearly dominant.

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Declarations

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