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# Precipitation during the vegetation period in Central Serbia over 70 years

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**Abstract**— In this study, the trend for a category of variables, that is, for the total average annual amount of precipitation for the vegetation period (P-VP) from April to October is presented. Moreover, with the help of Geographic Information System (GIS) numerical analysis, geospatial distribution of the obtained results on the territory of the Central Serbia is described. The main objective of this study is the possible changes in trends for the total average annual amount of precipitation for the vegetation period in the observed area. In terms of methodology, trend testing was conducted using the Mann-Kendall trend test (M-K), trend equation, and trend magnitude. The data used for the necessary analysis were taken from the Meteorological Yearbooks of the Republic Hydrometeorological Institute of Serbia, with a total of 24 meteorological stations, for the observed time period from 1949 to 2018. A total of 24 time series were analyzed. The average annual amount of precipitation for the vegetation period of the observed area is 427.6 mm. The values range from 362.3 mm to 625.5 mm. The lowest value was recorded in Nis, while the highest value was recorded in Zlatibor. Based on the obtained results, a statistically significant positive trend was recorded in 2 time series, whereas in the remaining 22 time series there was no trend. Furthermore, the results obtained by the trend equation, and trend magnitude indicate a slight increase in the total average annual precipitation in 21 time series and a decrease was recorded in the remaining 3 time series. A decrease in the average annual amount of precipitation for the vegetation period was recorded in three cities, namely: Jagodina (-15.9 mm), Bujanovac (-4.6 mm), and Zajecar (-0.5 mm). Comprehending the interaction between precipitation and vegetation period is crucial for implementing adaptation and mitigation measures in terrestrial ecosystems. The preliminary findings of this study can offer a technical foundation and valuable reference for water resource and sustainable ecological management strategies in the Republic of Serbia, benefiting policymakers and stakeholders involved.

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

## *1. Introduction*

Both in the rest of the world and in Serbia, climate change is being talked about more and more often, and we are witnessing more and more frequent changes, especially when it comes to two key climate elements – temperature and precipitation. These changes are becoming more and more dynamic, faster, and intense during the last two decades, which is confirmed by many scientific studies devoted to this issue and this very current topic all over the world.

Changes in total average annual precipitation, especially during the vegetation period, can have significant consequences in various sectors, including agriculture, biodiversity, human health, hydrology, forestry, water resources, and others. This kind of research has not been carried out so far, so this study is gaining in importance. Each climate element is variable, to a greater or lesser extent, while spatiotemporal variability is particularly distinctive in precipitation (*Jones*, 1999).

The intensity, distribution, and frequency of precipitation vary around the world and are often subject to climate change, which is confirmed by the results of modern scientific studies by a group of authors (*Musellman et al*., 2018; *Pall et al*., 2019; *Roderick et al*., 2019, 2020; *Ali et al*., 2021; *Chen et al*., 2021; *Visser et al*., 2021; *Masamichi* and *Sugimoto*, 2022; *Derdour et al*., 2022; *Kimberley* and *Barkdoll*, 2023; *Salazar et al*., 2023; *Nosratpour* and *Rahimzadegan*, 2023; *Konstali et al*., 2023; *Lai, et al*., 2023; *Hines et al*., 2023; *Ghanghas et al*., 2023). Observing the influence of the general air circulation in the atmosphere on precipitation variability, it is concluded that changes in the total amount of precipitation are greater in the tropical and subtropical zones than in the temperate zone (*Morales*, 1977). In addition, global warming has a major impact on precipitation patterns, leading to extreme weather conditions such as droughts or heavy rainfall (*IPCC*, 2018). The total amount of precipitation in most of the world will increase due to climate change, which also applies to the intensity of extreme events (*Masamichi*, 2021).

This study tries to answer the following questions: (1) if the total annual precipitation for the vegetation period in Central Serbia changed in the period from 1949–2018; (2) whether precipitation trends for the vegetation period are decreasing or increasing; (3) if the obtained trends are statistically significant, and finally, (4) what is the regional representation of precipitation changes for the vegetation period in Serbia. The answers to these questions are provided by the analysis of the annual amounts of precipitation for the vegetation period 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 for the vegetation period in Central Serbia for the time period from 1949–2018, using the Mann Kendall trend test, trend equation, and trend magnitude. Also, with the help of GIS numerical analysis, the geospatial distribution of the obtained results in the observed area is shown.

### *1.1. Overview of previous research*

The earliest research related to climate change and precipitation variability in Europe shows us that the European continent has the smallest range of variability compared to other continents (*Conrad*, 1941). In the past decade, many researches related to climate change in Europe, and the variability of the total amount of precipitation have been conducted.

In the north of Europe (Norway) there are no sudden changes in the distribution of precipitation, but a noticeable growing trend has been recorded (*Zhou et al.,* 2022). In the southern part of Europe (Italy), the precipitation trend shows a slight increase of an average of 5.42 mm per year, but none of the analyzed trends is statistically significant (*Faqueseh* and *Grossi*, 2024). In the central part of Europe (Hungary), the results of previous research indicate that trend analysis for medium and extreme precipitation rarely shows significant trends (*Maheras et al*., 2018). The results obtained in the western part of the European continent (Southeast of France) indicate that there is no statistically significant trend (*Ramesh et al*., 2010). The same case was recorded on the territory of Belgium as well (*De Jongh et al*., 2006). In the eastern part of the European continent (Lithuania and Belarus), it was determined that the amount of precipitation in Lithuania slightly increased by 10 mm, while in Belarus it significantly decreased by 109 mm (*Tripolskaja* and *Pirogovskaja*, 2013).

Meanwhile, a positive trend is present in almost the entire part of southeast Europe (*Leščešen et al*., 2023). Similar results were obtained in the Balkan Peninsula, the Balkan region, and Serbia (*Ducić* and *Luković*, 2005; *Đorđević*, 2008; *Ducić et al*., 2009, 2010; *Stanojević,* 2012; *Hrnjak et al*., 2013; *Radevski et al*., 2013; *Luković et al.,* 2014; *Gavrilov et al*., 2015; *Ivanova* and *Radeva*, 2016;

*Bačević et al.*, 2017; *Popov et al.*, 2018; *Gavrilov et al.,* 2019*; Alsafadi et al*, 2020; *Culafić et al*., 2020; *Porja* and *Nunaj*, 2020; *Živanović et al*., 2020; *Gocić et al*., 2020; *Erić et al*., 2021; Milentijević et al., 2021; *Popov* and *Svetozarević*, 2021; *Spiridonov* and *Balabanova*, 2021; *Amiri* and *Gocić*, 2023; *Barbulescu* and *Postolache*, 2023), indicating that in most cases there is no significant trend, and that there are no major changes in the geospatial distribution of precipitation, possibly in some cases a slight increase in the total amount of precipitation was recorded, which coincides with this study and with most of the other studies referring to the entire European continent and being quoted in this chapter.

Such obtained results are a manifestation of several factors, namely: climate changes (increase in average air temperature), the influence of the Atlantic Ocean and the Mediterranean, and the orography of the observed territory. *Wu et al*. (2015) noted a widespread agreement among scholars regarding the significant spatial heterogeneity in vegetation response to precipitation variability. *White et al*. (2005) demonstrated that the dynamic response of terrestrial vegetation in the United States to precipitation changes relies on various topographic attributes such as elevation, slope, and aspect. *Propastin et al*. (2008) attributed the considerable spatial variability in the relationship between vegetation growth and precipitation in Central Asia to distinct vegetation types. *Chamaillé-Jammes* and *Fritz* (2009) calculated correlations between normalized difference vegetation index (NDVI) and precipitation fluctuations in eastern and southern African savannas, revealing that mean annual precipitation (MAP) actively determines the spatial distributions of vegetation sensitivity to altered precipitation patterns.

Recent studies have attempted a more comprehensive analysis of the spatial patterns of vegetation response to precipitation variability, considering multiple external factors simultaneously. *Zeraatkar et al*. (2022) investigated vegetation response to climatic parameters using zonal statistics, finding a decrease in annual precipitation from 1990 to 2020 with an increase in 2020. They observed a positive relationship between NDVI and precipitation at the annual scale, indicating a decrease in vegetation growth by approximately 90% between 2000 and 2010 due to observed climatic variations. *Camberlin et al*. (2007) examined the response of NDVI to precipitation variations in tropical Africa, associating the spatially heterogeneous vegetation response with MAP, vegetation type, and soil properties. *Hawinkel et al*. (2016) analyzed the precipitation-vegetation relationship over East Africa, highlighting MAP, vegetation type, and elevation as primary controllers of vegetation sensitivity to precipitation variability. *Ayanlade et al*. (2021) assessed spatial and temporal changes in precipitation and their effects on vegetation greenness across six ecological zones in Nigeria, finding that rainfall seasonality significantly influences vegetation greenness in all ecological zones. *Chen et al*. (2020) investigated vegetation response to precipitation anomalies in East Asia (China) and explored factors influencing varied vegetation responses to precipitation variability, including precipitation frequency, and distribution. *Soomro et al*. (2021) studied the relationship between precipitation and vegetation to devise sustainable management measures for fragile biomes. Their analysis of trends and correlations between precipitation and NDVI from 1982 to 2015 over the Kunhar River basin, Pakistan, suggested that precipitation is not the sole factor influencing vegetation growth, with other climatic and biogeographic factors also playing significant roles.

*Eisfelder et al*. (2023) conducted a systematic study of seasonal vegetation trends across Europe over 30 years using a novel NDVI time series, revealing varied spatial patterns: positive spring trends in Scandinavia, Russia, and parts of Europe; negative summer trends in southern Russia and western Kazakhstan; and positive autumn trends across the region. Overall, their findings support previous observations of vegetation greening in Europe during the growing season. Knowing the rainfall regime for the vegetation period has great scientific, but also practical importance in almost all domains of modern society, and it is of particular importance in water supply, ecology, flood protection, and agriculture.

## *2. Data and methods*

### *2.1. Research area*

The Republic of Serbia is divided into three main regions, namely: Vojvodina, Central Serbia, and Kosovo and Metohija. Central Serbia (observed area) covers the area of 55,967 km², which makes up three quarters of the total national territory and, in percents, it is about 63%. The observed territory consists of three statistical regions: 1) the city of Belgrade; 2) Sumadija and Western Serbia; and 3) Eastern and Southern Serbia. The observed area stretches between 42º 13’ 51” N and 45˚ 05' 49'' N and 19º 06’ 27” E and 23º 11’ 47” E (*Ilić* and *Stanković,* 2007).

The important geographical regions of Central Serbia are: Sumadija, Macva, Timocka dolina, Pomoravlje, Podunavlje, Posavina, Podrinje, Zlatibor, Raska region, Toplica, Ponisavlje, Jablanica, Vlasina, and Krajiste (*Drobnjaković* and *Čikić,* 2020). Also, in addition to administrative borders, it also has clearly defined natural borders to neighboring regions. The rivers Danube and Sava represent the natural border with Vojvodina. The Danube River separates Central Serbia from Romania in the northeast, whereas the Drina River represents the natural border with Bosnia and Herzegovina in the west. In the southwest, the natural border with Montenegro is represented by the Dinarides (mountain range), and in the south it is Kopaonik, the high mountains (Besna Kobila, Kozjak and Starac) and the Pcinja river valley, which separate the observed territory from Kosovo and Metohija, and North Macedonia. In the east, the Carpatho-Balkanides form the border with Bulgaria (*Radaković et al.,* 2018).

In terms of orography, three main mountain ranges can be distinguished, which are located within the observed territory (*Fig. 1*). These are the Dinarides, in the west and southwest parts of Central Serbia, the Carpatho-Balkanides in the east and the Rhodopes in the southeast. Speaking of the hydrological objects in Central Serbia, the Velika Morava River (the longest river) and its tributaries the rivers Juzna Morava and Zapadna Morava stand out, representing the most important and largest river system of this territory at the same time. Furthermore, many artificial lakes can be singled out: the Celije, Djerdap, Zlatar, Gruza, Gazivode, Vlasina, and Sjenica lakes, and many others *(Božić et al.*, 2006).


*Fig. 1.* Geographical position of Central Serbia with the analyzed meteorological stations and their altitude.

## *2.2. Materials*

The total amount of precipitation that was discharged during the vegetation period (P-VG) from 1949 to 2018 was calculated on the basis of publicly available data of the Republic Hydrometeorological Institute of Serbia (https://www.hidmet.gov.rs/). 24 meteorological stations were used, the data of which are given in *Table 1* (*Bačević, et al.*, 2021), while their position is given in *Fig. 1*. For the purposes of this research, data on precipitation from 24 meteorological stations were used. Details of station names, geographic coordinates, geographic position, and their altitude are shown in *Fig. 1* and *Table 1*.

*Table 1.* List of meteorological stations located in Central Serbia, names of time series, their 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. | Cuprija | CU-P | 43º56′ | 21º23′ | 123 |
| 4. | Dimitrovgrad | DI-P | 43º01′ | 22º45′ | 450 |
| 5. | Jagodina | JA-P | 43º59′ | 21º23′ | 115 |
| 6. | Knjazevac | KZ-P | 43º34′ | 22º15′ | 263 |
| 7. | Kragujevac | KG-P | 44º02′ | 20º56′ | 181 |
| 8. | Kraljevo | KV-P | 43º43′ | 20º42′ | 215 |
| 9. | Krusevac | KS-P | 43º37′ | 21º15′ | 166 |
| 10. | Kursumlija | 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. | Nis | NI-P | 43º20′ | 21º54′ | 202 |
| 15. | Novi Pazar | NP-P | 43º08′ | 20º31′ | 545 |
| 16. | Pirot | PI-P | 43º09′ | 22º35′ | 373 |
| 17. | Pozega | PZ-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 Gradiste | VG-P | 44º45′ | 21º30′ | 80 |
| 22. | Vranje | VR-P | 42º33′ | 21º55′ | 433 |
| 23. | Zajecar | ZA-P | 43º53′ | 22º17′ | 144 |
| 24. | Zlatibor | ZL-P | 43º44′ | 19º43′ | 1029 |

## *2.3. Methods*

### *2.3.1. Statistical data processing*

In this paper, three statistical approaches were used in the analysis of trends in the total average annual precipitation for the vegetation period, and the geospatial distribution of data (precipitation) in the observed area was determined. The trend equation represents the first approach, which is calculated for each time series separately (*Bačević et al.*, 2022). The second approach (independently of the first approach) represents data testing using and applying the non-parametric MK trend test (*Papić et al*., 2020). The third approach consists of determining the trend magnitude obtained by means of the trend equation (*Bačević et al*., 2020). Trend analyses were carried out with the help of the XLSTAT extension (https://www.xlstat.com/en) in the Excel Microsoft Office package.

The first method includes linear regression, which describes the equation of the vegetation period precipitation trend for each meteorological station, in general form:

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

where $y$ represents the total amount of precipitation in the vegetative period in mm, $a$ is a slope that can be positive, negative or non-existent, $x$ is a time series, while $b$ is the value of precipitation at the beginning of the analyzed period (*Bačević et al.,* 2018; *Vukoičić et al.,* 2018). After this analysis, a trend magnitude analysis was conducted (*Gavrilov et al*., 2018):

$$\Delta y = y(P_b) - y(P_e), \tag{2}$$

where $\Delta y$ represents the trend magnitude in mm, $y(P_b)$ is the value of precipitation during the vegetation period in the first analyzed year, while $y(P_e)$ is the same value in the last year of the time series. The trend magnitude can be zero in case the specified values are equal, positive, or negative. In the first case the trend magnitude does not exist, in the second it is increasing, and in the third it is decreasing.

The third analytical method used in this paper is the use of the Mann-Kendall test on the time series of precipitation of the vegetation period in Central Serbia (*Mann,* 1945; *Kendall,* 1975). Each data in the time series is assigned a rank. Mutual differences in pairs of ranks are used to calculate the trend direction and strength, after which the variance of the test statistic, i.e., the randomness of the variability in the data, is determined. If the variance is small, the data are slightly scattered and vice versa. The last step is to determine the significance of the trend. This process begins by comparing the calculated test statistic with the data distribution, assuming that there is no trend ($H_0$ hypothesis). If the test statistic exceeds the critical value from the distribution, it means that there is a statistically significant trend ($H_a$ hypothesis). This value that tells how much the test statistic exceeds the critical value from the distribution is called *p-valu*e. If this value is less than 0.05 or 5%, the trend results are statistically significant and we have to reject $H_0$ (*Gavrilov,* 2016; *Stojićević,* 2016; *Razavi et al.,* 2016).

*2.3.2. 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 evaluating and calculating meteorological data of an area (*Tomazos* and *Butler*, 2009; *Blake et al.*, 2007; *Valjarević et al.*, 2022). In this paper, preference is given to the kriging method within the interpolation to show the geographical distribution of the average amount of precipitation during the vegetation period in the analyzed period.

The results of the statistical analysis are spatially represented using the Create Thiessen Polygons tool of the Arc GIS software. This method was developed by Thiessen (*Thiessen*, 1911), a meteorologist, more than a century ago, and refers to the creation of a polygon in the center of which is the entered coordinate (*Radaković*, 2017), 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 the linear regression and the Mann-Kendall test are the same: the trend in precipitation during the vegetation period exists as positive, negative, or non-existent.

All procedures and approaches used for the purpose of this research are presented in the flow chart given in *Fig. 2*.

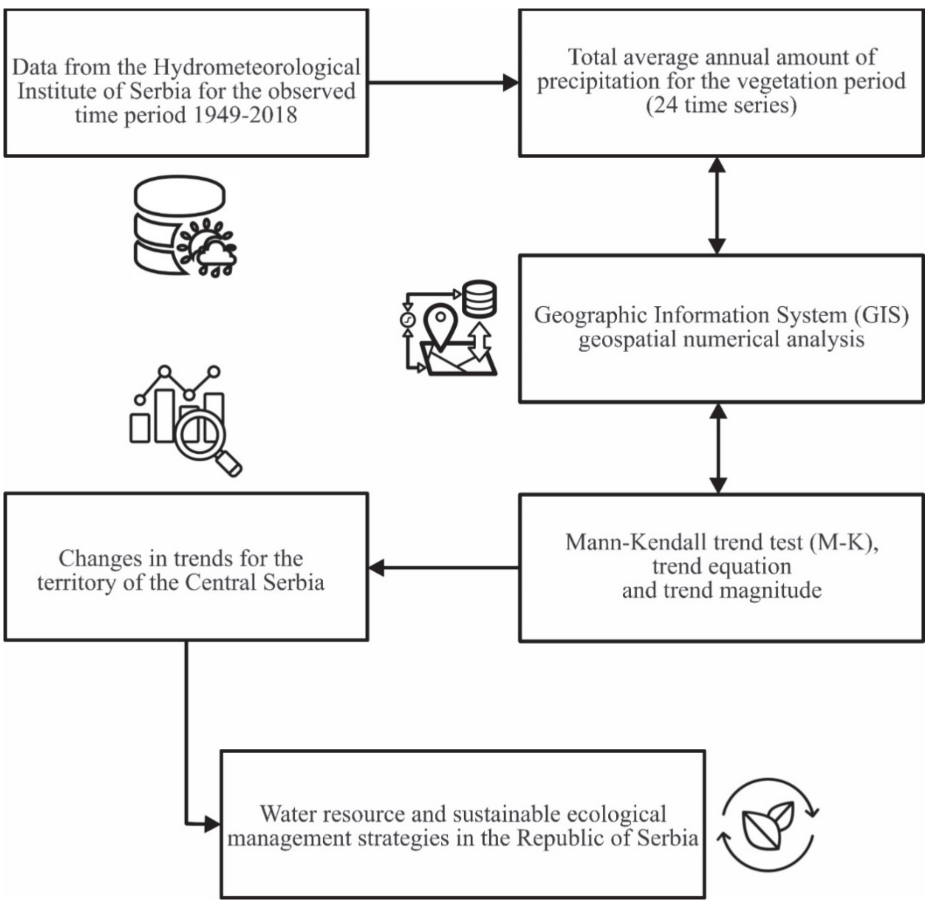


*Fig. 2*. Flow chart with all the procedures and methods used in this research.

## *3. Results*

### *3.1. Trend parameters*

In this scientific study, the obtained results are presented and summarized in *Table 2*, as well as in *Figs. 3, 4, 5,* and *6*. Also, the analysis is presented for a total of 24 meteorological stations and the same number of time series, which are located in the territories of Central Serbia. Based on these variables, the values of the total annual amount of precipitation during the vegetation period (April-October) were calculated. Results for average annual precipitation (P-VP), trend equation results, linear trend equation, and trend magnitude are presented visually in *Table 2* and *Figs. 3* and *4*. The p-value, results of trend testing using the MK trend test and the evaluation of hypotheses for accepting or rejecting the trend are shown in *Fig. 4*, for each meteorological station, especially in the territory of Central Serbia, for the time interval from 1949 to 2018. The spatial distribution of the total annual amount of precipitation in Central Serbia is shown in *Fig. 6*.

*Table 2.* Names of time series, trend equation *y*, trend magnitude *Δy*, and average annual amount of precipitation for the vegetation period for 24 time series, which refer to the territory of Central Serbia.

| Time series | Trend equation | *Δy* (mm) | Average amount of precipitation for the vegetation period (mm) |
|---|---|---|---|
| BG-P-VP | $y$=0.3001$x$ + 431.37 | 20.7 | 442.0 |
| BU-P-VP | $y$=-0.0667$x$ + 371.82 | -4.6 | 369.5 |
| CU-P-VP | $y$=0.2259$x$ + 408.11 | 15.6 | 416.1 |
| DI-P-VP | $y$=0.761$x$ + 384.49 | 52.5 | 411.5 |
| JA-P-VP | $y$=-0.2304$x$ + 383.89 | -15.9 | 375.7 |
| KZ-P-VP | $y$=0.2966$x$ + 366.77 | 20.5 | 377.3 |
| KG-P-VP | $y$=0.3828$x$ + 402.75 | 26.4 | 416.3 |
| KV-P-VP | $y$=0.0792$x$ + 489.06 | 5.5 | 491.9 |
| KS-P-VP | $y$=0.0646$x$ + 412.19 | 4.5 | 414.5 |
| KU-P-VP | $y$=0.6421$x$ + 378.99 | 44.3 | 401.8 |
| LE-P-VP | $y$=0.7006$x$ + 350.9 | 48.3 | 375.8 |
| LO-P-VP | $y$=1.0137$x$ + 502.1 | 70.0 | 538.1 |
| NG-P-VP | $y$=0.1107$x$ + 374.9 | 7.6 | 378.8 |
| NI-P-VP | $y$=0.7311$x$ + 336.36 | 50.4 | 362.3 |
| NP-P-VP | $y$=1.1527$x$ + 360.74 | 79.5 | 401.7 |
| PI-P-VP | $y$=0.535$x$ + 356.48 | 37.0 | 375.5 |
| PZ-P-VP | $y$=0.4888$x$ + 474.84 | 32.7 | 492.2 |
| SJ-P-VP | $y$=1.5411$x$ + 415.72 | 106.3 | 470.4 |
| SP-P-VP | $y$=1.2584$x$ + 370.19 | 86.8 | 414.9 |
| VA-P-VP | $y$=0.8308$x$ + 489.06 | 57.3 | 518.6 |
| VG-P-VP | $y$=0.4541$x$ + 430.82 | 31.3 | 446.9 |
| VR-P-VP | $y$=0.0545$x$ + 369.97 | 3.7 | 371.9 |
| ZA-P-VP | $y$=-0.0073$x$ + 374.55 | -0.5 | 374.3 |
| ZL-P-VP | $y$=1.9215$x$ + 557.24 | 132.5 | 625.5 |

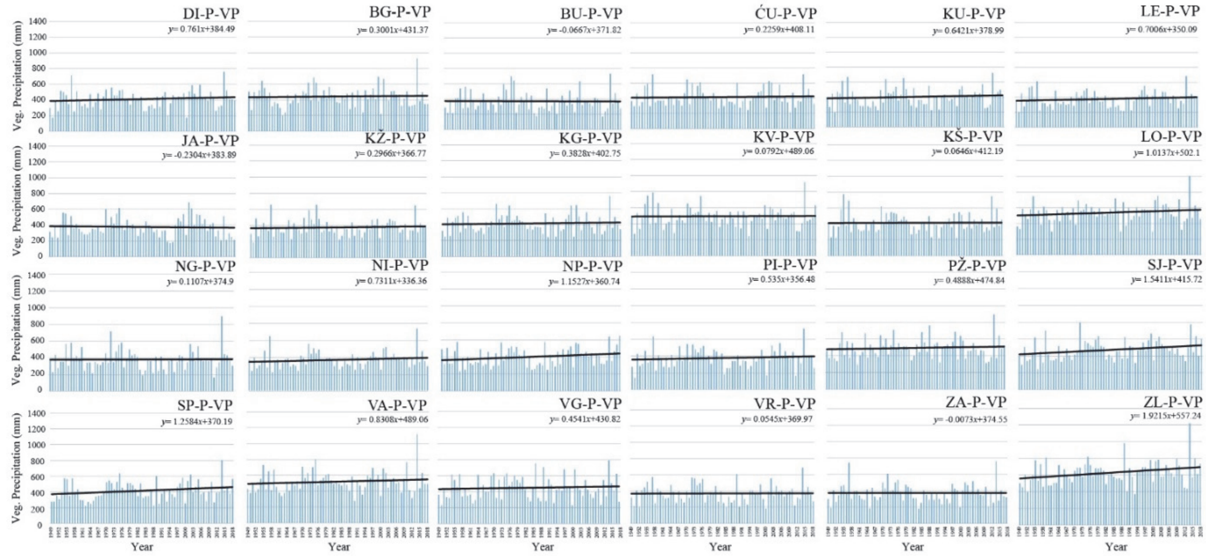


*Fig. 3.* Visual representation of the average annual precipitation for the vegetation period, trend equation, and linear trend for selected meteorological stations, which are arranged from the station with the lowest to the station with the highest average annual precipitation in Central Serbia for the observed time period from 1949 to 2018.

The obtained results of the abovementioned parameters, which are shown in *Fig. 3* and *Table 2*, indicate a slight increase in the average total annual precipitation (P-VP) in the territory of Central Serbia, which is not the case for three time series (BU-P-VP, JA-P-VP, and ZA-P-VP) in which a negative balance was recorded. Out of a total of 24 time series, a slight increase in the average annual amount of precipitation for the vegetation period was recorded in 21 time series, while the total amount of precipitation for the vegetation period was decreasing in the remaining 3 time series. The highest increase in the average total annual precipitation of 132.5 mm was recorded in the time series Zl-P, followed by the time series SJ-P-VP and SP-P-VP, where the increases of 106.3 mm and 86.8 mm were recorded, respectively. The lowest increase in the average total annual precipitation of 3.7 mm was recorded in the time series VR-P-VP, followed by the time series KS-P-VP (4.5 mm) and KV-P-VP (5.5 mm). The highest decrease in the total average annual precipitation of -15.9 mm was recorded in the JA-P-VP time series. It is followed by the time series BU-P-VP and ZA-P-VP having the decrease of -4.6 mm and -0.5 mm respectively. Data on the total amount of precipitation from *Table 2* for each meteorological station in Central Serbia are described and shown in more detail in *Fig. 6* and in Section 3.3. GIS numerical analysis.

### *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 spatially in *Fig. 4*. Out of a total of 24 time series, a significant statistically positive trend was recorded in 2 time series, where the $H_a$ hypothesis prevails and where the p-value is lower than the significance level $\alpha$, whose value is 0.05, whereas in 22 time series there is no trend. For these 2 time series in Sjenica and Zlatibor (SJ-P-VP and ZL-P-VP), where a significant positive statistical trend and $H_a$ hypothesis prevails, there is a very small percentage of risk, ranging between 2.36% and 4.08%, that the given hypothesis will be rejected.

Out of a total of 22 time series, where there is no trend and where the $H_0$ hypothesis prevails, in most cases the risk of rejecting this hypothesis is very high. The risk values to reject this hypothesis range from 7.39% to 97.93%. A risk whose value is between 5.00% and 10.00% was recorded in one time series in Novi Pazar (NP-P-VP), which indicates that there will certainly be no trend in the future. Values between 10.00% and 50.00% were recorded in seven time series in Dimitrovgrad, Kursumlija, Leskovac, Loznica, Nis, Pirot, and Smederevska Palanka (DI-P-VP, KU-P-VP, LE-P-VP, LO-P -VP, NI-P-VP, PI-P-VP, and SP-P-VP), which indicates that the trend is in stagnation.

In the last 14 time series: Belgrade, Bujanovac, Cuprija, Jagodina, Knjazevac, Kragujevac, Kraljevo, Kursumlija, Negotin, Pozega, Valjevo, Veliko Gradiste, Vranje, and Zajecar (BG-P-VP, BU-P-VP, CU -P-VP, JA-P-VP, KZ-P-VP, KG-P-VP, KV-P-VP, KS-P-VP, NG-P-VP, PZ-P-VP, VA-P -VP, VG-P-VP, VR-P-VP, and ZA-P-VP), the risk value ranges between 50.00% and 93.93%. These results indicate that in the area of Central Serbia, the total annual amount of precipitation for the vegetation period is stagnant.

In most analyzed cases, the results of the trend equation deviate from the results of the MK trend test, more precisely in 17 time series. In 5 time series the results match each other. As far as non-matching is concerned, mostly the trend equation indicates a positive trend, and the MK test indicates no trend (14 time series). In 3 time series, the trend equation indicates a negative trend, while the MK test indicates that the trend does not exist. These results are shown in more detail in *Figs. 4* and *5*.

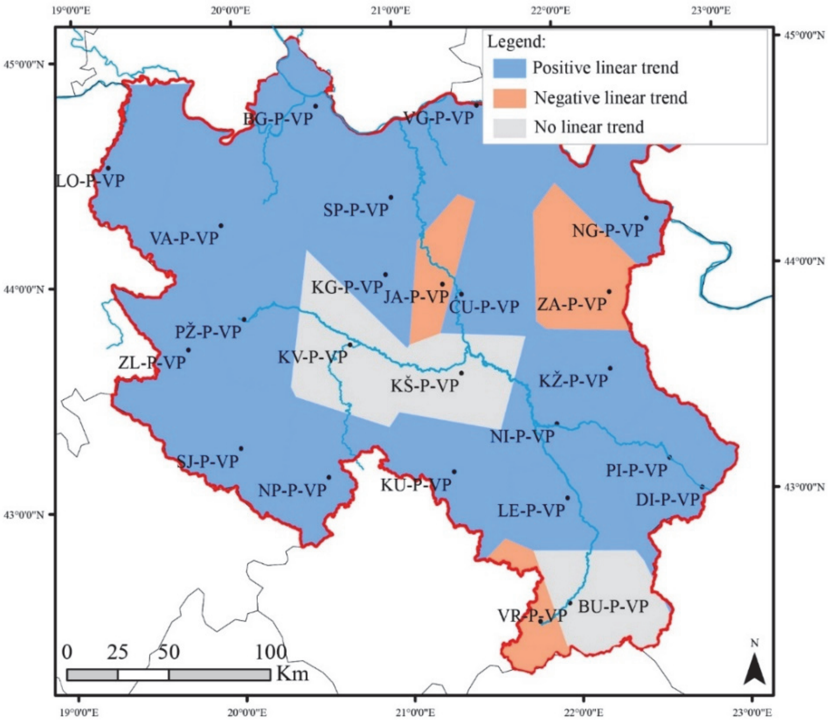


*Fig. 4.* Cartographic representation of the obtained results of the movement of the linear equation of the total annual amount of precipitation for the vegetation period in Central Serbia, from 1949 to 2018.

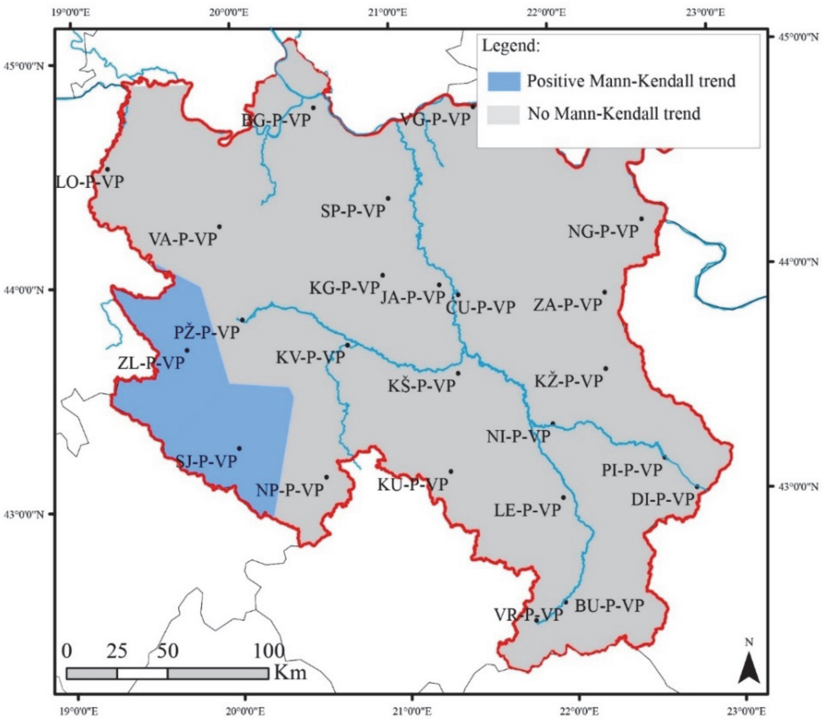


*Fig. 5.* Cartographic representation of the Mann-Kendall trend test results of the total annual precipitation for the vegetation period in Central Serbia, from 1949 to 2018.

*3.3. GIS numerical analysis*

The spatial distribution of the total annual amount of precipitation for the vegetation period in the time interval from 1949 to 2018 in Central Serbia is shown in more details in *Fig. 6*.

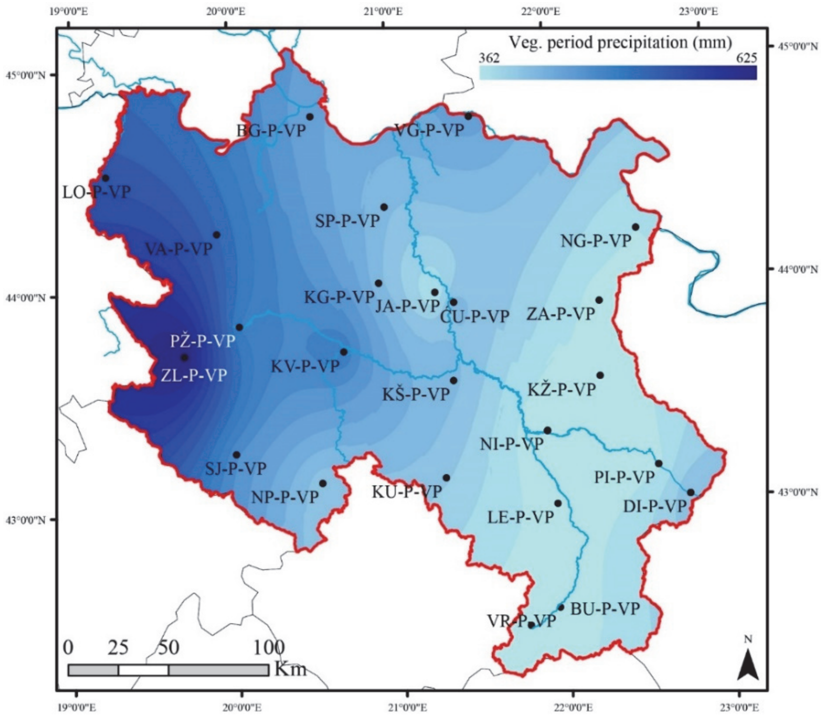


*Fig. 6.* Spatial distribution of average annual precipitation for the vegetation period from 1949 to 2018 in Central Serbia.

*Fig. 6* shows geospatial distribution of the average annual precipitation for the vegetation period (P-VP) in the observed area. Interregional differences in the average annual amount of precipitation are caused by several reasons, among which the followings stand out: the effect of the influx of air masses from the Atlantic Ocean, the effect of the Mediterranean, and the effect of the terrain morphology. Because of this, higher average annual amount of precipitation was recorded in the western and northwestern parts of the observed area, while in the central, southern, and southeastern parts, lower average annual amount of precipitation was recorded for the vegetation period.

Values for the total annual amount of precipitation for the vegetation period in Central Serbia for the time interval from 1949 to 2018 are 427.6 mm rangeing between 362.3 – 625.5 mm. The lowest value of the average annual precipitation (362.3 mm) was recorded in Nis and the highest value (625.5 mm) was recorded in Zlatibor. Other values for the average annual amount of precipitation are shown chronologically from the lowest to the highest, namely: Bujanovac (369.5 mm), Vranje (371.9 mm), Zajecar (374.3 mm), Pirot (375.5 mm), Jagodina (375.7 mm), Leskovac (375.8 mm), Knjazevac (377.3 mm), Negotin (378.8 mm), Novi Pazar (401.7 mm), Kursumlija (401.8 mm), Dimitrovgrad (411.5 mm), Krusevac (414.5 mm), Smederevska Palanka (414.9 mm), Cuprija (416.1 mm), Kragujevac (416.3 mm), Beograd (442 mm), Veliko Gradiste (446.9 mm), Sjenica (470.4 mm), Kraljevo (491.9 mm), Pozega (492.2 mm), Valjevo (518.6 mm), and Loznica (538.1 mm).

## *4. Discussion*

The same or similar researches, referring to the total average amount of precipitation for the vegetation period in Central Serbia have not been conducted so far. Similarities and differences of the obtained results were compared with and commented based on previous researches which refer to the total annual amount of precipitation in Central Serbia, as well as to the territory of the Republic of Serbia, to the region, to Europe, and to the world.

This scientific study presents a detailed analysis of research results related to the total amount of precipitation during the vegetation period in Central Serbia. Based on the analyzed climate variable, several key aspects can be highlighted and 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 value of the total annual precipitation, MK trend test, and GIS numerical analysis.

According to the results obtained from the trend equation and trend magnitude, an increase in the total amount of precipitation for the vegetation period was recorded in twenty-one cities of Central Serbia. A decrease in the average annual amount of precipitation for the vegetation period was recorded in three cities of Central Serbia (*Table 2*). The highest increase in the total amount of precipitation for the vegetation period (132.5 mm) in the past 70 years was recorded in the time series Zlatibor Zl-P-VG, and the lowest increase in the average amount of precipitation for the vegetation period (3.7 mm) was recorded in the time series Vranje VR-P-VP. A decrease in the average annual amount of precipitation for the vegetation period was recorded in three time series, namely: Jagodina JA-P-VP (-15.9 mm), Bujanovac BU-P-VP (-4.6 mm), and Zajecar ZA-P-VP (-0.5 mm). Using the MK test, the obtained results indicate that a statistically significant positive trend in the analyzed parameters was recorded in 2 time series. On the other hand, there is no change (no trend) in 22 time series. The spatial distribution of the average annual amount of precipitation in Central Serbia is 427.6 mm. Its range is between 362.3 – 625.5 mm.

In the paper of *Bačević et al.* (2024), which refers to the same observed area (Central Serbia) and which has the same research methodology, but a different variable (total annual precipitation), the following results were obtained, which are very similar to the results of this scientific study, namely: a) based on the trend equation and trend magnitude, an increase in the total annual amount of precipitation was recorded in seventeen time series. The highest average increase in the average annual precipitation of 233.3 mm was recorded in the case of ZL-YP. The lowest increase in total annual precipitation (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. The lowest decrease in total annual precipitation (-8.0 mm) was recorded in the case of ZA-YP, while the highest increase (-49.9 mm) was recorded in the case of NG-YP; b) Using the MK test, the obtained results indicate that in 5 time series a statistically significant positive trend in the analyzed parameters was recorded. On the other hand, in 19 time series there is no change (no trend); c) The spatial distribution of the average annual amount of precipitation in Central Serbia is 679.9 mm. Its range is between 591.4 – 973.9 mm (*Table 3* and *Fig. 7*).

*Table 3*. Names of time series, trend equation y, trend magnitude *Δy*, probability p, for 24 time series (*Bačević, et al.*, 2024).

| **Time series** | **Trend equation** | ***Δy* (rr)** | **Average amount of precipitation (rr)** |
|---|---|---|---|
| BG-P | $y$=0.1551$x$ + 687.34 | 10.7 | 692.8 |
| BU-P | $y$=-0.6316$x$ + 646.14 | -43.6 | 623.7 |
| CU-P | $y$=0.5536$x$ + 637.93 | 38.2 | 658.1 |
| DI-P | $y$=0.8719$x$ + 614.78 | 60.2 | 644.4 |
| JA-P | $y$=-0.1305$x$ + 596.07 | -9.0 | 591.4 |
| KZ-P | $y$=0.4094$x$ + 598.74 | 28.2 | 613.3 |
| KG-P | $y$=0.6743$x$ + 612.23 | 47.0 | 635.4 |
| KV-P | $y$=-0.1497$x$ + 764.39 | -10.3 | 757.8 |
| KS-P | $y$=0.4411$x$ + 640.38 | 30.4 | 656 |
| KU-P | $y$=0.7866$x$ + 630.65 | 54.3 | 658.6 |
| LE-P | $y$=1.1444$x$ + 591.42 | 79.0 | 633.2 |
| LO-P | $y$=1.5447$x$ + 790.19 | 106.6 | 845 |
| NG-P | $y$=-0.6369$x$ + 679.52 | -43.9 | 656.9 |
| NI-P | $y$=1.0139$x$ + 561.62 | 70.0 | 597.6 |
| NP-P | $y$=1.5142$x$ + 585.9 | 105.0 | 639.7 |
| PI-P | $y$=0.5151$x$ + 575.32 | 35.0 | 593.6 |
| PZ-P | $y$=0.2877$x$ + 740.7 | 19.9 | 750.9 |
| SJ-P | $y$=2.4294$x$ + 653.17 | 167.6 | 739.4 |
| SP-P | $y$=1.5509$x$ + 591.91 | 107.0 | 647 |
| VA-P | $y$=0.9847$x$ + 756.25 | 67.9 | 791 |
| VG-P | $y$=-0.188$x$ + 694.84 | -13.0 | 688.2 |
| VR-P | $y$=-0.2131$x$ + 621.29 | -14.7 | 613.7 |
| ZA-P | $y$=-0.1163$x$ + 619.64 | -8.0 | 615.5 |
| ZL-P | $y$=3.3817$x$ + 859.51 | 233.3 | 973.9 |

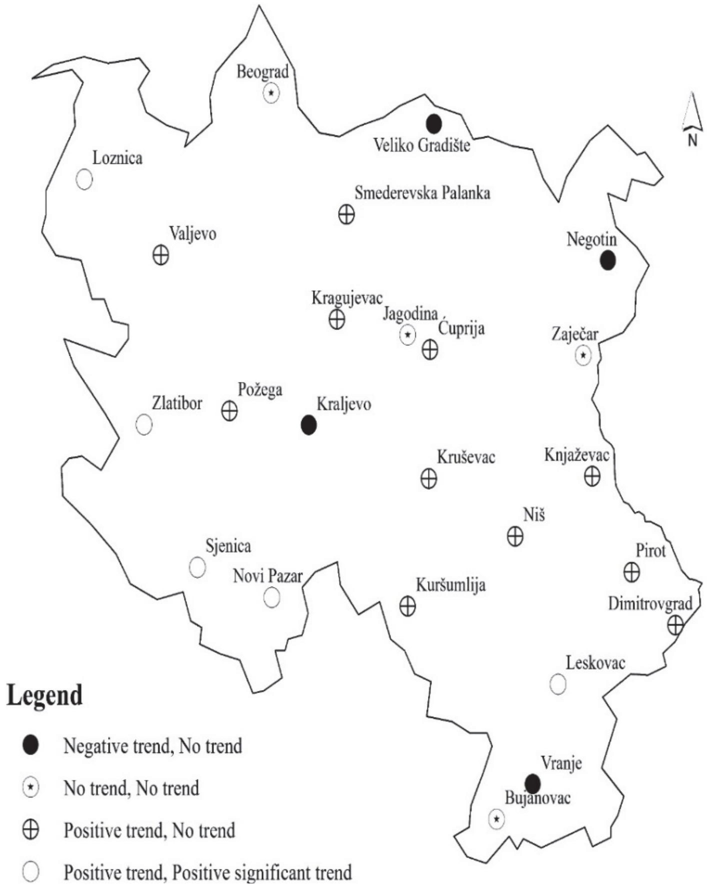


*Fig. 7*. Cartographic representation of the obtained results of the movement of linear equation and the Mann-Kendall trend test for the total annual amount of precipitation in Central Serbia for the time period from 1949 to 2018 (*Bačević, et al*., 2024).

The results of this research show a similarity with the research from 2024 in the paper of *Bačević et al*. (2024). In both researches, a slight increase was observed for climate variables related to the climate element of precipitation (mm) in most of the time series. In this paper, a slight increase in the average amount of precipitation for the vegetation period was recorded in 21 time series, while in the paper of *Bačević et al.* (2024) this increase was recorded in 17 time series. In the first case, negative balance for the analyzed variables was recorded in 3 time series, and in the second case in 7 time series, which is confirmed by the trend equation and trend magnitude.

Out of a total of 24 time series, the results are identical for 20 time series, while they differ in the remaining 4. For time series where results differ, positive balance is recorded in the first case, while, in the second case, the balance is negative. Furthermore, the MK trend test shows a lot of similarity between the results of both researches. The hypothesis $H_0$ (no trend) prevails in both cases, while positive trend was recorded in much fewer cases. In this paper, the total number of cases, where no trend was recorded, amounts to 22 time series, while in the paper of *Bačević et al*. (2024) this number amounts to 19 time series.

Positive trend was recorded in 2 time series in the first case, and in 5 time series in the second case.

Similarities and differences in the obtained results from these two researches arise from the fact that they include the same observed territory, apply the same methodology, and analyze the same number of time series. The only difference is in the variables (total precipitation for the vegetation period and average total annual precipitation).

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

In the paper of *Milentijević et al.* (2022), which includes the territory of Backa (northwestern part of Serbia), the trends of the average annual amount of precipitation for the vegetation period (for five meteorological stations) were analyzed. In all analyzed time series, a slight increase in the total amount of precipitation for the vegetation period was recorded, which is confirmed by the trend equation and trend magnitude. Out of a total of five time series, the hypothesis $H_0$ (no trend) prevails in four time series, while the hypothesis $H_a$ (positive trend) prevails in only one time series, as shown in *Table 4*. These results match the results of this study because the distance between the observed meteorological stations is very small.

*Table 4*. Trend equation ($y$), trend magnitude ($\Delta y$) and probability of confidences ($p$) for precipitation time series (from 1949 to 2018) in Backa. Abbreviations are listed in Section 2.2. (*Milentijević et al*., 2022).

| **Time series** | **Trend equation** | **$\Delta y$ (mm)** | **$p$ (%)** |
|---|---|---|---|
| BP-YP | $y = -0.0792x + 616.86$ | -5.5 | 0.8480 |
| BP-$\mathbf{P_\Sigma}$-VP | $y = 0.8409x + 365.96$ | 58.0 | 0.2438 |
| B-YP | $y = 0.0684x + 590.86$ | 4.7 | 0.8520 |
| B-$\mathbf{P_\Sigma}$-VP | $y = 0.5936x + 365.6$ | 40.9 | 0.2954 |
| N-YP | $y = 1.4727x + 572.45$ | 101.6 | 0.1455 |
| N-$\mathbf{P_\Sigma}$-VP | $y = 1.712x + 349.03$ | 118.1 | 0.0586 |
| P-YP | $y = 1.4039x + 509.03$ | 96.9 | 0.0615 |
| P-$\mathbf{P_\Sigma}$-VP | $y = 1.3171x + 318.84$ | 90.9 | 0.0963 |
| S-YP | $y = 1.2902x + 555.14$ | 89.0 | 0.1304 |
| S-$\mathbf{P_\Sigma}$-VP | $y = 1.2298x + 351.17$ | 84.9 | 0.0450 |

Similar results were obtained in most of the researches conducted in Serbia. Actually, a slight increase in the total amount of precipitation was recorded in the past period, which coincides with the results of these researches (*Unkašević* and *Tošić*, 2011; *Tošić et al*., 2014, 2017; *Gavrilov et al*., 2015; *Putniković et al*., 2016;

*Milovanović et al*., 2017; *Anđelković et al*., 2018; *Tošić* and *Putniković*, 2021; *Amiri* and *Gocić*, 2021a, 2021b; *Vujadinović et al*., 2022; *Stošić et al*., 2024).

The results obtained in these researches indicate a slight increase in the total annual amount of precipitation for the observed area, and that climate variability is not sufficiently pronounced. Also, they indicate a higher total annual amount of precipitation in the western part of Central Serbia compared to its eastern parts. Such results are consistent with these researches. Additionally, the findings of this study somewhat align with a more recent study by *Eisfelder et al.* (2023), which highlights that during the spring season, positive NDVI trends extend to Southeast Europe (including Hungary, Romania, Serbia, Bulgaria, North Macedonia, Albania, and Greece), suggesting a relationship between precipitation variability and seasonal vegetation trends.

These conditions are consistent with the observations of Goncić and Trajković (2013), who explained that the lack of significant trends in summer and winter precipitation series stemmed from increasing trends in both annual and seasonal minimum and maximum air temperatures, along with a significant decrease in relative humidity. The authors further noted that most stations showed no significant trends on an annual scale, yet a recent study by *Bačević et al*. (2024) reveals statistically positive trends for Loznica, Zlatibor, Sjenica, Novi Pazar, and Leskovac, respectively. This finding correlates with Djordjević (2008) discovery that precipitation quantities are increasing on an annual level, with the highest increase observed during winter.

## *5. Conclusion*

This study presents the analyzed trends and geospatial distribution of the obtained results of the average annual amount of precipitation for the vegetation period (one category of variables) in Central Serbia. The observed time interval is from 1949 to 2018, which is a total period of 69 years. The data used for these researches were taken from the Meteorological Yearbooks of the Republic Hydrometeorological Institute of Serbia, with a total of 24 meteorological stations. The Mann-Kendall trend test was used for data processing and trend analyses. Furthermore, trend equations and trend magnitudes were calculated using appropriate formulas and the obtained results were displayed cartographically using GIS numerical analysis.

By analyzing the presented results of this study, it can be concluded that the total annual amount of precipitation for the vegetation period 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 twenty-one cities of Central Serbia, while a decrease in the average annual amount of precipitation was recorded in three cities of Central Serbia (*Table 2*). The highest increase in the total amount of precipitation for the vegetation period in the past 69 years

(132.5 mm) was recorded in the time series Zl-P-VG, and the lowest increase in the average amount of precipitation in the vegetation period (3.7 mm) was recorded in the time series VR-P-VP. A decrease in the average annual amount of precipitation for the vegetation period was recorded in three time series, namely: JA-P-VP (-15.9 mm), BU-P-VP (-4.6 mm), and ZA-P-VP (-0.5 mm).

Based on the analysis of the MK trend test shown in *Figs. 5* and *6*, it is concluded that there are significant variations in the trends of the annual amount of precipitation for the vegetation period in Central Serbia. A significant statistically positive trend, where the $H_a$ hypothesis prevails, was identified in only two time series, with a small percentage (2.36% – 4.08%) of the risk of rejecting this claim. In 22 time series, where the $H_0$ hypothesis prevails, there is no significant trend. The risk of rejecting this hypothesis is high in most cases (7.39% – 97.93). It can be concluded that there will be no trend in the observed territory in the future.

The distribution of the total amount of precipitation for the vegetation period in Central Serbia for a time interval of a total of 69 years (1949–2018) can be clearly seen in *Fig. 6*, providing a visual representation of regional differences, on the basis of which it can be concluded that it is greater in its western part in relation to the eastern parts. The average annual amount of precipitation for the vegetation period of the observed area is 427.6 mm. The values range from 362.3 mm to 625.5 mm. The lowest value was recorded in Nis, while the highest value was recorded in Zlatibor.

The general conclusion of the results obtained in this way, indicating a slight increase in the total amount of precipitation for the vegetation period in Central Serbia, significant variations and the lack of statistical significance in most time series emphasizes the complexity of climate changes in that area, which coincides with the results obtained at the global level.

The preliminary findings of this study can offer a technical foundation and valuable reference for water resource and sustainable ecological management strategies in the Republic of Serbia, benefiting policymakers and stakeholders involved.

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