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*Quarterly Journal of the HungaroMet Hungarian Meteorological Service
Vol. 130, No. 1, January – March, 2026, pp. 1–28*

Air temperature variability during the vegetation period in Central Serbia over the last 70 years

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(Manuscript received in final form March 31, 2025)

Abstract— This study analyzes trends in three temperature variables (average annual air temperature, maximum air temperature, and minimum air temperature) for 72 time series from 24 meteorological stations in Central Serbia, spanning from 1949 to 2018. Data was sourced from meteorological yearbooks on the website of the Republic Hydrometeorological Institute of Serbia. Three statistical approaches were used: trend equation, trend magnitude, and the non-parametric Mann-Kendall (MK) trend test. GIS was applied to visualize geospatial data distribution. The results indicate a temperature increase in 66 of the 72 time series, with the largest increase of 4.3 °C and the smallest of 0.2 °C. Temperature decreases were recorded in 6 time series, with the largest decrease of -0.5 °C. The MK trend test revealed a statistically significant positive trend in 53 time series. Geospatial analysis showed varying temperatures across the region, with average annual air temperatures ranging from 10.6 °C in Dimitrovgrad to 18.1 °C in Belgrade. These findings offer insights into climate change in Central Serbia, highlighting areas of temperature increase and decrease, and provide a foundation for future climate research and strategy development.

Key-words: climate change, Serbia, average annual temperature trends, vegetation period, Mann-Kendall trend test, GIS

1. Introduction

In this study, for the first time, analyses will be presented for the average annual air temperature (YT-VP), average annual maximum air temperature (YT-VPx), and average annual minimum air temperature (YTn-VP) for the vegetation period on the territory of Central Serbia in the time interval from 1949 to 2018. Numerous works in world literature deal with climate change in a similar or almost the same way, a very popular topic having great importance at the global level. The importance of trend analysis lies in determining changes in a time series of no less than 30 years for a certain variable, which can directly affect changes in the environment (agriculture, flora and fauna, water resources, climatic conditions, ecosystems, etc.), and have an impact also on humans.

Numerous scientific studies deal with the trend analysis of various variables in different parts of our planet (*Hamlet et al.*, 2005; *Minetti et al.*, 2010; *Li et al.*, 2011; *Hua et al.*, 2013; *Zeoural et al.*, 2013; *Martinez-Austria et al.*, 2016; *O'Neil et al.*, 2017; *Kabanda*, 2018; *Birara et al.*, 2018; *Caloiero*, 2018; *Malik and Kumar*, 2020; *Mallick et al.*, 2021; *Ahmed et al.*, 2022; *Lornezhad et al.*, 2023; *Ceyhunlu and Ceribasi*, 2024;). Mann's method, which Mann himself presented in his paper "*Nonparametric Tests Against Trend*" in 1945 (*Mann*, 1945), is most often used for such researches. Also, in addition to the abovementioned studies, there are numerous reports from the United Nations (UN) organization known as the "*Intergovernmental Panel on Climate Change*" (IPCC) which is responsible for assessing scientific knowledge about climate change and whose results point to climate change (increasing average temperatures) and give recommendations to governments and international organizations on how to deal with the challenges posed by climate change (IPCC, 2022). The results from the paper by *Hajas and Zempléni* (2020), which contains an analysis of network data on daily

temperatures for the time interval from 1950 to 2017 on the European continent, indicate accelerated warming in the last 40 years, especially in the central and southwestern areas of Europe. Moreover, an increase in air temperatures has been recorded in the eastern and central parts of Europe since the 1990s, mostly in the warmer part of the year caused by the greater frequency of arrival of air masses from lower latitudes, which is a consequence of advancing global warming (Bartoszek and Kaszewski, 2020). An increase in air temperature was also recorded in Northern Europe, as temperature drops were occasionally recorded between 1940 and 1970 and between 1998 and 2013, which can be correlated with the behavior of the Pacific and Atlantic Oscillation and can be considered as climatic fluctuations within climate change (Gulev et al., 2013).

Many scientific studies deal with changes in air temperature in the region, namely in Slovenia (Milošević et al., 2013; Tošić et al., 2016), Croatia (Radilović et al., 2020), Bosnia and Herzegovina (Trbić et al., 2017; Popov et al., 2017, 2018a, 2018b), and Montenegro (Luković et al., 2013; 2024; Burić et al., 2014, 2015, 2018). Changes in air temperature patterns have already been recorded in the observed area, as indicated by the results obtained by numerous authors. Papers on climate change in Serbia can be classified into two categories: papers that analyze average air temperatures (Unkašević and Tošić, 2013, 2015; Gocić and Trajković, 2013; Malinović-Milićević et al., 2016; Putniković et al., 2018; Vukočić et al., 2018; Tošić et al., 2021; Baumgertel et al., 2024) and papers that monitor aridity (Gocić and Trajković, 2014a, 2014b; Hrnjak et al., 2014; Gavrilov et al., 2019; Radaković et al., 2018; Milentijević et al., 2018; Trajković et al., 2020; Burić et al., 2023; Zivanovic et al., 2024). In most cases, speaking of the scientific studies mentioned above, air temperatures are generally increasing, which is also in line with this scientific study. A certain number of papers on climate change was carried out at the regional level on the territory of Serbia: Kosovo and Metohija (Bačević et al., 2017, 2018; Gavrilov et al., 2018; Radaković et al., 2018) and Vojvodina (Hrnjak et al., 2014; Gavrilov et al., 2015, 2016, 2019; Milentijević et al., 2020).

As pointed out by Chervenkov and Slavov (2021), air temperature is a key environmental factor influencing crop growth, development, and yields, particularly the rate of development. On one hand, crops require specific temperatures to complete certain phenophases or their entire life cycle. On the other hand, extremely high and low temperatures can negatively impact crop growth, development, and yield respectively (Mandić et al., 2022). This is why variability in average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature should be investigated to conduct regional impact assessments focused on enhancing climate change resilience.

The main goal of this study is the analysis and assessment of long-term trends in average air temperature, average maximum air temperature, and average minimum air temperature for the vegetation period during the time period from

1949 to 2018 in the territory of Central Serbia. The emphasis is placed on the study of the 72 time series for 24 meteorological stations in order to determine variability of various climate parameters, with special reference to the vegetation period from April to October. The analysis includes the application of a non-parametric test (Mann-Kendall test) for detecting trends, assessing the significance of changes, as well as assessing the risk of rejecting or accepting hypotheses about the presence of a trend. Furthermore, one of the goals is to show the geospatial data distribution, whereas the ultimate goal is to provide an overview and understanding of climate change in Central Serbia, to identify areas with an increase or decrease in air temperatures for the analyzed categories, as well as to provide a basis for future research and climate strategies.

2. Material and methods

2.1. Research area

Central Serbia has an exceptional geographical position, because it occupies the central part of the Balkan Peninsula, and thus, represents the most important land connection between the Balkans and this part of Europe. The northern border is represented by the rivers Danube and Sava. The eastern border coincides with the borders of the Republic of Serbia with the Republic of Bulgaria and Romania. The southern border is represented by the border of the Republic of Serbia and the Republic of North Macedonia, as well as the contact between the Autonomous Province of Kosovo and Metohija and Central Serbia. The western border coincides with the borders of Serbia and Montenegro, after which it follows the course of the Drina River. In a regional-geographical sense, Central Serbia includes the following mesoregions: Western Serbia, Eastern Serbia, Southern Serbia, Central Serbia, as well as the microregions of Stari Vlah and Raška and Ibar-Kopaonik region (*Pavlović, 2019a, 2019b*).

The mountain ranges of Dinarides, Rhodopes (Serbian-Macedonian massif) and Carpatho-Balkanides are crossed by river courses, among which the Velika Morava, with its tributaries, dominates. Most of the precipitation comes from the east, that is, from the Atlantic Ocean and the Adriatic Sea. The effect from the Adriatic weakens rashly during crossing of the Dinarides. The amount of precipitation varies from 600 mm, and in some places it exceeds 1100 mm per year. In the southeastern and southwestern parts of Central Serbia, the lowest average annual air temperature is around 2 °C, while the highest average annual temperatures occur in the largest populated places, where the warmest is Belgrade with around 12 °C (*Milovanović et al., 2022a*).

2.2. Materials

The average annual air temperature (YT-VP), average annual maximum air temperature (YT_x-VP), and average annual minimum air temperature (YT_n-VP) during the vegetation period (P-VG) from 1949 to 2018 were calculated based on publicly available data of the Republic Hydrometeorological Institute of Serbia (<https://www.hidmet.gov.rs/>). Twenty-four meteorological stations were used, whose data are given in *Table 1* (Bačević, et al., 2021), while their position is given in *Fig. 1*. For the purposes of these studies, data on precipitation from 24 meteorological stations were used. Details of station names, geographic coordinates, geographic location and their altitude are shown in *Fig. 1* and *Table 1*.



Fig. 1. Geographical position of Central Serbia in the regional context and in Europe (upper right corner). Meteorological stations used in this study are indicated by black dots.

Table 1. List of meteorological stations located in Central Serbia, their geographic coordinates and altitude, and the name of time series used in this study

No.	Meteorological station	Name of time series	ϕ ($^{\circ}$ N)	λ ($^{\circ}$ E)	h (m)
1.	Belgrade	BG-YT-VP; BG-YTx-VP; BG-YTn-VP	44 $^{\circ}$ 48'	20 $^{\circ}$ 28'	132
2.	Bujanovac	BU-YT-VP; BU-YTx-VP; BU-YTn-VP	42 $^{\circ}$ 27'	21 $^{\circ}$ 46'	399
3.	Ćuprija	CU-YT-VP; CU-YTx-VP; CU-YTn-VP	43 $^{\circ}$ 56'	21 $^{\circ}$ 23'	123
4.	Dimitrovgrad	DI-YT-VP; DI-YTx-VP; DI-YTn-VP	43 $^{\circ}$ 01'	22 $^{\circ}$ 45'	450
5.	Jagodina	JA-YT-VP; JA-YTx-VP; JA-YTn-VP	43 $^{\circ}$ 59'	21 $^{\circ}$ 23'	115
6.	Knjaževac	KZ-YT-VP; KZ-YTx-VP; KZ-YTn-VP	43 $^{\circ}$ 34'	22 $^{\circ}$ 15'	263
7.	Kragujevac	KG-YT-VP; KG-YTx-VP; KG-YTn-VP	44 $^{\circ}$ 02'	20 $^{\circ}$ 56'	181
8.	Kraljevo	KV-YT-VP; KV-YTx-VP; KV-YTn-VP	43 $^{\circ}$ 43'	20 $^{\circ}$ 42'	215
9.	Kruševac	KS-YT-VP; KS-YTx-VP; KS-YTn-VP	43 $^{\circ}$ 37'	21 $^{\circ}$ 15'	166
10.	Kuršumlija	KU-YT-VP; KU-YTx-VP; KU-YTn-VP	43 $^{\circ}$ 08'	21 $^{\circ}$ 16'	384
11.	Leskovac	LE-YT-VP; LE-YTx-VP; LE-YTn-VP	42 $^{\circ}$ 59'	21 $^{\circ}$ 57'	231
12.	Loznica	LO-YT-VP; LO-YTx-VP; LO-YTn-VP	44 $^{\circ}$ 32'	19 $^{\circ}$ 14'	121
13.	Negotin	NG-YT-VP; NG-YTx-VP; NG-YTn-VP	44 $^{\circ}$ 14'	22 $^{\circ}$ 32'	42
14.	Niš	NI-YT-VP; NI-YTx-VP; NI-YTn-VP	43 $^{\circ}$ 20'	21 $^{\circ}$ 54'	202
15.	Novi Pazar	NP-YT-VP; NP-YTx-VP; NP-YTn-VP	43 $^{\circ}$ 08'	20 $^{\circ}$ 31'	545
16.	Pirot	PI-YT-VP; PI-YTx-VP; PI-YTn-VP	43 $^{\circ}$ 09'	22 $^{\circ}$ 35'	373
17.	Požega	PZ-YT-VP; PZ-YTx-VP; PZ-YTn-VP	43 $^{\circ}$ 51'	20 $^{\circ}$ 02'	311
18.	Sjenica	SJ-YT-VP; SJ-YTx-VP; SJ-YTn-VP	43 $^{\circ}$ 16'	20 $^{\circ}$ 00'	1038
19.	Smederevska Palanka	SP-YT-VP; SP-YTx-VP; SP-YTn-VP	44 $^{\circ}$ 22'	20 $^{\circ}$ 57'	121
20.	Valjevo	VA-YT-VP; VA-YTx-VP; VA-YTn-VP	44 $^{\circ}$ 17'	19 $^{\circ}$ 55'	174
21.	Veliko Gradište	VG-YT-VP; VG-YTx-VP; VG-YTn-VP	44 $^{\circ}$ 45'	21 $^{\circ}$ 30'	80
22.	Vranje	VR-YT-VP; VR-YTx-VP; VR-YTn-VP	42 $^{\circ}$ 33'	21 $^{\circ}$ 55'	433
23.	Zaječar	ZA-YT-VP; ZA-YTx-VP; ZA-YTn-VP	43 $^{\circ}$ 53'	22 $^{\circ}$ 17'	144
24.	Zlatibor	ZL-YT-VP; ZL-YTx-VP; ZL-YTn-VP	43 $^{\circ}$ 44'	19 $^{\circ}$ 43'	1029

2.3. Methods

For the purposes this scientific study, three different statistical methods were used to analyze trends in average annual air temperature (YT-VP), average annual maximum air temperature (Ytx-VP), and average annual minimum air temperature (YTn-VP) during the vegetation period. The first method involves calculating of the trend equation for each time series separately (Bačević *et al.*, 2022). The second statistical method is the application of the non-parametric

Mann-Kendall trend test to the existing sample (*Papić et al., 2020*). The third method is determining the trend magnitude based on the trend equation (*Bačević et al., 2020*). Trend analysis was calculated using the XLSTAT extension (<https://www.xlstat.com/en>) within the EXCEL MICROSOFT OFFICE package.

Calculation of the trend equation is based on the application of linear regression to calculate the precipitation trend equation during the vegetation period for each meteorological station, and the equation reads

$$y = ax + b . \quad (1)$$

In this equation, y denotes the average annual air temperature (YT-VP), average annual maximum air temperature (YT_x-VP), i.e., average annual minimum air temperature (YT_n-VP) in the vegetation period expressed in °C, a represents the trend slope that can be positive, negative, or with no trend, x represents the time series, while b represents the value of the air temperature at the beginning of the analyzed period (*Bačević et al., 2018, 2024; 2025 in press; Vukoičić et al., 2018*). After this analysis, the determination of the trend magnitude is carried out (*Gavrilov et al., 2018*)

$$\Delta y = y(Pb) - y(Pe) , \quad (2)$$

where Δy represents the trend magnitude in °C, $y(Pb)$ is the temperature value (YT-VP, YT_x-VP, and YT_n-VP) in the first year of the observed period, while $y(Pe)$ is the temperature value (YT-VP, YT_x-VP, and YT_n-VP) in the last year of the time series. In relation to that, the trend magnitude can be positive (increasing) and negative (decreasing). The trend magnitude can be with no trend, if the specified values are equal.

The third method used in this paper is the Mann-Kendall (MK) trend test for the analysis of air temperature time series (YT-VP, YT_x-VP, and YT_n-VP) during the vegetation period in Central Serbia (*Mann, 1945; Kendall, 1975*). Each value in the time series is assigned a rank. Differences between pairwise ranks are used to calculate the direction and strength of the trend, after which the variance of the MK test is determined to show the randomness of the variability in the data. Low variance indicates low data dispersion, and vice versa. Then follows the calculation of the trend significance, which begins by comparing the calculated test statistic with the data distribution, assuming that there is no trend (H_0 hypothesis). If the test statistics is greater than the critical value from the distribution, it indicates that there is a statistically significant trend (H_a hypothesis). p denotes the value that indicates how much the test statistic exceeds the critical value. In the case when p is less than 0.05 or 5%, the trend results are statistically significant and the H_0 hypothesis is rejected (*Gavrilov et al., 2018; Razavi et al., 2016*).

2.3.1. Spatial data analysis

All digital cartographic analyses were conducted using ArcGIS Pro: 3.2.0. Data, which are necessary for mapping, were taken from the Internet and from established databases, obtained during statistical processing. GIS and data modeling are very powerful tools for assessing and calculating meteorological data of an area. In this paper, the kriging method is preferred within the interpolation framework to show the geographical distribution of average precipitation during the vegetation period in the analyzed period. The results of the statistical analysis are spatially represented using the Create Thiessen Polygons analysis. This method was developed by Thiessen, a meteorologist, more than a century ago, and it refers to the creation of a polygon in the center of which a coordinate is entered (Radaković, 2018), in this case the coordinate of a meteorological station. Using this method, the entire territory of Central Serbia is divided into areas where the results of linear regression and the Mann-Kendall test are the same: the trend in precipitation during the vegetation period exists as positive, negative, or no trend. All procedures and approaches used for the purpose of this research are presented in the flow chart given in Fig. 2.

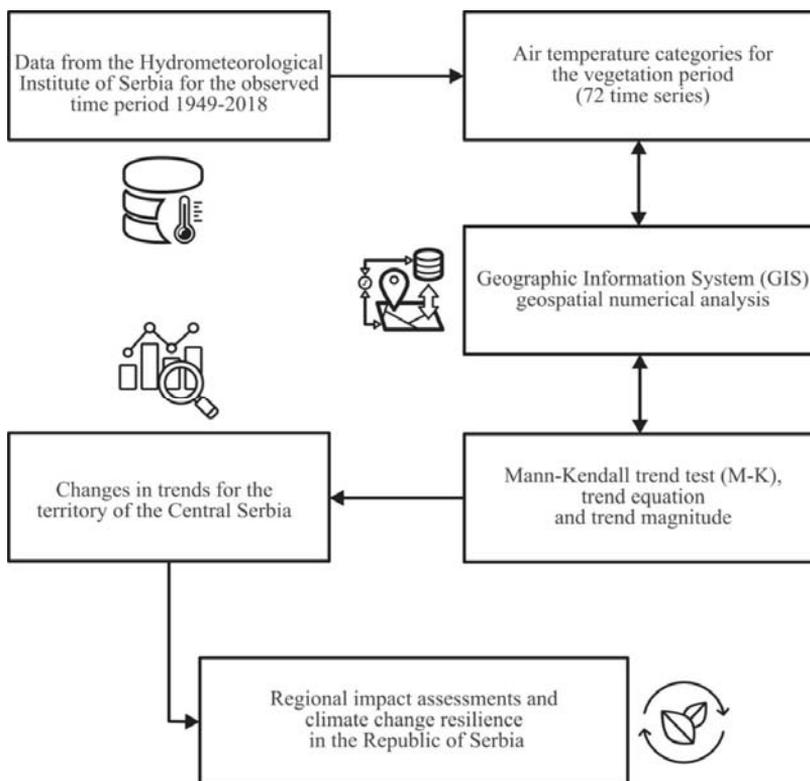


Fig. 2. Flow chart with all the procedures and methods used in this research.

3. Results

3.1. Trend parameters

The results of this scientific study are shown in *Table 2* and *Figs. 3, 4, 5,* and *6*. The analysis for 24 meteorological stations, which are located in the territory of Central Serbia for the time interval from 1949 to 2018, is presented. The processed data and performed analyses refer to the vegetation period (April - October) for the observed area and, based on those variables, the values of the observed equations were calculated. Also, the analysis of 72 time series is presented, which was conducted using a non-parametric trend test (MK). *Table 2* and *Fig. 2* visually show the results obtained for the average annual air temperature, average annual maximum air temperature, average annual minimum air temperature, trend equation, linear trend equation, and trend magnitude. Furthermore, *Fig. 2* visually shows the obtained results for the p values, results of trend testing, and evaluation of hypotheses for accepting the trend, that is, rejecting the trend. Spatial distributions for the average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature are shown in *Fig. 7*.

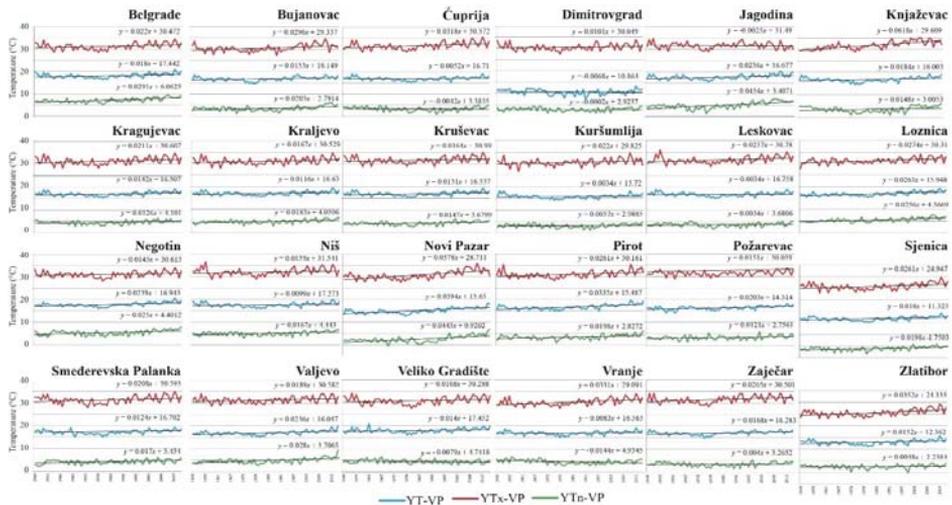


Fig. 3. Results of the average annual surface air temperature Yt-VP (blue), average maximum annual surface air temperature YTx-VP (red), and average minimum annual surface air temperature YTn-VP (green) for the vegetation period (April-October, 1949–2018) for 24 meteorological stations in Central Serbia.

Table 2. Names of time series, trend equation y , trend magnitude Dy , average annual air temperature, average annual maximum air temperature and average annual minimum air temperature for the vegetation period for 72 time series, which refer to the territory of Central Serbia

Time series	Trend equation	Dy_{YT-VP} (°C)	Average temperature (°C)
BG-YT-VP	$y=0.018x+17.442$	1.24	18.1
BG-Ytx-VP	$y=0.022x+30.472$	1.52	31.3
BG-Ytn-VP	$y=0.0291x+6.0625$	2.0	7.1
BU-YT-VP	$y=0.0153x+16.149$	1.0	16.7
BU-YTx-VP	$y=0.0296x+29.337$	2.0	30.4
BU-YTn-VP	$y=0.0203x+2.7914$	1.4	3.5
CU-YT-VP	$y=0.0052x+16.71$	0.3	16.9
CU-YTx-VP	$y=0.0318x+30.572$	2.2	31.7
CU-YTn-VP	$y=-0.0042x+3.3835$	-0.3	3.2
DI-YT-VP	$y=-0.0068x+10.864$	-0.5	10.6
DI-YTx-VP	$y=0.0101x+ 30.049$	0.7	30.4
DI-YTn-VP	$y=-0.0002x+2.9237$	-0.01	2.9
JA-YT-VP	$y=0.0236x+16.677$	1.6	17.5
JA-YTx-VP	$y=-0.0025x+31.49$	-0.2	31.4
JA-YTn-VP	$y=0.0454x+3.4071$	3.1	5.0
KZ-YT-VP	$y=0.0184x+16.003$	1.3	16.7
KZ-YTx-VP	$y=0.0618x+29.609$	4.3	31.8
KZ-YTn-VP	$y=0.0148x+3.0053$	1.0	3.5
KG-YT-VP	$y=0.0142x+16.507$	1.0	17.0
KG-YTx-VP	$y=0.0211x+30.607$	1.4	31.4
KG-YT-nVP	$y=0.0126x+ 4.101$	0.9	4.5
KV-YT-VP	$y=0.0116x+16.63$	0.8	17.0
KV-YTx-VP	$y=0.0167x+30.529$	1.1	31.1
KV-YTn-VP	$y=0.0183x+4.0596$	1.3	4.7
KS-YT-VP	$y=0.0131x+16.537$	0.9	17.0
KS-YTx-VP	$y=0.0164x+ 30.99$	1.1	31.6
KS-YTn-VP	$y=0.0147x+3.6799$	1.0	4.2
KU-YT-VP	$y=0.0034x+15.72$	0.2	15.8
KU-YTx-VP	$y=0.022x+29.825$	1.5	30.6
KU-YTn-VP	$y=0.0057x+2.9885$	0.4	3.2
LE-YT-VP	$y=0.0034x+16.758$	0.2	16.9
LE-YTx-VP	$y=0.0237x+30.78$	1.6	31.6
LE-YTn-VP	$y=0.0034x+3.6806$	0.2	3.8
LO-YT-VP	$y=0.0263x+15.948$	1.8	16.9
LO-YTx-VP	$y=0.0274x+30.31$	1.9	31.3
LO-YTn-VP	$y=0.0256x+4.5669$	1.8	5.5
NG-YT-VP	$y=0.0239x+16.943$	1.6	17.8
NG-YTx-VP	$y=0.0145x+30.613$	1.0	31.1
NG-YTn-VP	$y=0.025x+4.4012$	1.7	5.3
NI-YT-VP	$y=0.0099x+17.273$	0.7	17.6
NI-YTx-VP	$y=0.0159x+31.541$	1.1	32.1
NI-YTn-VP	$y=0.0167x+4.443$	1.1	5.0
NP-YT-VP	$y=0.0394x+13.65$	2.7	15.0

Time series	Trend equation	DyYT-VP (°C)	Average temperature (°C)
NP-YTx-VP	$y=0.0578x+28.711$	3.9	30.8
NP-YTn-VP	$y=0.0443x+0.9202$	3.0	2.5
PI-YT-VP	$y=0.0335x+15.487$	2.3	16.7
PI-YTx-VP	$y=0.0261x+30.161$	1.8	31.1
PI-YTn-VP	$y=0.0198x+2.8272$	1.4	3.5
PZ-YT-VP	$y=0.0203x+14.514$	1.4	15.2
PZ-YTx-VP	$y=0.0151x+30.039$	1.0	30.6
PZ-YTn-VP	$y=0.0121x+2.7561$	0.8	3.2
SJ-YT-VP	$y=0.016x+11.323$	1.1	11.9
SJ-YTx-VP	$y=0.0261x+24.947$	1.8	25.9
SJ-YTn-VP	$y=0.0198x-1.7503$	1.4	-1.0
SP-YT-VP	$y=0.0124x+16.702$	0.8	17.1
SP-YTx-VP	$y=0.0208x+30.593$	1.4	31.3
SP-YTn-VP	$y=0.017x+3.434$	1.2	4.0
VA-YT-VP	$y=0.0236x+16.047$	1.6	16.9
VA-YTx-VP	$y=0.0189x+30.582$	1.3	31.3
VA-YTn-VP	$y=0.028x+3.7065$	1.9	4.7
VG-YT-VP	$y=0.014x+17.452$	0.9	17.9
VG-YTx-VP	$y=0.0168x+30.288$	1.1	30.9
VG-YTn-VP	$y=-0.0079x+4.7418$	-0.5	4.5
VR-YT-VP	$y=0.0083x+16.565$	0.6	16.9
VR-YTx-VP	$y=0.0331x+29.091$	2.3	30.3
VR-YTn-VP	$y=-0.0144x+4.9345$	-1.0	4.4
ZA-YT-VP	$y=0.0168x+16.283$	1.1	16.9
ZA-YTx-VP	$y=0.0265x+30.501$	1.8	31.4
ZA-YTn-VP	$y=0.004x+3.2652$	0.3	3.4
ZL-YT-VP	$y=0.0152x+12.362$	1.0	12.9
ZL-YTx-VP	$y=0.0352x+24.335$	2.4	25.6
ZL-YTn-VP	$y=0.0048x+2.2384$	0.3	2.4

The presentation of the obtained results of the above parameters, which are visually shown in *Fig. 3* and *Table 2*, indicates an increase in the average annual air temperature (YT-VP), average annual maximum air temperature (YTx-VP), and average annual minimum air temperature (YTn-VP) for the vegetation period in the observed area. Out of a total of 72 time series, a positive balance (increase in temperature) was recorded in 66 time series, and a negative balance (decrease in temperature) was recorded in 6 time series. The recorded increase in temperature for the variables mentioned above ranges from 0.2 °C (time series KU-YT-VP, LE-YT-VP, and LE-YTn-VP) to 4.3 °C (time series KZ-YTx-VP). Negative balance was recorded for a total of six time series (CU-YTn-VP, DI-YT-VP, DI-YTn-VP, JA-YTx-VP, VG-YTn-VP and VR-YTn-VP), whose values range from -0.01 °C (time series DI-YTn-VP) to -0.5 °C (time series DI-YT-VP and VG-YTn-VP). The average annual air temperature for the vegetation period is 16.2 °C. The average annual maximum air temperature for the vegetation period is 30.7 °C. The average

annual minimum air temperature for the vegetation period is 3.9 °C. More detailed results for other time series are shown in *Table 2*. Moreover, in the same table, the results for the average annual air temperature, average annual maximum air temperature and average annual minimum air temperature, in the vegetation period are shown separately for each meteorological station in the past 70 years in the observed territory.

3.2. Trend assessment

The spatial description of the results obtained by the MK trend test analysis and the evaluation of hypotheses (p values, type of hypothesis - the risk of rejecting the hypothesis) are shown in *Figs. 4, 5, and 6*. Out of a total of 72 time series, most show a statistically significant positive trend. More precisely, H_a hypothesis prevails in 53 time series, where the p value is lower than the significance level α , whose value is 0.05. In the remaining 19 time series, there is no trend, where H_0 hypothesis prevails and where the p value is higher than the significance level α , whose value is 0.05. Out of 53 time series (*Figs. 3, 4, and 5*), where a statistically positive trend and H_a hypothesis prevail, a very small percentage of the risk of rejecting this claim, ranging between 0.01% and 1.00%, was recorded in 39 time series. In the remaining 14 time series, the percentage of risk to reject such a claim is insignificantly higher and ranges between 1.00% to 5.00%.

These results for the abovementioned time series indicate that in most cases, the trend is positive and that the temperature has increased in the entire analyzed territory, and that it will continue to be so in the future as well. Also, after the analyses performed in the MK trend test, results were obtained, where there is no trend in 19 time series. The percentage of risk to reject such a claim is significantly higher compared to the recorded risk for time series, where the trend is positive. The risk percentage ranges from 5.14% to 77.17%. In 4 time series (KV-YTx-VP, KS-YTx-VP, PZ-YTx-VP, and VR-YTn-VP) the risk percentage ranges from 5.14% to 6.59%, which indicates that there will certainly be no trend in the future. In 12 time series (CU-YT-VP, CU-YTn-VP, DI-YT-VP, DI-YTx-VP, KZ-YTn-VP, KU-YT-VP, KU-YTn-VP, LE-YT-VP, VG-YTn-VP, VR-YT-VP, ZA-YTn-VP, and ZL-YTn-VP) the percentage of risk to reject this claim ranges from 10.06% to 47.47%, which indicates that a positive trend is possible in the future and that the air temperature may increase. In the remaining 3 time series, the risk percentage of rejecting this claim is above 50.00%. More precisely, the percentage of risk is 57.94% for the time series LE-YTn-VP, 77.17% for the time series DI-YTn-VP, and 77.57% for the time series JA-Ytx-VP, which indicates that it will certainly change to a positive trend in the future and that an increase in air temperature will be recorded.

The obtained results for the trend equation differ from the obtained results of the MK trend test analysis, where a greater number of time series with positive trend was recorded. A total of 59 time series were recorded, where a positive trend

was recorded for 6 more. In 7 time series there is no trend, and in 6 time series the trend is negative, which is also less for 6 time series in relation to the results obtained using MK trend test. These results are shown in more detail in *Figs. 3, 4, 5, and 6.*

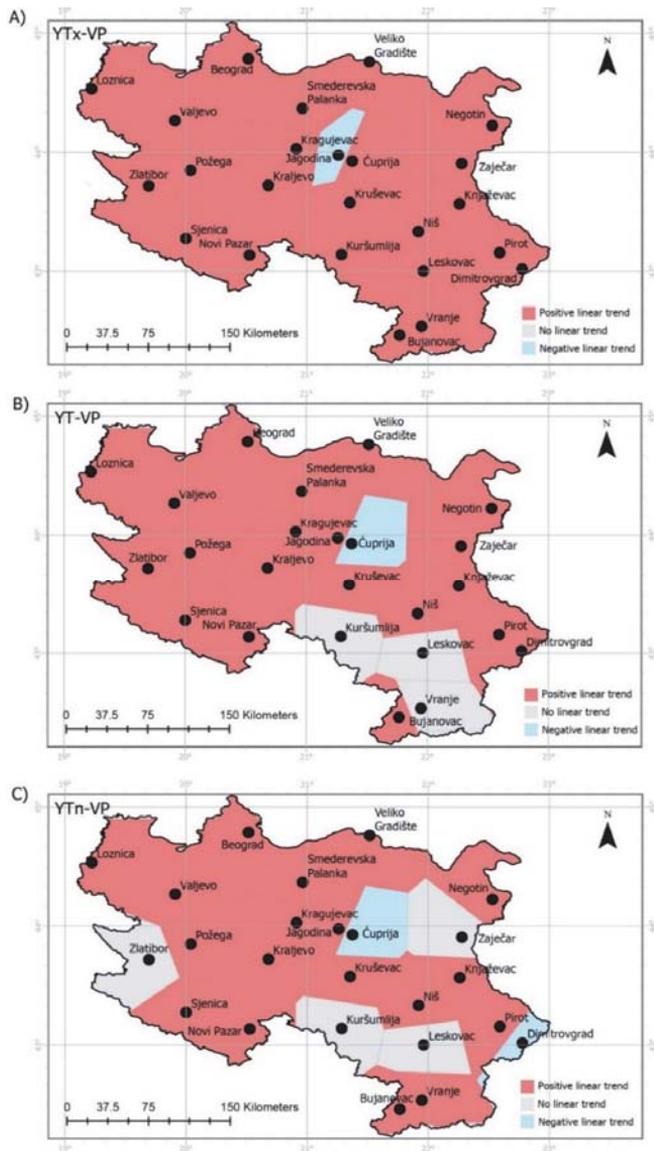


Fig. 4. Cartographic presentation of the obtained results of the linear trend equation movement of A) average annual maximum, B) average annual, and C) average annual minimum air temperatures for the vegetation period in Central Serbia, in the time interval from 1949 to 2018.

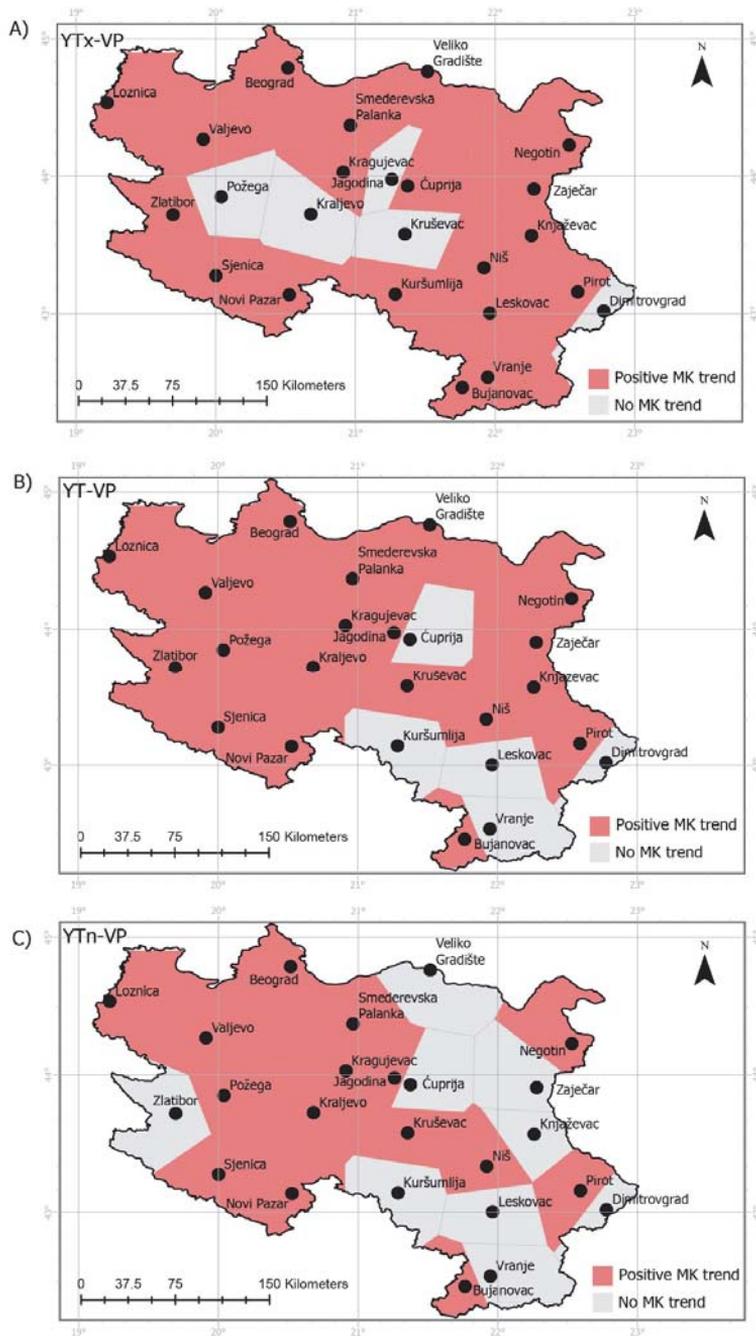


Fig. 5. Cartographic representation of the results obtained from Mann-Kendall trend test of A) average annual maximum, B) average annual, and C) average annual minimum air temperatures for the vegetation period in Central Serbia, in the time interval from 1949 to 2018.

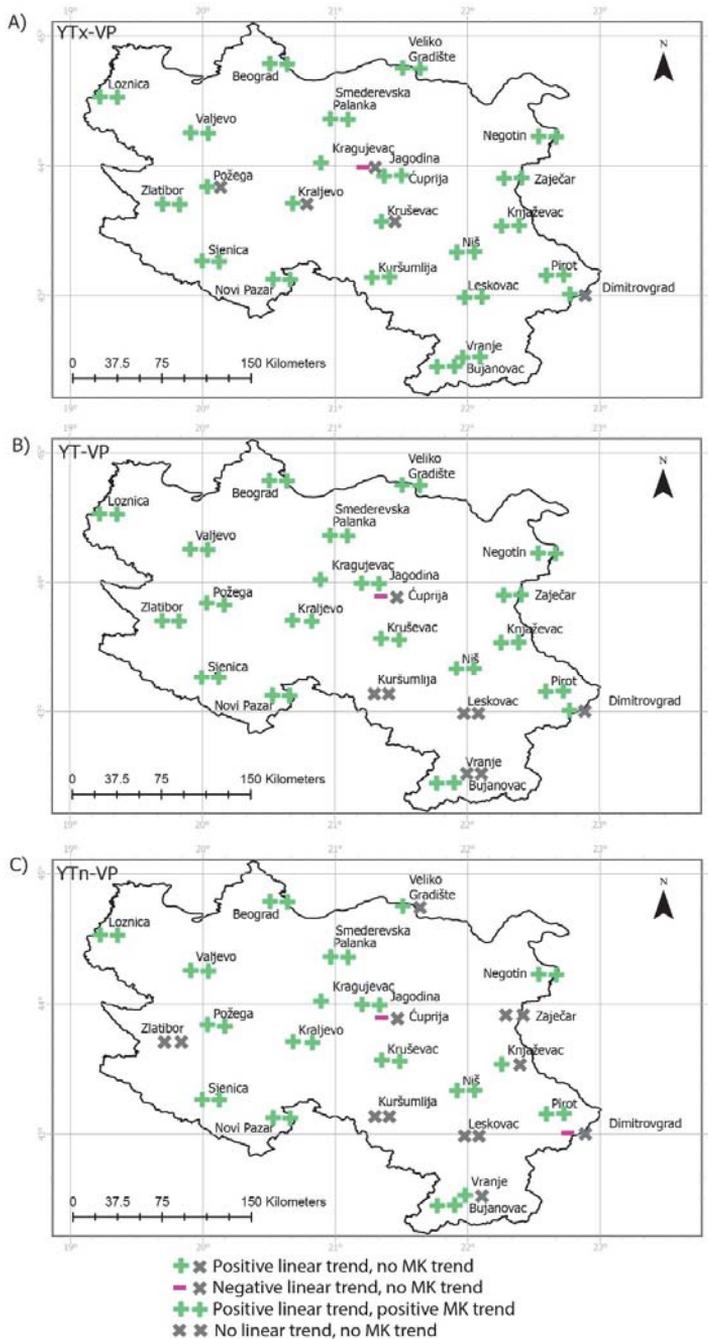


Fig. 6. Comparative presentation of the obtained results of the linear and Mann-Kendall trends of A) average annual maximum, B) average annual, and C) average annual minimum air temperatures for the vegetation period in Central Serbia, in the time interval from 1949 to 2018.

3.3. GIS numerical analysis

Spatial distributions of the average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature for the vegetation period in the time interval from 1949 to 2018 in Central Serbia are shown in more detail in Fig. 6 (a-c).

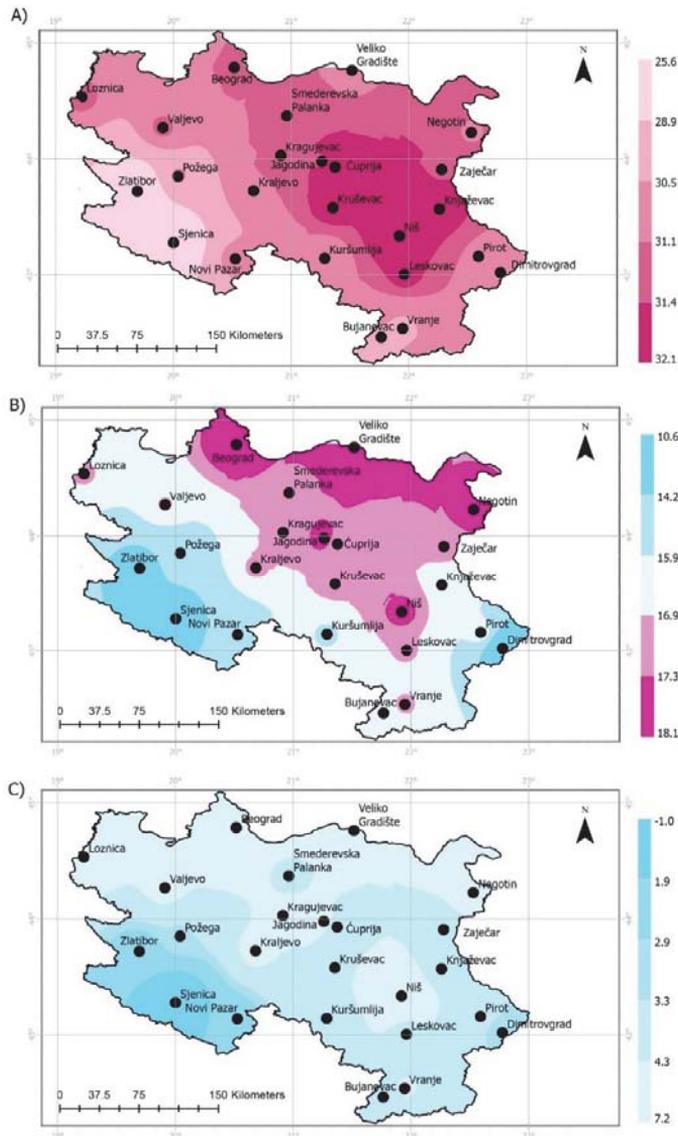


Fig. 7. Spatial distribution of A) average annual maximum, B) average annual, and C) average annual minimum air temperatures for the vegetation period in Central Serbia in °C, in the time interval from 1949 to 2018.

Fig. 6 shows the average annual air temperature (YT-VP), average annual maximum air temperature (YT_x-VP), and average annual minimum air temperature (YT_n-VP) for the vegetation period in Central Serbia for the time interval from 1949 to 2018. The isotherms follow the temperature values and indicate the influence of the geographical position, orography, altitude, proximity to the Adriatic Sea, and in the last period, the anthropogenic influence should also be mentioned. Average annual air temperatures for the vegetation period in the observed area range from 10.6 °C in Dimitrovgrad to 18.1 °C in Belgrade. Other values of the average annual air temperature for the vegetation period are shown from the lowest to the highest, namely: Sjenica 11.9 °C, Zlatibor 11.9 °C, Novi Pazar 15 °C, Požega 15.2 °C, Kuršumlija 15.8 °C, Bujanovac 16.7 °C, Knjaževac 16.7 °C, Pirot 16.7 °C, Čuprija 16.9 °C, Loznica 16.9 °C, Leskovac 16.9 °C, Valjevo 16.9 °C, Vranje 16.9 °C, Zaječar 16.7 °C, Kragujevac 17 °C, Kraljevo 17 °C, Kruševac 17 °C, Smederevska Palanka 17.1 °C, Jagodina 17.5 °C, Niš 17.6 °C, Negotin 17.8 °C, Veliko Gradište 17.9 °C.

Average annual maximum air temperatures for the vegetation period in the observed area range from 32.1 °C in Niš to 25.6 °C in Zlatibor. Other values of the average annual air temperature for the vegetation period are shown from the lowest to the highest, namely: Sjenica 25.9 °C, Vranje 30.3 °C, Bujanovac 30.4 °C, Dimitrovgrad 30.4 °C, Kuršumlija 30.6 °C, Požega 30.6 °C, Novi Pazar 30.8 °C, Veliko Gradište 30.9 °C, Kraljevo 31.1 °C, Negotin 31.1 °C, Pirot 31.1 °C, Belgrade 31.3 °C, Loznica 31.3 °C, Smederevska Palanka 31.3 °C, Valjevo 31.3 °C, Jagodina 31.4 °C, Kragujevac 31.4 °C, Zaječar 31.4 °C, Kruševac 31.6 °C, Leskovac 31.6 °C, Čuprija 31.7 °C, Knjaževac 31.8 °C.

Average annual minimum air temperatures for the vegetation period in the observed area range from -1 °C in Sjenica to 7.1 °C in Belgrade. Other values of the average annual air temperature for the vegetation period are shown from the lowest to the highest, as follows: Zlatibor 2.4 °C, Novi Pazar 2.5 °C, Dimitrovgrad 2.9 °C, Čuprija 3.2 °C, Kuršumlija 3.2 °C, Požega 3.2 °C, Zaječar 3.4 °C, Bujanovac 3.5 °C, Knjaževac 3.5 °C, Pirot 3.5 °C, Leskovac 3.8 °C, Smederevska Palanka 4 °C, Kruševac 4.2 °C, Vranje 4.4 °C, Kragujevac 4.5 °C, Veliko Gradište 4.5 °C, Kraljevo 4.7 °C, Valjevo 4.7 °C, Jagodina 5 °C, Niš 5 °C, Negotin 5.3 °C, Loznica 5.5 °C.

4. Discussion

Such or similar research, referring to the average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature for the vegetation period in the time interval from 1949 to 2018 has not been done so far in Central Serbia. The obtained results, their differences and similarities were compared with similar results of previous research, whose research subject

is partly the same or similar to the research subject of this scientific study, and they refer to the same observed area, region, European continent, and the world.

With this scientific study, key aspects related to the analyzed climate variables can be highlighted and the followings can be stated. A total of 72 time series were analyzed. Analyses were conducted using trend equations, trend magnitude indicating average increase or decrease in the average annual air temperature, average annual maximum air temperature and average annual minimum air temperature, non-parametric MK test and GIS numerical analysis. The results of the trend equation and trend magnitude indicate an increase in air temperature in most time series. A positive balance was recorded in 66 time series.

Meanwhile, negative balance was recorded in 6 time series. The recorded increase in temperature for the variables mentioned above ranges from 0.2 °C (time series KU-YT-VP, LE-YT-VP, and LE-YTn-VP) to 4.3 °C (time series KZ-YTx-VP). The recorded decrease in air temperature for the variables mentioned above ranges from -0.01 °C (time series DI-YTn-VP) to -0.5 °C (time series DI-YT-VP and VG-YTn-VP) (*Table 2*). The results obtained from the analysis of the MK trend test indicate a positive trend in 53 time series, with a small percentage of risk to reject this claim. No trend was recorded in the remaining 19 time series, with a high percentage of risk to reject this claim (*Figs. 3, 4, and 5*).

Average annual air temperatures for the vegetation period in the observed area range from 10.6 °C in Dimitrovgrad to 18.1 °C in Belgrade. Average annual maximum air temperatures for the vegetation period in the observed area range from 32.1 °C in Nis to 25.6 °C in Zlatibor. Average annual minimum air temperatures for the vegetation period in the observed area range from -1 °C in Sjenica to 7.1 °C in Belgrade (*Table 2 and Figs. 5, 6, and 7*). From the results presented above, it can be concluded that the increase in the average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature for the vegetation period is dominant in Central Serbia.

Similar results were presented in the work of *Bačević et al. (2021)*, which refers to the same observed territory. The aforementioned paper uses the same research methodology but deals with a different variable. The differences between these studies lie in the variables: while one analyzed the entire annual period, the other focused on the vegetation period. The results obtained based on the trend equation and trend magnitude indicate an increase in temperature in 70 time series, and a decrease in temperature in the remaining two time series, which is the difference in 4 time series, when it comes to a positive balance. Whereas, in the case where a negative balance occurs, the difference is in 4 time series.

The largest increase in the average air temperature was recorded in the case of the average annual maximum air temperatures for KZ-YTx time series, where the temperature increased by 4.2 °C. This is the same result as in this scientific study, with the exception that the average annual maximum air temperature increased by 4.5 °C. The lowest increase in air temperature was recorded in the case of the average minimum air temperatures (time series ZA-YTn). In this

particular case, an average increase in air temperature of only 0.1 °C was recorded. This differs from the obtained results of this study, where the lowest increase in air temperature of 0.2 °C was recorded in three time series (KU-YT-VP, LE-YT-VP, and LE-YTn-VP).

A decrease in air temperature was recorded in two time series (VR-YTn and VG-YTn), the values of which are -0.6 °C and -0.4 °C, and in this work, this is the case with 6 time series (CU-YTn-VP, DI-YT-VP, DI-YTn-VP, JA-YTx-VP, VG-YTn-VP, and Vr-YTn-VP), whose values range from -0.01 °C to -0.5 °C. (Tables 2 and 3). Such differences lie in the number of time series, amounts and range of reduction in the average air temperature. The first case shows a smaller range of values that vary compared to the second case, where the range of obtained values is significantly larger.

Using the MK trend test, the results from the study by *Bačević et al. (2021)* indicate that a positive trend was recorded in 61 time series, while there was no trend in 11 time series. In this paper, the results are somewhat different: a positive trend is observed in 53 time series, while in 19 time series there is no trend. The difference between the results obtained by MK trend test analysis is primarily in the number of time series in which a positive trend is recorded and those in which there is no trend. This means that, in this paper, there is a smaller number of time series (by 8) with a positive trend and a larger number of time series (by 8) with no trend (Figs. 4 and 8).

This study can serve as a basis for future research, which would contribute to new additional knowledge about climate changes in the observed territory.

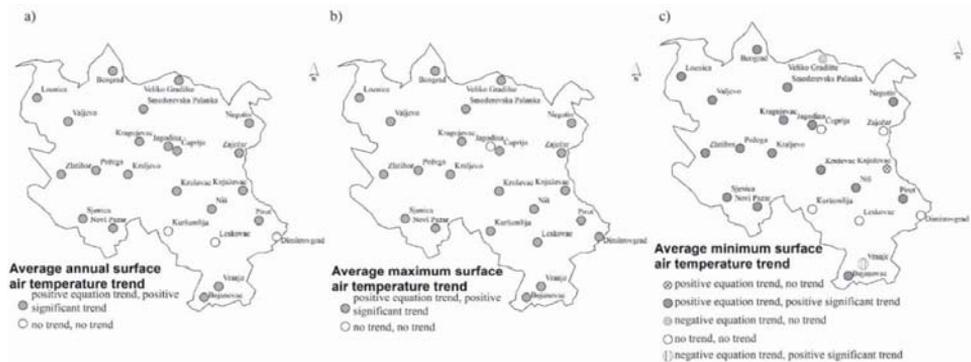


Fig. 8. The results of linear equation trends and MK test: a) average annual surface air temperature; b) average maximum surface air temperature; c) average minimum surface air temperature (*Bačević et al., 2021*).

Table 3. Names of times series, trend equation y , trend magnitude Δy , and probability value p of the confidences for 72 time series (Bačević et al., 2021)

Time series	Trend equation	Δy (°C)	Average temperature (°C)
BG-YT	$y = 0.0292x + 11.36$	2.0	12.1
BG-YT _x	$y = 0.0319x + 24.636$	2.2	25.8
BG-YT _n	$y = 0.0307x + 0.5603$	2.1	1.6
BU-YT	$y = 0.0157x + 10.481$	1.1	11.0
BU-YT _x	$y = 0.0363x + 22.988$	2.5	24.3
BU-YT _n	$y = 0.0237x - 3.1391$	1.6	-2.3
CU-YT	$y = 0.0131x + 10.747$	0.9	11.2
CU-YT _x	$y = 0.0358x + 24.629$	2.5	25.9
CU-YT _n	$y = 0.0065x - 2.5549$	0.5	-2.3
DI-YT	$y = 0.0085x + 9.7802$	0.6	10.1
DI-YT _x	$y = 0.0259x + 23.89$	1.8	24.8
DI-YT _n	$y = 0.0035x - 2.887$	0.2	-2.8
JA-YT	$y = 0.0204x + 10.954$	1.4	11.7
JA-YT _x	$y = 0.0027x + 25.412$	0.2	25.5
JA-YT _n	$y = 0.0438x - 2.3001$	3.0	-0.7
KZ-YT	$y = 0.0183x + 10.148$	1.3	10.8
KZ-YT _x	$y = 0.0611x + 23.941$	4.2	26.1
KZ-YT _n	$y = 0.0157x - 2.7361$	1.1	-2.2
KG-YT	$y = 0.0194x + 10.792$	1.3	11.5
KG-YT _x	$y = 0.0319x + 24.8$	2.2	25.9
KG-YT _n	$y = 0.0143x - 1.7176$	1.0	-1.2
KV-YT	$y = 0.0319x + 24.8$	1.1	11.4
KV-YT _x	$y = 0.0319x + 24.8$	1.6	25.6
KV-YT _n	$y = 0.0319x + 24.8$	1.4	-1.0
KS-YT	$y = 0.0178x + 10.666$	1.2	11.3
KS-YT _x	$y = 0.03x + 24.93$	2.1	26.0
KS-YT _n	$y = 0.0193x - 2.3684$	1.3	-1.7
KU-YT	$y = 0.0069x + 10.179$	0.5	10.4
KU-YT _x	$y = 0.0231x + 24.366$	1.6	25.2
KU-YT _n	$y = 0.0064x - 2.8218$	0.4	-2.6
LE-YT	$y = 0.0081x + 10.895$	0.6	11.2
LE-YT _x	$y = 0.0253x + 25.078$	1.7	25.9
LE-YT _n	$y = 0.0054x - 2.1455$	0.4	-2.0
LO-YT	$y = 0.0296x + 10.387$	2.0	11.4
LO-YT _x	$y = 0.0287x + 25.353$	2.0	26.3
LO-YT _n	$y = 0.0331x - 1.3454$	2.3	-0.2
NG-YT	$y = 0.0279x + 10.641$	1.9	11.6
NG-YT _x	$y = 0.0272x + 24.042$	1.9	25.0
NG-YT _n	$y = 0.0281x - 1.9027$	1.9	-1.0
NI-YT	$y = 0.0168x + 11.263$	1.2	11.1

Time series	Trend equation	Δy (°C)	Average temperature (°C)
NI-YT _x	$y = 0.0235x + 25.561$	1.6	26.4
NI-YT _n	$y = 0.0185x - 1.0556$	1.3	-0.3
NP-YT	$y = 0.0405x + 8.1268$	2.8	9.5
NP-YT _x	$y = 0.0514x + 23.047$	3.5	24.9
NP-YT _n	$y = 0.0413x - 4.8405$	2.8	-3.4
PI-YT	$y = 0.0305x + 9.9109$	2.1	11.0
PI-YT _x	$y = 0.0244x + 24.522$	2.1	25.4
PI-YT _n	$y = 0.0198x - 2.9205$	1.4	-2.2
PZ-YT	$y = 0.0207x + 8.8474$	1.4	9.6
PZ-YT _x	$y = 0.0232x + 24.139$	1.6	24.9
PZ-YT _n	$y = 0.0239x - 3.7112$	1.7	-2.8
SJ-YT	$y = 0.0207x + 5.8387$	1.4	6.6
SJ-YT _x	$y = 0.0371x + 19.309$	2.6	20.6
SJ-YT _n	$y = 0.0243x - 8.8094$	1.7	-8.0
SP-YT	$y = 0.0191x + 10.818$	1.3	12.0
SP-YT _x	$y = 0.0346x + 24.482$	2.4	25.7
SP-YT _n	$y = 0.0171x - 2.2929$	1.2	-1.8
VA-YT	$y = 0.0303x + 10.342$	2.1	11.4
VA-YT _x	$y = 0.0275x + 25.246$	2.0	26.2
VA-YT _n	$y = 0.041x - 2.4819$	2.8	-1.1
VG-YT	$y = 0.016x + 10.743$	1.1	11.4
VG-YT _x	$y = 0.0261x + 23.804$	1.8	24.8
VG-YT _n	$y = -0.0062x - 0.9246$	-0.4	-1.1
VR-YT	$y = 0.012x + 10.739$	0.8	11.2
VR-YT _x	$y = 0.0369x + 23.108$	2.6	24.4
VR-YT _n	$y = -0.0092x - 0.9409$	-0.6	-1.3
ZA-YT	$y = 0.0172x + 10.227$	1.2	10.8
ZA-YT _x	$y = 0.0359x + 24.518$	2.5	25.8
ZA-YT _n	$y = 0.0011x - 2.6094$	0.1	-2.6
ZL-YT	$y = 0.0211x + 6.8797$	1.5	7.6
ZL-YT _x	$y = 0.0437x + 19.045$	3.0	20.5
ZL-YT _n	$y = 0.0148x - 3.9099$	1.0	-3.4

The trends for the average annual air temperature were also analyzed in the papers of *Gavrilov et al.* (2018) and *Milentijević et al.* (2022). The first paper covers the territory of Kosovo and Metohija (southward of the observed area), while the second paper covers the territory of Backa (northward of the observed area). In both papers, trends in the average annual air temperature were analyzed, where a slight increase in air temperature was established, which is confirmed by the trend equation and trend magnitude. The results obtained by the MK trend test

indicate that the H_a hypothesis (positive trend) prevails in most cases. These results match the results of this study, because the distance between the observed meteorological stations is very small.

Similar results were obtained in most of the research conducted in the observed area, showing an increase in the average air temperature and a positive trend. This is consistent with the results of this scientific study (*Bajat et al.*, 2015; *Mimić et al.*, 2017; *Milentijević et al.*, 2021; *Milovanović et al.*, 2022b; *Tošić et al.*, 2022). Also, the obtained results are in accordance with the research conducted in the region, which coincide with the results of other authors (*Kendrovski and Spasenovska*, 2011; *Burić et al.*, 2019, 2023; *Milošević et al.*, 2017; *Popov et al.*, 2019; *Tadić et al.*, 2019; *Bačević et al.*, 2020, 2022; *Papić et al.*, 2020). The results coincide with the findings of other authors who investigated the area of the Balkan Peninsula (*Tsiotas et al.*, 2021; *Georgoulis et al.*, 2022; *Nikolov and Dimitrov*, 2022; *Sakalis*, 2023).

There are also researches that were conducted on the European continent and at the global level, that is, in different parts of the world (*Li et al.*, 2013; *Almazroui et al.*, 2017; *Fallah-Ghalhari et al.*, 2019; *Pasten-Zapata et al.*, 2019; *Burić and Penjišević*, 2023; *Gentilucci et al.*, 2023; *Zareaatkar et al.*, 2024). Finally, it is important to mention the official report of the International Panel on Climate Change (IPCC), which also supports these results. These data contribute to the general understanding of climate trends and climate change at local, regional, and global levels.

5. Conclusion

Based on the obtained results of the analyzed variables, as well as the geospatial distribution of the average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature for the vegetation period in the time interval from 1949 to 2018 in the observed area, the following conclusions can be drawn. Necessary data used in this scientific study were taken from meteorological yearbooks of the Republic Hydrometeorological Institute of Serbia, with a total of 24 meteorological stations. Mann-Kendall trend test was used for data processing and trend analysis, for a total of 72 time series. Also, trend equation and trend magnitude were calculated. The geospatial data distribution was done using GIS numerical analysis.

The general conclusion of this scientific study, after the obtained results, is that the average annual air temperature, average annual maximum air temperature, and average annual minimum air temperature for the vegetation period in the territory of Central Serbia are increasing. Based on the trend equation and trend magnitude, an increase in the specified temperatures was recorded in 66 time series, while a decrease in temperature was recorded in 6 time series. The smallest increase of 0.2 °C in the average annual air temperature for the vegetation period

in the observed area was recorded in three time series: KU-YT-VP, LE-YT-VP, and LE-YTn-VP, while the largest increase was recorded in one time series KZ-YTx-VP, and its value is 4.3 °C. The smallest decrease in the average annual air temperature for the vegetation period was recorded in the DI-YTn-VP time series (-0.01 °C), while the largest decrease was recorded in 2 time series, namely: DI-YT-VP and VG-YTn-VP, both with a temperature decrease of -0.5 °C (Table 2).

The MK trend test results show that in 53 time series, H_a hypothesis is dominant, where the p value is lower than the significance level α (0.05). On the other hand, there is no trend in the remaining 19 time series, where H_0 hypothesis prevails, with a p value greater than the significance level α (0.05). The geospatial data distribution shows the average air temperature values for each time series individually: a) Average annual air temperatures for the vegetation period in the observed area range from 10.6 °C in Dimitrovgrad to 18.1 °C in Belgrade; b) Average annual maximum air temperatures for the vegetation period in the observed area range from 32.1 °C in Nis to 25.6 °C in Zlatibor; c) Average annual minimum air temperatures for the vegetation period in the observed area range from -1 °C in Sjenica to 7.1 °C in Belgrade (Fig. 7). For the entire territory of Central Serbia, the obtained values are as follows. The average annual air temperature for the vegetation period is 16.2 °C. The average annual maximum air temperature for the vegetation period is 30.7 °C. The average annual minimum air temperature for the vegetation period is 3.9 °C.

These results indicate a warming trend in Central Serbia, which may have significant consequences on the local climate and agriculture, as well as on other aspects of the ecosystem (Mandić *et al.*, 2022). A decrease in precipitation in some areas, combined with an increase in temperature, may lead to an increased risk of droughts and forest fires (Bačević *et al.*, 2024). This indicates the need for adaptation and development of climate change mitigation strategies in this area, as well as in other areas.

Acknowledgement: MGR is grateful for L'Oréal-UNESCO For Women in Science award. SBM is grateful for grant F-178 of Serbian Academy of Sciences and Arts. MGR, NT, TT, SBM, and TL gratefully acknowledge the support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No 451-03-137/2025-03/ 200125, 451-03-136/2025-03/200125 & 451-03-65/2024-03/ 200123). Furthermore, SBM and TL emphasize that part of the research was supported by the Program of Cooperation with the Serbian Scientific Diaspora – Joint Research Projects – DIASPORA 2023, from the Science Fund of the Republic of Serbia, under the project LAMINATION (The Loess Plateau Margins: Towards Innovative Sustainable Conservation), Project number: 17807.

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