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Changes and contemporary trends in the annual amounts of precipitation in Serbia

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ABSTRACT

The Republic of Serbia is a continental country located in the western part of the Balkan Peninsula, in Southeast Europe. In terms of physical characteristics, Serbia is divided into two parts: Pannonian part and mountainous part. The northern part of the country is located in the valley of the Middle Danube, the Sava River valley and the Tisza River valley. In the middle part of the country, the river valleys of the Drina, the Kolubara and the Morava are located. For the purposes of this research, the authors have used the annual precipitation data from 15 meteorological stations distributed throughout the Republic of Serbia. The data from these meteorological stations for the period between 1991 and 2019 has been provided by The Serbian Institute of Meteorology and Hydrology. This data has been used to calculate the annual amount of precipitation, and the trends in annual precipitation.

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1. Introduction

Climate change in different regions of the world has been one of the most developed topics since the second mid-20th century. In recent decades, the researchs are focused on changes in air temperature and the possible consequences of these changes, in order to facilitate the adaptation of the natural and the socio-economic systems to them. Precipitation is one of the most important climatic elements which could become a natural hazard due to climate change. This could directly affect human society and its economic activities, as well as natural vegetation and ecosystems (Kangas and Brown, 2007). At the same time, emphasis is placed on the changing amount and regime of precipitation, which is an important component, determining the development of these systems. The spatial variability of the sign, magnitude, seasonality and trends in precipitation over Europe has been established in a number of studies focused on different European countries, the Balkans, the Mediterranean region, and Europe as a whole (e.g. Osborn et al. 2000; Frei and Schär 2001; Alpert et al. 2002; Klein Tank and Können 2003; Hundecha and Bárdossy 2005; Schmidli and Frei 2005; Moberg et al. 2006; Bartholy and Pongrácz 2007; Kyselý 2009; Łupikasza et al. 2010, Buric 2011, Gajić-Čapka et al. 2014). The topic of this paper is a regional survey of the annual precipitation in Serbia. According to data from the Center for Drought Management in Southeast Europe, a visible trend of increasing droughts and decreasing precipitation has been established on the Balkan Peninsula, starting from the end of the 20th century and the beginning of the 21st century (http://www.dmcsee.org). However, in the Lower Danube Valley (northern Bulgaria) positive trends have been observed in some areas (Rachev, Assenova, 2016). The relevance and the importance of the study is determined by the revealed latest trends in the annual precipitation in Serbia.

2. Materials and methods

The Republic of Serbia has a total area of 88 361 km^2, of which Serbia covers 55 970 km^2, Vojvodina – 21 510 km^2 and Kosovo – 10 890 km^2. About two-thirds of the country is located south of the rivers Danube and Sava, and one-third – in the Pannonian Plain. Serbia is located on the Balkan Peninsula, in Southeast Europe, covering the far southern edges of the Pannonian Plain and the central Balkans. The Pannonian Plain covers the northern one-third of the country and includes 7 of the studied stations (Belgrade, Valjevo, Novi Sad, Kikinda, Zrenjanin, Sombor, and Sremska Mitrovica). The terrain of central Serbia consists mainly of hills and low to medium-high mountains, interspersed with numerous rivers and creeks. This area includes some of the studied stations, three of which are mountainous (Crni Vrh, Kopaonik, Sjenica). Mountains dominate the southern one-third of Serbia. The Dinaric Alps stretch to the west and the southwest, following the valleys of the rivers Drina and Ibar. There are about 30 mountain peaks at an altitude of over 2000 m, the highest of which is Midžor in Stara Planina Mountain (the Balkan Range) – 2169 m, which is located in eastern Serbia. The second highest mountain is Kopaonik (Pančićev peak – 2017 m), in central Serbia, and in the Pannonian Plain – Vršac Mountains (Gudurički peak – 639 m). The lowest point is located on the border with Romania and Bulgaria, at the confluence of the rivers Timok and Danube, at 28 m above sea level. Because of the high number of mountains in Serbia, there are many valleys. Looking from south to north, the largest valleys are: Vranska, Grdelička, Leskovacka, Niška, and some others.

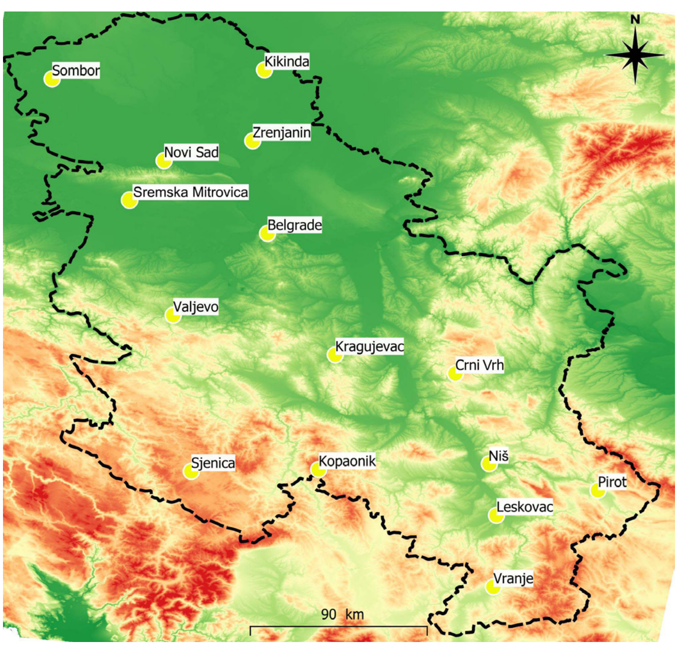

Figure 1. Distribution of the studied stations in Serbia.

The study area is located in 3 climate zones. The main climatic characteristics of the country are determined by its geographical location, remoteness from the Adriatic and Mediterranean Seas, and the Atlantic Ocean, as well as by the country's relief. Vojvodina and eastern Serbia are open to the air masses of northern and eastern Europe. Pomoravlje, i.e. the valley of the Velika Morava River, due to its openness to northern Europe, has a continental climate, while in western, eastern and southern Serbia, due to the significant segmentation of the terrain, a temperate-continental climate prevails. The high mountains to the west and south, block the warm air masses of the Adriatic and the Aegean Sea.

Data on the average annual amounts of precipitation for the periods 1961-1990 and 1991-2019, obtained from 15 meteorological stations evenly distributed on the territory of the Republic of Serbia were used for the purpose of the study. Three of the stations are located above 1000 m a.s.l., while the remaining 12 are within the hypsometric belt below 1000 m a.s.l. (Table 1). The data source of the study are the meteorological yearbooks of the Republican Hydrometeorological Institute of Serbia (RHMIS). The linear trend method was used to determine the trends in the annual precipitation amounts. Fisher's F-test was used to determine their statistical significance.

Table 1. Station names, their longitude, latitude and altitude.

Station	longitude	latitude	altitude (m)
Belgrade	20° 28'	44° 48'	132
Valjevo	19° 55'	44° 17'	174
Vranje	21° 55'	42° 33'	433
Zrenjanin	20° 23'	45° 24'	80
Kikinda	20° 28'	45° 51'	81
Kopaonik	20° 48'	43° 17'	1711
Kragujevac	20° 56'	44° 02'	181
Leskovac	21° 57'	42° 59'	231
Niš	21° 54'	43° 20'	202
Pirot	22° 36'	43° 09'	373
Novi Sad	19° 50'	45° 19'	86
Sjenica	20° 00'	43° 16'	1038
Sombor	19 ° 05'	45 ° 46'	87
Sremska Mitrovica	19° 33'	45 ° 01'	81
Crni Vrh	21° 58'	44 ° 08'	1037

3. Results and discussion

Regional studies provide a more precise insight regarding the precipitation changes in Southeast Europe. According to Gajić-Čapka et al. (2015), in the eastern part of Croatia, there was a slight positive trend in the annual precipitation during the period between 1961 and 2010. During that same period, however, Hungary did not record changes in the annual precipitation (Klapwijk et al. 2013), while some stations in western Romania recorded a statistically significant increase in the mean annual precipitation during the period between 1961 and 2013. The stations in the southwest of Romania, on the other hand, recorded a statistically significant decrease in the mean annual precipitation (Croitoru et al. 2016). During the period between 1961 and 2005, Bulgaria recorded a precipitation decrease, but with no statistical significance (Bocheva et al. 2009). In southwestern Serbia and in northern Montenegro, there was an increase in the annual precipitation during the period between 1951 and 2010 (Burić et al. 2015). All these changes in the precipitation are in accordance with the trends observed in Serbia in a previous study, which made almost the same observation for the period between 1961 and 2010 (Milovanović et al. 2017). In this study, the precipitation for two periods – 1961-1990 and 1991-2019 – has been compared.

The average values of the annual precipitation amounts for the period 1991-2019 vary from 575 mm at Kikinda station to 1032 mm at Kopaonik station. The analysis of the two periods shows that the largest increase in the annual amount of precipitation is observed at Kopaonik and in Sjenica region, while at Crni Vrh and Sremska Mitrovica areas, the precipitation amounts – according to the data for the second studied period – decreased. (Fig.1 and Table 2). In the above-mentioned yearbooks there is no data for Pirot station, for the period between 1961 and 1990.

Higher amount of rainfall is typical for stations at higher altitudes. Kikinda and other stations in northern Serbia are located at lower altitudes, and therefore, they observe 30-40 % less rainfall (Zrenjanin station – 597 mm, Sremska Mitrovica station – 611 mm, Sombor station – 639 mm, Novi Sad – 676 mm) compared to the mountainous stations (Kopaonik station – 1032 mm). They are followed by the stations in southeastern and southern Serbia (Pirot station – 581 mm, Niš station – 603 mm, Leskovac station – 659 mm, Vranje station – 599 mm). The stations in central Serbia observe a higher amount of precipitation than the others (Belgrade – 700 mm, Crni Vrh – 798 mm). The annual precipitation amounts in Kragujevac and Leskovac are equal – 650 mm. The highest amount of precipitation is recorded at the stations in western Serbia (Valjevo – 806 mm and Sjenica – 792 mm).

The analysis of the linear trend for the period 1991-2019 (Table 2) shows that negative change of the precipitation amount are only observed at Sremska Mitrovica station (-2.2 mm/10 years). All other stations exhibit a positive linear trend, with the least increase being observed at the stations of Belgrade, Novi Sad and Zrenjanin. The highest values are reported at Kopaonik station (84.5 mm/10 years) and Crni Vrh station (70.1 mm/10 years).

The annual amount of precipitation is a result of many complex factors, one of the most important of them being the terrain, e.g. the presence of mountains. Mountains represent an orographic barrier for air masses. Therefore, windward slopes usually receive more rainfall than valleys and plains. After crossing the mountains, the air masses descend and heat up, and hence the difference in the amount of rainfall on the eastern and the western slopes of the mountains in Serbia, and the valleys around those mountains. An example of this is the area of Valjevo – it is located at a lower altitude than the other stations, but observes a larger amount of precipitation – 806 mm. In the summer months, the amount of precipitation in the valleys depends on the local air circulation caused by thermal convection. The high temperatures above the valleys lead to intense convection of light warm air, formation of Cb-clouds and precipitation in the late afternoon. The distance to the sea is also very important for the amount of precipitation. Dukić (2005) found, that stations at the same altitude and approximately the same characteristics, receive 1.11 mm less precipitation per kilometer from west to east.

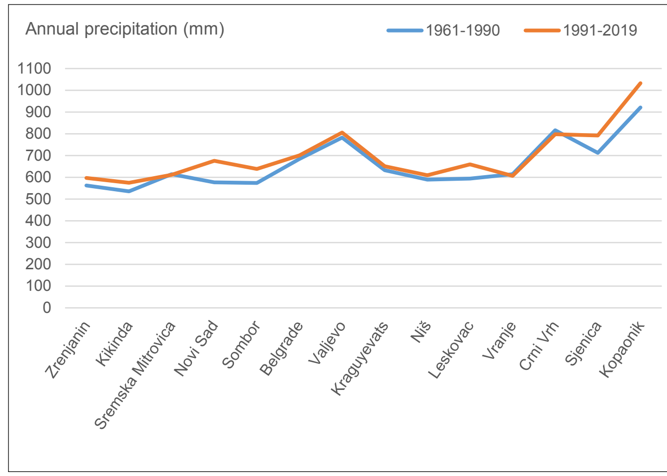

Figure 2. Changes in the average annual amount of precipitation (the stations are arranged according to their altitude, ranging from lower to higher).

Table 2. Average annual amount of precipitation in mm for the periods 1961-1990 and 1991-2019, and linear trend for the period 1991-2019.

Station	Average Annual Precipitation 1961-1990	Average Annual Precipitation 1991-2019	Equation of linear trendline 1991-2019	Significance of trend
Belgrade	684	700	y = 0.6029x + 691.3	Nonsignificant
Valjevo	782	806	y = 2.7157x + 764.86	Nonsignificant
Vranje	614	606	y = 6.6096x + 496.07	Nonsignificant
Zrenjanin	562	597	y = 0.5951x + 587.63	Significant
Kikinda	535	575	y = 1.5467x + 551.85	Nonsignificant
Kopaonik	921	1032	y = 8.4524x + 888.14	Nonsignificant
Kragujevac	632	650	y = 4.723x + 579.52	Nonsignificant
Leskovac	594	659	y = 5.0021x + 583.85	Nonsignificant
Niš	590	610	y = 5.5752x + 516.8	Nonsignificant
Pirot	No data	584	y = 4.8741x + 505.33	Nonsignificant
Novi Sad	577	676	y = 0.1506x + 673.76	Nonsignificant
Sjenica	713	792	y = 5.1518x + 709.2	Nonsignificant
Sombor	574	639	y = 2.3356x + 603.48	Nonsignificant
Sremska Mitrovica	615	611	y = -0.2188x + 614.64	Nonsignificant
Crni Vrh	816	798	y = 7.0164x + 679.57	Nonsignificant

According to an isochietic map in the climate atlas of the SFR of Yugoslavia, the least amount of precipitation is observed in southern Pomoravlje – especially in the Niš-Leskovac valley and the Vranska valley, northeastern Bačka and northern Banat – below 600 mm. However, according to the data for the period 1991-2019, used in this study, Leskovac station has an average annual rainfall of 659 mm. The driest place is Bela Palanka, near Pirot station (525 mm) (Rakicevic, 2011). The lowest amount of precipitation in Bela Palanka and Pirot can be explained by the fact that in addition to being the easternmost of all stations, they are also surrounded by Suva Mountain and Stara Planina Mountain, which puts these areas in a kind of "precipitation shadow". Banat County (Kikinda) is also one of the driest areas in the country. The lowest amount of precipitation in that region is observed at Kikinda station – 575 mm. This is due to the low humidity, the flat terrain, the location of the northernmost station far from the surrounding seas, and Banat being the most continental part of Serbia. In summer, the extreme south of Serbia, like the Mediterranean, is under the influence of the Azores anticyclone, which determines clear, dry and hot weather. In winter, the southern parts of Serbia – being a part of the central Balkans – are influenced by an anticyclonic circulation, depending on the type of weather conditions (Central European maximum, Eastern European maximum, or stationary anticyclone). This fact, together with the remoteness of the Adriatic Sea, results in less rainfall, which contradicts the thesis that higher altitudes exhibit more rainfall than lower altitudes.

Another example in support of the above statement are the areas of Valjevo and Belgrade, which are at a lower altitude than the areas of Pirot, Niš and Leskovac, but exhibit a higher amount of precipitation. This means that, as far as Serbia is concerned, the amount of precipitation does not always increase with higher altitudes.

Fig. 3 shows the average annual rainfall during the period 1991-2019. At most stations, the rainiest year during the study period was 2014, with the highest amount of precipitation received at Valjevo station (among the studied stations) in May – 324 mm (Prohaska et al., 2014). The driest years in the study period are 1993, 2000 and 2011.

Figure 3. Annual precipitation and trend for the period 1991-2019.

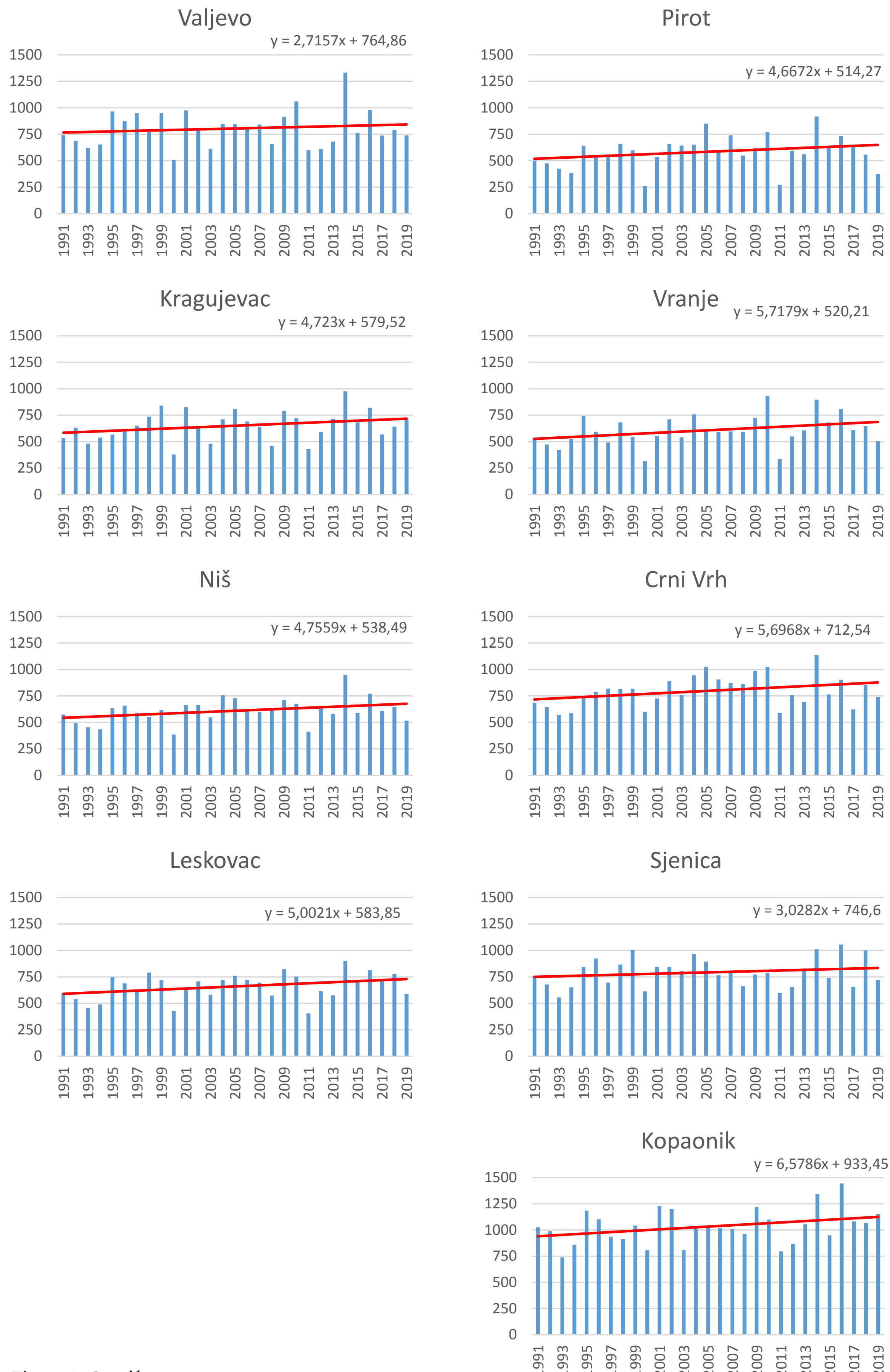

Figure 3. *Cont'd*

In May 2014, cold air advection through the Alps, created a huge, well developed in altitude, Mediterranean cyclone. The cyclone trajectory crossed the Adriatic Sea toward the western part of the Balkan Peninsula. The main part of the clouds and rainfall zone of the cyclone, positioned over the western part of the Balkans, was stationary. For the period 14th -18th May, 2014, that cyclone was the reason for the heavy rainfall over the country (Fig. 4 and 5). According to the Serbian Met Service, the rainfall measured was over 200 mm, but locally, at some places, the measured amount was over 300 mm. Another cyclone which formed between 12th and 20th June, was the reason for a great amount of rainfall, but only in mountainous areas (Zlatibor, Miroč, Stara Planina).

Throughout the summer, the cyclonic circulation maintained, causing a large amount of precipitation at Belgrade, Valjevo and Crni Vrh. The appearance of cyclones over Serbia in 2014 was a consequence of the retention of unstable air masses in the periphery of the cyclonic circulation from western Europe, with a short-term increase in its geopotential and temperature. (Prohaska et al., 2014) Throughout 2014, during each of the cyclones that passed, formed and/or remained over Serbia, the highest rainfall was recorded at Valjevo station, followed by the area of Belgrade. The precipitation in April and May, 2014, significantly exceeded the average precipitation amounts for April. The stations in the northern part of the country and in Vojvodina, were the least affected by the April cyclone. In May, the stations in western and central Serbia were the most affected ones (Table 3).

Table 3. Average monthly precipitation for April and May, 2014, and in the period 1991-2019.

Period	2014		1991-2019	
Stations	**April**	**May**	**April**	**May**
Belgrade	85.3	280.4	53.0	69.9
Valjevo	177.1	323.7	60.7	92.7
Vranje	161.8	125.3	51.3	63.2
Zrenjanin	76.0	159.9	42.0	61.4
Kikinda	36.9	125.7	41.9	61.9
Kopaonik	217.6	183.6	95.4	119.1
Kragujevac	129.1	227.0	55.2	68.8
Leskovac	185.3	122.7	63.8	68.2
Niš	121.7	177.1	57.2	68.1
Pirot	124.6	118.2	51.1	64.1
Novi Sad	51.2	202.1	47.8	79.2
Sjenica	127.4	143.6	58.5	82.0
Sombor	42.8	145.0	40.9	65.9
Sremska Mitrovica	74.2	187.0	45.3	68.1
Crni Vrh	152.4	159.0	72.0	85.8

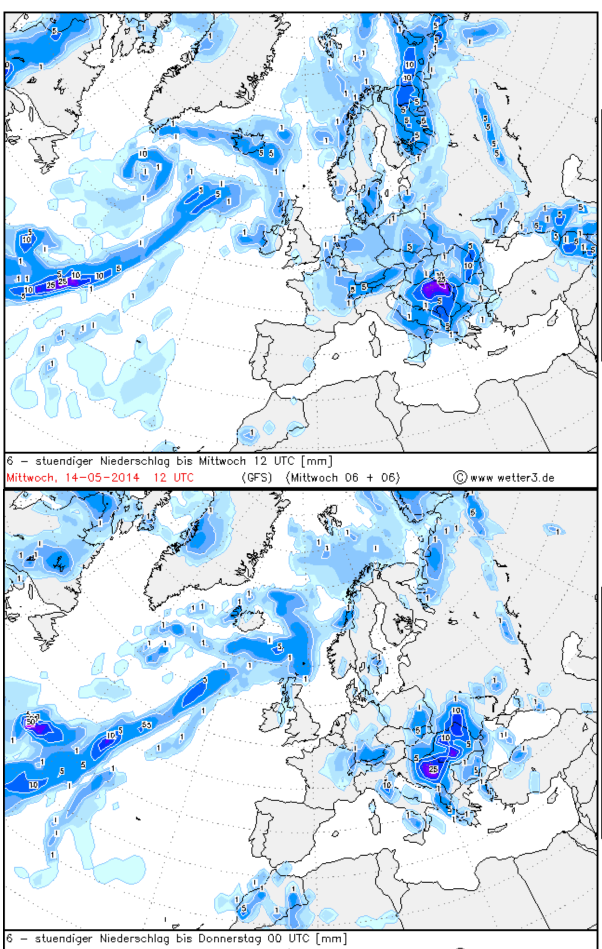

Figure 4. Precipitation map – 14th-15th May, 2014. Source: www.wetter3.de

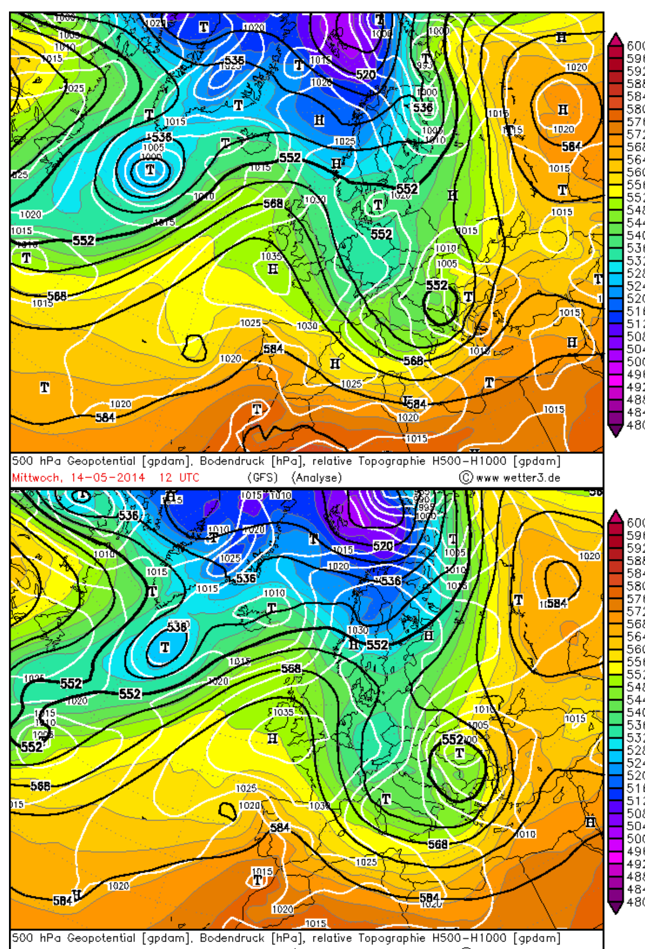

Figure 5. Relative topography 500/1000 hPa – 14th-15th May, 2014. Source: www.wetter3.de

4. Conclusion

From the analysis of the results of this study, we can draw the following conclusions: The average annual rainfall in Serbia in the period 1991-2019 varied between 575 mm (Kikinda region) and 1032 mm (Kopaonik region). The region of Sremska Mitrovica is characterized by negative values of the linear trend (-2.1 mm/10 years) for the period 1991-2019. The data for the rest of the study area shows a positive linear trend. The highest values are recorded in mountainous areas (Kopaonik – 84.5 mm/10 years, and Crni Vrh – 70.1 mm/10 years). From the analysis of the annual precipitation amounts for the period 1991-2019, we can summarize that the driest year was 2000. The annual precipitation amounts for the regions of southern Serbia exhibited similar values in 2011. In the region of Vojvodina, the year of the highest annual precipitation values was 2010. In southern and central Serbia, the year of the highest annual precipitation values was 2014. In the studied mountainous areas, the driest year was 1990. The highest annual precipitation values were recorded in 2014 at Crni Vrh and Sjenica, and in 2016 at Kopaonik station.

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