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Determination of changes in the total amount of precipitation using the Mann-Kendall trend test in Central Serbia for the period from 1949 to 2018

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Abstract— This study presents the trend analysis for a specific category of variables, namely the average annual precipitation. The geospatial distribution of the obtained results in Central Serbia is visualized using Geographic Information System (GIS) numerical analysis. The primary objective of this study is to identify potential changes in the trends of average annual precipitation within the observed area. Methodologically, the Mann-Kendall trend test, trend equation, and trend magnitude were employed for trend analysis. The data used for the analysis were sourced from the Meteorological Yearbooks of the Republic Hydrometeorological Service of Serbia, encompassing a total of 24 meteorological stations and spanning the period from 1949 to 2018. Based on the obtained results, statistically significant positive trends were observed in 17 time series, favoring the alternative hypothesis. Conversely, a decline in precipitation was noted in the remaining 7 time series. Among the time series, the largest increases in the total amount of precipitation over the past 69 years were recorded ont he area of the Dinaric Mountains. Conversely, the lowest increase in average precipitation was observed in the central part od the country.Furthermore, the time series with the greatest decrease in average annual precipitation was recorded ont he southeastern part of the country. In order to effectively address water-related challenges associated with precipitation fluctuations, it is essential to gain a comprehensive understanding of the shifting trends in precipitation over the region of Central Serbia.

Key–words: climate change, precipitation variability, Central Serbia, average annual precipitation trends, Mann-Kendall trend test, GIS

1. Introduction

We are witnessing increasingly frequent modern climate changes, which, in the opinion of many world scientists, are faster, more dynamic, and more intense in the last three decades than those from some past eras. The basic property of precipitation is its spatial and temporal variability. Each climate element is variable, to a greater or lesser extent, while the spatial and temporal variability of precipitation is particularly pronounced (*Jones*, 1999). Variations in precipitation patterns have direct implications for the sustainable development of the environment, agriculture, energy production, and the planning and management of water resources. These variations can also impact the realization of sustainable development goals related to water (*Amiri* and *Gocic*, 2021a). Consequently, there has been a concerted effort over the past few decades to analyze trends in precipitation time series on different spatiotemporal scales. Different statistical methods have been employed, often with assumptions about the normality, independence, and temporal consistency of the time series, to actively explore these trends (*Amiri* and *Gocic*, 2021b).

The variability of the total amount of precipitation was among the first to be investigated by the scientist *Biel* (1929), who covered the space of the entire Earth. He came to the conclusion that the variability of the total amount of annual precipitation increases in areas with a small amount of precipitation, and vice versa, it decreases in areas with a bigger amount of precipitation.

According to *Biel* (1929), Europe has the smallest range of variability compared to other continents. On the territory of Europe and North America, in the subpolar and polar zones, the variability of precipitation is lower than the average values. On the other hand, the areas above the oceans and their coasts of the abovementioned continents, which are under the influence of cold sea currents, have high values of variability of the total amount of precipitation in relation to the average (*Conrad*, 1941). At the global level, observing the influence of the general air mass circulation in the atmosphere on the variability of the total annual amount of precipitation, led to the conclusion, that the variability is bigger in the tropical and subtropical zones than in the temperate zone (*Morales*, 1977).

Similar claims as stated above are confirmed by the results obtained from the following modern scientific studies by the group of authors (*Trenberth et al.*, 2003; *Tebaldi et al.*, 2006; *Pall et al.*, 2007; *Lenderink* and *Van Meijgaard*, 2008; *Hardwick Jones et al*., 2010; *Lenderink et al.,* 2011, 2017; *Utsumi et al.*, 2011; *Mishra et al.*, 2012; *Berg et al.*, 2013; *Collins et al.*, 2013; *Kharin et al.*, 2013; *Westra et al.*, 2014; *Roderick et al.*, 2019, 2020; *Ali et al.*, 2021; *Visser et al.*, 2021).

Previous research in the area of the Balkan Peninsula and surrounding countries dealt with the problem of analyzing trends in the total amount of precipitation and their variability (*Maradin*, 2011; *Radevski et al.*, 2013; *Ivanova* and*Radeva*, 2016; *Popov et al.*, 2018; *Alsafadi et al.*, 2020; *Ćulafić et al.*, 2020; *Porja* and *Nunaj*, 2020; *Spiridonov* and *Balabanova*, 2021; *Barbulescu* and *Postolache*, 2023; *Lukić et al*., 2019). The obtained research results in the Balkans (*Valcheva* and *Spiridonov*, 2023) are very similar to the results of scientific studies for the analyzed area of Central Serbia, which in most cases indicate a slight increase in the total annual amount of precipitation and a positive trend, which is characteristic for almost the entire area of Southeastern Europe (*Leščešen et al*., 2023).

The existing or similar studies for the observed and analyzed area of Central Serbia are rare and scarce, but there is a lot of research that refer to the entire territory of Serbia. The analysis of precipitation trends in the last few decades as a part of climate change is the subject of research of many researchers in Serbia (*Ducić* and *Luković*, 2005; *Đorđević,* 2008; *Ducić et al.,* 2009, 2010; *Stanojević*, 2012; *Luković et al*., 2014; *Gavrilov et al*., 2015; *Živanović et al.*, 2020; *Erić et al.*, 2021; *Popov* and *Svetozarević*, 2021; *Velimirović et al.*, 2021; *Amiri* and *Gocić*, 2021a,b, 2023). The results obtained in the previously mentioned research indicate a slight increase in the total annual amount of precipitation for the observed area, and that climate variability is not expressed sufficiently. They also indicate a higher total annual amount of precipitation in the western part of Central Serbia compared to its eastern parts. Furthermore, they indicate the influence of the Atlantic Ocean, the Mediterranean, and the orography of the terrain, which relate to the total annual amount of precipitation for the observed territory.

In the previous decade, the trend in the research of climate elements was taken over by climate models. Due to the area of the researched territory, regional climate models performed the best, and their results can be useful for agriculture as well (*Ruml et al.,* 2012). Precipitation predictions until the end of this century, based on climate models, indicate that the frequency of extreme precipitation will increase, and that their spatial distribution will shift to the south of Serbia (*Erić et al.,* 2021). However, there is no single best climate model; therefore, the results from multiple climate models for a specific region are always considered. Due to their unreliability, measured data will be utilized in this paper.

Knowledge of precipitation regimes has great scientific and practical importance in almost all domains of modern society, and they are of particular importance in water supply, ecology, and flood protection. This study tries to answer the following questions: (1) if the total annual precipitation in Central Serbia changed in the period 1949–2018, (2) whether the precipitation trends are decreasing or increasing, (3) if the obtained trends are statistically significant, and finally, (4) what is the regional context of precipitation changes in Serbia.

The answers to the given questions are provided by the analysis of the annual amount of precipitation at 24 meteorological stations located in the observed area. The main goal of this study is to perform the necessary analysis of the variability of the change in the total average annual precipitation in Central Serbia for the time period 1949–2018, using the Mann Kendall (MK) trend test, trend equation and trend magnitude analysis. Also, the geospatial distribution of the obtained results over the investigated territory were shown with the help of GIS numerical analysis.

2. Data and methods

2.1. Research area

Central Serbia is located in the central part of the Balkan Peninsula and is a toponym referring to the territory of Serbia without the Autonomous Provinces (*Fig. 1*). The total area of the observed territory is 55.947 km². The natural borders of Central Serbia towards neighboring countries are represented by the following natural entities: 1) to the west, there is the Drina River, which forms a natural border with Bosnia and Herzegovina; 2) to the north, it extends to the rivers Sava and Danube, which separate the observed territory from Vojvodina in the north and from Romania in the northeast; 3) to the east, the Balkan and Rhodope Mountains represent the border with Bulgaria; 4) and to the south and southwest, the state border is determined by the administrative line with the Republic of North Macedonia, as well as the provincial border with the Autonomous Province of Kosovo and Metohija, which continues to the state border with Montenegro (*Radaković, et al.,* 2018).

The morphological structure of this territory is complex and consists of three main mountain areas: the Dinaric Mountains stretching to the west, the Carpathian-Balkan Mountains to the northeast and the Rhodope Mountains to the east and southeast (*Bačević, et al.,* 2021). The hypsometric differences of the terrain are distinguished: the highest point of the terrain is the mountain peak Midzor, 2168 m above sea level (Stara planina), and the lowest point is the confluence of the Timok river with the Danube (28 m above sea level) (*Marković,* 1966). The total difference in altitude between these two points is 2140 m. The following orographic units have a great influence on the climate and transformation of air masses in Central Serbia: the Pannonian Basin and two mountain ranges – the Dinarides and the Carpatho-Balkanides. Arctic continental air masses arrive in the observed area over the Pannonian Basin in the colder half of the year, while the Dinarides and Carpatho-Balkanides represent an orographic barrier which weakens the flow of air masses (*Ducić* and *Radovanović*, 2005).

As a consequence of this atmospheric circulation, three main climate types prevail in Central Serbia: continental, moderate-continental, and modified Mediterranean climates (*Bajat, et al.,* 2015). According to the Köppen's classification, Central Serbia falls under two climate categories: 1) Cfa climate (average temperature above 20 °C during warmer months and above -3 °C during colder months), 2) Dfa climate on high mountains (above 1500 m) (average temperature below 20 °C during warmer months and below -3 °C during colder months) (*Radinović*, 1981). The average annual air temperature for the time interval from 1949 to 2018 in Central Serbia is 10.7 °C, and the average amount of precipitation is 685.3 mm.

Fig. 1. The location of the meteorological stations in the studied area.

2.2. Materials

During the research, testing and analysis of trends was performed for one category of parameters, that is, for the total average annual precipitation as a climate variable for the area that includes Central Serbia. It is a time series of a total of 69 years (1949–2018). The data necessary for this type of research were taken from the Meteorological Yearbooks of the Republic Hydrometeorological Service of Serbia (RHMZ) (http://www.hidmet.gov.rs/) covering two 30-year cycles, which is in accordance with the World Meteorological Organization (WMO) standards. For the purposes of this study, precipitation data from 24 meteorological stations were used. The altitude of meteorological stations in Central Serbia varies: a) up to 200 m: Negotin, Veliko Gradište, Jagodina, Loznica, Smederevska Palanka, Belgrade, Ćuprija, Zaječar, Kruševac, Valjevo, and Kragujevac, b) from 200 to 500 m: Niš, Kraljevo, Leskovac, Knjaževac, Požega, Pirot, Kuršumlija, Bujanovac, Vranje, and Dimitrovgrad, c) from 500 to 1000 m: Novi Pazar, and d) over 1000 m: Zlatibor and Sjenica (*Bačević, et al.,* 2021).

Station names, geographic coordinates, and elevation belts are shown in *Fig. 1* and *Table 1.* The homogeneity of the annual precipitation series was examined according to *Alexandersson* (1986). The homogeneity test showed that the precipitation time series for 24 stations used in this study are homogeneous.

2.3. Methods

Three statistical approaches were used in the analysis of trends in the total average annual precipitation. The first approach is the linear trend equation (*Bačević et al.*, 2020; *Mudelsee*, 2014), which is determined for each time series individually. Completely independent of the first step, all trends were tested using the non-parametric MK trend test (*Milentijević et al.*, 2018; *Zeleňáková et al.*, 2018). The third step consists of determining the trend magnitude obtained on the basis of the trend equation (*Bačević et al.*, 2022; *Gavrilov et al.,* 2016). The Exel program from the Microsoft Office software package was used to determine trends in the total average annual precipitation. The XLSTAT software was used for calculating the confidence level *p*, as well as for testing of the hypotheses (https://www.xlstat.com/en).

Table 1. List of meteorological stations located in Central Serbia, names of time series, geographic coordinates, and altitudes.

No.	Meteorological station	Name of time series	φ (°N)	λ (°E)	*h* (m)
1.	Belgrade	BG-P	44º48′	20º28′	132
2.	Bujanovac	BU-P	42º27′	21º46′	399
3.	Ćuprija	ĆU-P	43º56′	21º23′	123
4.	Dimitrovgrad	DI-P	43º01′	22º45′	450
5.	Jagodina	JA-P	43º59′	21º23′	115
6.	Knjaževac	KŽ-P	43º34′	22º15′	263
7.	Kragujevac	KG-P	44º02′	20º56′	181
8.	Kraljevo	KV-P	43º43′	20º42′	215
9.	Kruševac	KŠ-P	43º37′	21º15′	166
10.	Kuršumlija	KU-P	43º08′	21º16′	384
11.	Leskovac	LE-P	42º59′	21º57′	231
12.	Loznica	LO-P	44º32′	19º14′	121
13.	Negotin	NG-P	44º14′	22º32′	42
14.	Niš	NI-P	43º20′	21º54′	202
15.	Novi Pazar	NP-P	43º08′	20º31′	545
16.	Pirot	PI-P	43º09′	22º35′	373
17.	Požega	PŽ-P	43º51′	20º02′	311
18.	Sjenica	SJ-P	43º16′	20º00′	1038
19.	Smederevska Palanka	SP-P	44º22′	20º57′	121
20.	Valjevo	VA-P	44º17′	19º55′	174
21.	Veliko Gradište	VG-P	44º45′	21º30′	80
22.	Vranje	VR-P	42º33′	21º55′	433
23.	Zaječar	ZA-P	43º53′	22º17′	144
24.	Zlatibor	ZL-P	43º44′	19º43′	1029

2.3.1. The linear regression and the trend equation

The linear trend method is a technique of extreme importance for the analysis, evaluation, and distribution of short-term and long-term changes in the total average annual precipitation (*Bacevic et al.,* 2018; *Mudelsee,* 2019). Its general form is:

$$y = ax + b, \tag{1}$$

where y represents the total average annual precipitation expressed in mm, a is the magnitude of the slope, x is the time series, while b represents the total annual precipitation at the beginning of the period. The value of the precipitation trend is a function of the magnitude of the slope. There are three possible cases: a) the magnitude of the slope is greater than zero – the trend is positive (growing); b) when it is less than zero – the trend is negative (declining); c) when it is equal to zero – there is no trend (no changes).

2.3.2. The trend magnitude

The trend magnitude is determined from the linear trend equation (*Gavrilov et al.*, 2016):

$$\Delta y = y(Pb) - y(Pe), \tag{2}$$

where Δy represents the trend magnitude expressed in mm, y (1949) in the trend equation represents the total annual amount of precipitation at the beginning of the period, and y (2018) represents the total annual amount of precipitation at the end of the period. Speaking of the trend magnitude, there are three possible cases: a) when it is greater than zero - the trend is negative (decreasing); b) when Δy is less than zero – the trend is positive (growing); c) when it is equal to zero – there is no trend (no changes).

2.3.3. The Mann-Kendall non-parametric test

In addition to the regression analysis, the non-parametric MK trend test (*Mann*, 1945; *Kendall*, 1975) was used for additional assessment of the existence or absence of a trend. Using the MK test, two hypotheses were tested: the null hypothesis (H_o), which indicates the absence of a trend in the time series; and the alternative hypothesis (H_a), where there is a statistically significant trend in the time series for the set significance level (α). The p value plays a central role in the MK test (*Karmeshu*, 2012). The p value determines the confidence level of the hypothesis. If the p value is lower than the chosen significance level α (typically α=0.05 or 5%), the hypothesis H_o should be rejected and the hypothesis H_a accepted. On the contrary, if the p value is greater than the significance level α, then the null hypothesis is accepted (*Razavi et al.,* 2016).

2.3.4. QGIS analysis

All digital cartographic analyzes were approved using three open-source software programs, namely the Quantum Geographical Information System (QGIS 3.12), System for Automated Geoscientific Analyzes (SAGA 8.2.0), and Google EarthEngine. Satellite data were downloaded from the National Aeronautics and Space Administration's two databases EarthData (NASA), (https://ladsweb.modaps.eosdis.nasa.gov/search/imageViewer/1), at 30 m resolution.

The digital elevation model (DEM) was downloaded from the official United States Geological Survey (USGS) website at 30 m resolution. These data were recorded in AsterDem (*Valjarević et al.,* 2022). After the accurate determination of geographic coordinates (longitude, latitude, altitude), the next step was to determine the kriging belt of monthly and annual average precipitation data for the meteorological stations. For this purpose, SAGA 8.2.0 and QGIS 3.12 were used.

In the last step, superpixel classification was used with the Google Earth Engine software to better analyze the spatial distribution of meteorological stations (*Valjarević et al.,* 2018). These methods are also useful for analyzing climate characteristics within an area (see *Fig. 1*). Following the remote sensing and GIS analyzes, the kriging and interpolation belts are analyzed to better represent the precipitation distribution and characteristics in the analyzed periods (*Valjarević et al*., 2023; *Alexakis et al.,* 2013).

3. Results

3.1. Trend parameters

In this paper, the main results are presented in *Table 2* and *Figs. 2* and *3*. Furthermore, the paper presents the analysis for a total of 24 meteorological stations which are located in the area of Central Serbia and for the same number of time series. The obtained results for the average annual precipitation, the results of the trend equation, linear trend equation, and trend magnitude are presented visually in *Fig. 2* and *Table 2*. The *p* value, results of trend testing using the MK trend test, and evaluation of hypotheses for accepting or rejecting the trend are shown in *Fig. 2*, for each meteorological station in the territory of Central Serbia.

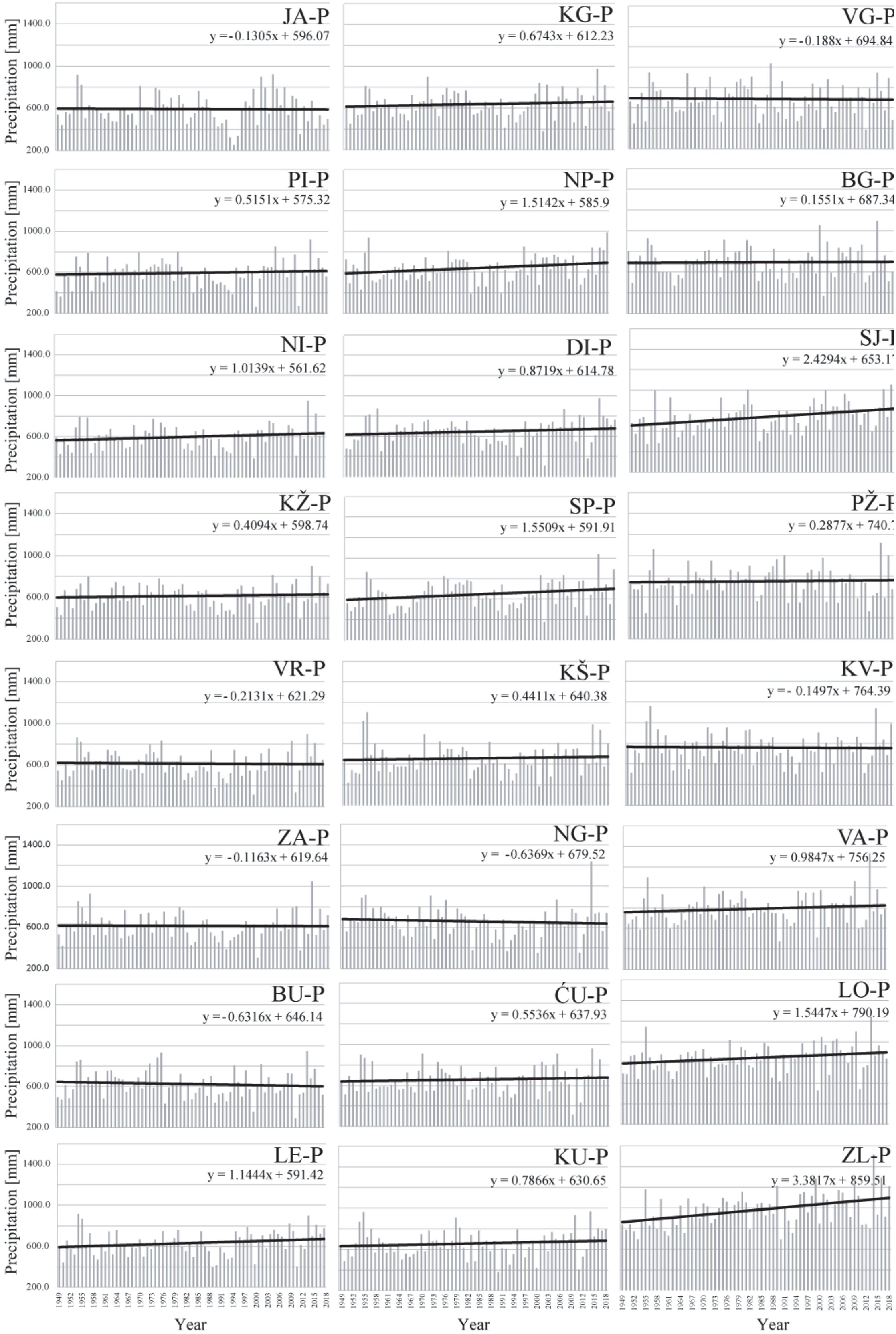

Fig. 2. Visual representation of average annual precipitation, trend equation, and linear trend for selected meteorological stations, arranged from the station with the lowest to the station with the highest average annual precipitation in Central Serbia for the observed time period from 1949 to 2018.

Table 2. Time series names, trend equation, trend magnitude Δy, and the average amount of precipitation, for 24 time series.

Time series	Trend equation	Δy (mm)	Average amount of precipitation (mm)
BG-P	y = 0.1551x + 687.34	10.7	692.8
BU-P	y = -0.6316x + 646.14	-43.6	623.7
ĆU-P	y = 0.5536x + 637.93	38.2	658.1
DI-P	y = 0.8719x + 614.78	60.2	644.4
JA-P	y = -0.1305x + 596.07	-9.0	591.4
KŽ-P	y = 0.4094x + 598.74	28.2	613.3
KG-P	y = 0.6743x + 612.23	47.0	635.4
KV-P	y = -0.1497x + 764.39	-10.3	757.8
KŠ-P	y = 0.4411x + 640.38	30.4	656.0
KU-P	y = 0.7866x + 630.65	54.3	658.6
LE-P	y = 1.1444x + 591.42	79.0	633.2
LO-P	y = 1.5447x + 790.19	106.6	845.0
NG-P	y = -0.6369x + 679.52	-43.9	656.9
NI-P	y = 1.0139x + 561.62	70.0	597.6
NP-P	y = 1.5142x + 585.90	105.0	639.7
PI-P	y = 0.5151x + 575.32	35.0	593.6
PŽ-P	y = 0.2877x + 740.70	19.9	750.9
SJ-P	y = 2.4294x + 653.17	167.6	739.4
SP-P	y = 1.5509x + 591.91	107.0	647.0
VA-P	y = 0.9847x + 756.25	67.9	791.0
VG-P	y = -0.1880x + 694.84	-13.0	688.2
VR-P	y = -0.2131x + 621.29	-14.7	613.7
ZA-P	y = -0.1163x + 619.64	-8.0	615.5
ZL-P	y = 3.3817x + 859.51	233.3	973.9

The results obtained from the above mentioned parameters, which are shown in *Fig. 2* and *Table 2*, indicate a slight increase in the average total annual precipitation in the territory of Central Serbia, which coincides with the results from the reports of other similar studies, which were carried out in countries from the region. Out of a total of 24 time series, a slight increase in the average total annual precipitation was recorded in 17 time series, while a decreasing amount of precipitation was recorded in the remaining 7 time series.

The biggest increase in the average total annual precipitation of 233.3 mm in the past 69 years was recorded in the Zl-P time series, followed by the SJ-P and SP-P time series, where the increase of 167.6 mm, and 107.0 mm was recorded respectively. The smallest increase in the average total annual precipitation of 10.7 mm was recorded in the BG-P time series, followed by the KZ-P and KS-P time series with the increase of 28.2 mm and 30.4 mm, respectively.

The biggest decrease in the total average annual precipitation of -43.9 mm was recorded in the NG-P time series. It is followed by the BU-P time series with the decrease of -43.6 mm and the VR-P time series with the decrease of -14.7 mm. Based on the obtained results, the total average annual precipitation in Central Serbia amounts to 679.9 mm.

3.2. Trend assessment

The results obtained from the analysis of the MK trend test and the evaluation of hypotheses (*p* values, type of hypothesis, risk of rejecting the hypothesis) are described in *Fig. 3*. From a total of 24 time series, a significant statistically positive trend was recorded in 5 time series, where the H_a hypothesis prevails and the *p* value is lower than the significance level α, whose value is 0.05, while in 19 time series there is no trend, and in these cases hypothesis H_o prevails, where the *p* value is greater than the significance level α.

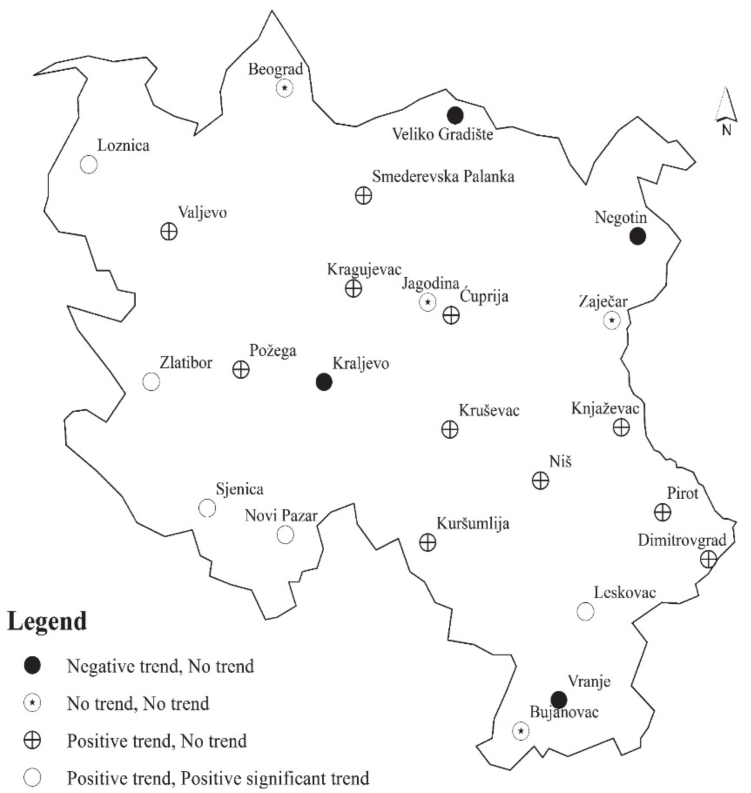

Fig. 3. Cartographic presentation of the obtained results of the linear equation and the Mann-Kendall trend test, respectively, for the total annual amount of precipitation in Central Serbia for the time period from 1949 to 2018.

From a total of 5 time series, where a significantly positive statistical trend prevails, hypothesis H_a prevails, with a very small percentage of risk ranging between 0.08% and 4.55% to reject the given hypothesis. From a total of 19 time series, where there is no trend and hypothesis H_o prevails in most cases, the risk of rejecting this hypothesis is very high. The risk values for rejecting this hypothesis range from 5.15% to 97.93%. A risk whose value is between 5.00% and 10.00% is recorded in one time series, which tells us that there is no trend. Values between 10.00% and 50.00% were recorded in nine time series, indicating that the trend is in stagnation. Furthermore, in the last nine time series the risk value ranges between 70.15% and 95.46%, where in the perspective the trend is likely to change to a positive one.

These results indicate that the total annual amount of precipitation in Central Serbia is stagnant, which coincides with the results of other researchers. In the majority of analyzed cases, the results of the trend equation deviate from the results of the MK trend test, more precisely in 15 time series. In the remaining 9 time series, the results coincide. In 11 cases (CU-P, DI-P, KZ-P, KG-P, KS-P, KU-P, NI-P, PI-P, PZ-P, SP-P, and VA-P) the MK trend test did not recognize a positive trend, while the trend equation indicates an increase in average annual precipitation, and in four cases (KV-P, NG-P, VG-P, and VR-P) the MK trend test indicates that there is no trend, while the trend equation indicates that the trend is negative. Time series in which the results coincide are: BG-P, BU-P, JA-P, LE-P, LO-P, NP-P, SJ-P, ZA-P , and ZL-P (*Fig. 3*).

3.3. GIS numerical analysis

The spatial distribution of the total annual amount of precipitation for the time period from 1949 to 2018 in Central Serbia is shown in more detail in *Fig. 4*.

Fig. 4 shows the geospatial distribution of average annual precipitation in the analyzed territory of Central Serbia. Interregional differences in the average annual amount of precipitation are caused by several reasons, among which the following could stand out: the influence of the influx of air masses from the Atlantic Ocean, the influence of the Mediterranean, presence of temporary atmospheric instabilities (on a season scale) that produce heavy showers, and the influence of the terrain morphology. Therefore, in the western and northwestern parts of the observed area, a higher average annual amount of precipitation was recorded, while in the central, southern, and southeastern parts, the average annual amount of precipitation was lower.

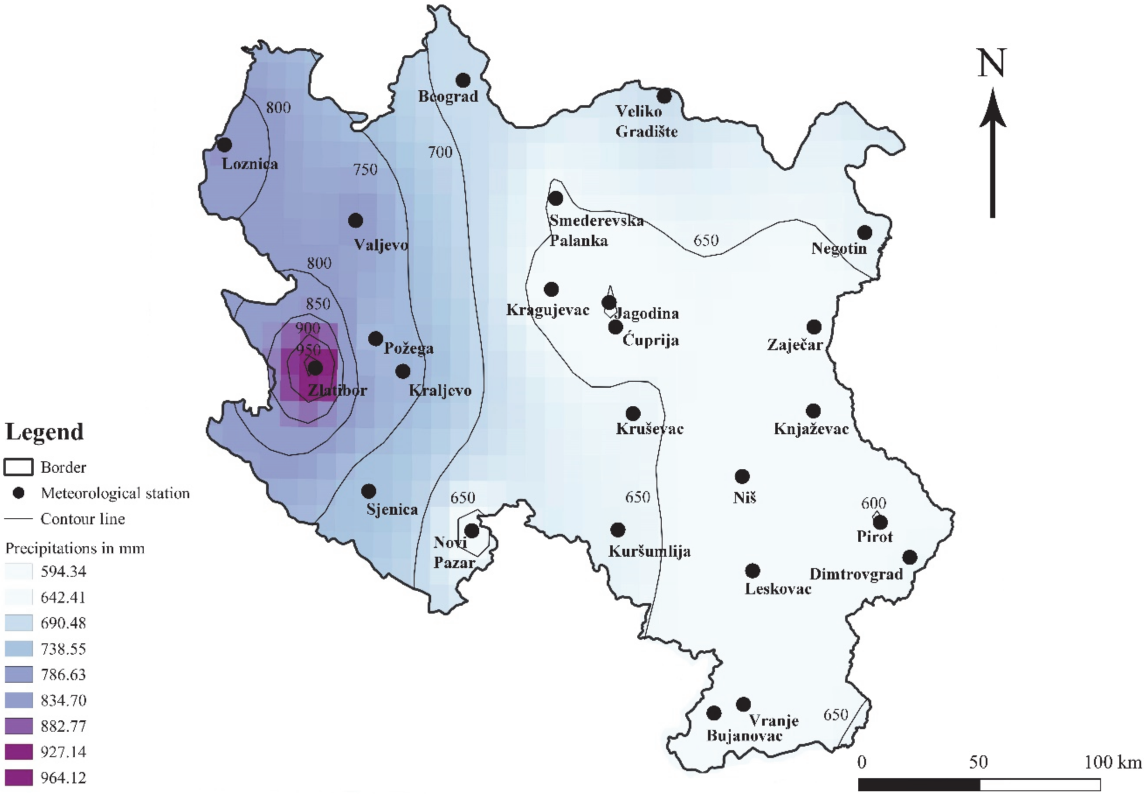

Fig. 4. Spatial distribution of the average amount of precipitation for the time period from 1949 to 2018 in Central Serbia.

The values for the total annual amount of precipitation in Central Serbia for the time period from 1949 to 2018 are 679.9 mm ranging between 591.4 and 973.9 mm. The lowest value of average annual precipitation (591.4 mm) was recorded in Jagodina, and the highest value (973.9 mm) was recorded in Zlatibor. Other values for the average annual amount of precipitation are shown chronologically from the lowest to the highest, and they are as follows: Pirot (593.6 mm), Niš (597.6 mm), Knjaževac (613.3 mm), Vranje (613.7 mm), Zaječar (615.5 mm), Bujanovac (623.7 mm), Leskovac (633.2 mm), Kragujevac (635.4 mm), Novi Pazar (639.7 mm), Dimitrovgrad (644.4 mm), Smederevska Palanka (647 mm), Kruševac (656 mm), Negotin (656.9 mm), Ćuprija (658.1 mm), Kuršumlija (658.6 mm), Veliko Gradište (688.2 mm), Belgrade (692.8 mm), Sjenica (739.4 mm), Požega (750.9 mm), Kraljevo (757.8 mm), Valjevo (791 mm), and Loznica (845 mm).

4. Discussion

Based on the analyzed climate variable, the following can be stated: in this paper, a total of 24 time series were analyzed using trend equations, trend magnitude indicating an average increase or decrease in the total annual precipitation, MK trend test, and GIS numerical analysis. According to the trend equation and trend magnitude, seventeen time series recorded an increase in the total annual amount of precipitation in the following cases, which are arranged chronologically from the smallest to the biggest increase: BG-YP, PZ-YP, KZ-YP, KS-YP, PI-YP, KG-YP, KU-YP, DI-YP, VA-YP, NI-YP, LE-YP, NP-YP, LO-YP, SP-YP, and ZL-YP.

The biggest average increase in the average annual precipitation of 233.3 mm was recorded in the case of ZL-YP. The smallest increase in total annual precipitation of 10.7 mm was recorded in the case of BG-YT. A decrease in the total annual amount of precipitation was recorded in seven time series related to the average annual amount of precipitation, which are arranged chronologically from the smallest to the biggest decrease: ZA-YP, JA-YP, KV-YP, VG-YP, VR-YP, BU-YP, and NG-YP.

The smallest decrease in total annual precipitation of -8.0 mm was recorded in the case of ZA-YP, while the biggest increase of -49.9 mm was recorded in the case of NG-YP. Speaking of the MK test, the obtained results indicate that a statistically significant positive trend was recorded in the analyzed parameters in 5 time series. On the other hand, there are no changes (no trend) in 19 time series. The spatial distribution of the average annual amount of precipitation in Central Serbia is 679.9 mm. It ranges between 591.4 and 973.9 mm.

In the paper of *Gocić* and *Trajković* (2013), the average annual and seasonal trends for seven meteorological variables, including the average annual amount of precipitation for twelve meteorological stations in Serbia were analyzed. The time period covered in this paper is from 1980 to 2010. As in this study, the non-parametric Mann-Kandell trend test was used to determine whether there is a positive or negative trend in the time series for the observed variable. Speaking of precipitation, no significant trends were observed in the given study, except in the case of one meteorological station, Sombor, which can be seen in *Table 3*.

In general, the results of this study are very similar to the research conducted by *Gocić* and *Trajković* (2013). In most cases, there is no trend in both papers when applying the MK test. In the research of *Gocić* and *Trajković*, a positive trend was noted only for one meteorological station, i.e. Sombor, and in this work, a positive trend was recorded for five meteorological stations, namely: Novi Pazar, Leskovac, Loznica, Sjenica, and Zlatibor. From these results, it is evident that there is no correlation between the findings from the two studies for the meteorological stations Loznica and Zlatibor. However, the results align for other investigated stations. In the work of *Gocić* and *Trajković* (2013), the trend for these two meteorological stations is negative, and in this study, the trend for them is positive, which can be seen in *Table 3* and *Fig. 3*. Such discrepancies presumably result from the difference in the observed time period of 39 years. Special attention should be given to the period of the last nine years, specifically from 2010 to 2018, due to the increasingly pronounced climate changes observed over the last two decades. This study can pave the way for new research, shedding light on the differences between these two studies, and contributing to fresh insights in the field.

Changes in the total annual amount of precipitation in the region differ depending on the country in which the research was conducted (e.g. *Lukić et al.,* 2019; *Micić Ponjiger et al.,* 2023). A slightly positive trend was recorded in the eastern part of Croatia, for the period from 1961 to 2010 (*Gajić-Čapka et al.,* 2014). The same is observed for the western parts of Romania, where an increase in total annual precipitation was also registered (*Croitoru et al.,* 2016). Also, the northern parts of Montenegro record an increase in the amount of precipitation for the time period from 1951 to 2010 (*Burić et al.,* 2015). These results coincide with this study.

In Hungary, no change was recorded in the total annual amount of precipitation (*Klapwijk et al.,* 2013), which, for example, is not in accordance with the results of this paper. The reason for the discrepancy between the results of these two studies is probably the influence of different orography, primarily the altitude at which the meteorological stations of the observed territories are located.

A slight decrease in the amount of precipitation, without statistical significance, was recorded in the paper written by *Bocheva et al.,* (2009) for the territory of Bulgaria. These results match the findings of this study for seven meteorological stations (Bujanovac, Jagodina, Kraljevo, Negotin, Veliko Gradište, Vranje, and Zaječar). Most of these meteorological stations are located in the eastern, southeastern, and southern regions of Central Serbia, i.e., in relative proximity to the border between Bulgaria and Serbia, which may indicate the similarities in the results of these two studies. Furthermore, these results align with other findings related to the European continent, where slight changes in precipitation were also observed (*Conrad,* 1941; *Klein Tank* and *Können*, 2003).

Table 3. Results of the statistical tests for seasonal and annual precipitation amounts over the period 1980–2010 (*Gocić* and *Trajković*, 2013)

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_s	-1.343	-0.476	1.003	0.136	-0.085
	Q_{med}	-2.333	-2.256	2.317	0.609	-0.333
Dimitrovgrad	Z_s	-0.573	-0.612	1.806	1.274	1.292
	Q_{med}	-1.050	-3.817	3.050	4.683	3.442
Kragujevac	Z_s	-1.173	-0.762	1.407	0.272	-0.051
	Q_{med}	-2.983	-2.600	2.367	0.875	-0.350
Kraljevo	Z_s	0.306	0.238	0.816	0.408	0.068
	Q_{med}	1.026	1.350	3.633	2.833	0.010
Loznica	Z_s	-0.001	0.646	1.241	1.802	1.870
	Q_{med}	-0.050	4.950	3.217	6.633	5.017
Negotin	Z_s	1.972*	0.136	0.935	1.122	0.340
	Q_{med}	2.550*	1.000	2.750	1.867	1.117
Niš	Z_s	0.357	-0.538	0.816	1.714	0.544
	Q_{med}	1.733	-2.433	3.133	3.367	1.055
Novi Sad	Z_s	0.612	0.417	2.532*	0.612	1.802
	Q_{med}	3.257	3.917	2.550*	2.583	4.579
Palić	Z_s	1.054	0.748	1.513	0.527	1.802
	Q_{med}	4.917	4.833	4.467	1.617	4.421
Sombor	Z_s	0.578	1.615	1.172	0.868	1.989*
	Q_{med}	2.070	3.700	3.800	3.300	4.183*
Vranje	Z_s	0.357	-0.382	1.394	0.544	1.309
	Q_{med}	1.850	-2.683	2.376	1.550	3.383
Zlatibor	Z_s	0.578	0.068	1.479	0.731	1.207
	Q_{med}	2.933	0.300	3.450	2.633	3.363**

Z_s: Mann – Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

5. Conclusion

This study presents the analyzed trends and geospatial distribution of the obtained results for the average annual amount of precipitation (one category of variables) in the region of Central Serbia. The observed time period is from 1949 to 2018, which is a period of 69 years. The data used for this research were taken from the Meteorological Yearbooks of the Republic Hydrometeorological Service of

Serbia, with a total of 24 meteorological stations. The Mann-Kendall trend test was used for data processing and trend analysis. Additionally, trend equations and magnitudes were calculated using suitable formulas, and the results were presented visually through GIS numerical analysis.

By analyzing the obtained results of this study, it can be noticed that the total annual amount of precipitation in the territory of Central Serbia is slightly increasing. Based on the trend magnitude, an increase in the average annual amount of precipitation was recorded in seventeen cities of Central Serbia, while a decrease in the average annual amount of precipitation was recorded in seven cities of Central Serbia (*Table 2*). Observing the geospatial distribution of the obtained results, it can be concluded that the total average annual amount of precipitation for the observed period in Central Serbia is 679.9 mm. It ranges from 591.4 to 973.9 mm. The values are higher in the western parts compared to the eastern parts.

The biggest increase in the total amount of precipitation of 233.3 mm in the past 69 years was recorded in the time series Zl-P, followed by the time series SJ-P and SP-P, where the increase of 167.6 mm and 107.0 mm was recorded, respectively. The smallest increase in the average amount of precipitation of 10.7 mm was recorded in the time series BG-P, followed by the time series KZ-P and KS-P with the increase of 28.3 mm and 30.4 mm, respectively.

The bigest decrease in the average annual precipitation was recorded in the time series NG-P -43.9 mm, followed by time series BU-P with a decrease of -43.6 and VR-P with a decrease of -14.7 mm. The general conclusion of the results obtained in this way, indicating interregional differences in the average annual amount of precipitation, is that they are presumably preconditioned by several reasons, among which the followings stand out: the influence of the influx of air masses from the Atlantic Ocean, the influence of the Mediterranean, presence of temporary atmospheric instabilities (on a season scale) that produce heavy showers, and the influence of terrain morphology, i.e., orography. The results of this study can be used to effectively address water-related challenges associated with precipitation fluctuations, and therefore, they are crucial for gaining a thorough understanding of the changing trends in precipitation across Central Serbia induced by climate change.

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