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ANALYSIS OF ANNUAL SUMS OF PRECIPITATION IN SERBIA

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Abstract: This paper analyses the series of annual sums of precipitation for 27 stations in Serbia for the period 1951-2010. The lowest average perennial precipitation values have been determined for stations in northern Serbia, that is, generally a reduction in precipitation is noticed from west to east of the country. Northeast, east, south and southeast show negative trend values, while a positive precipitation trend is confirmed for the rest of Serbia with the highest values in the west and southwest of Serbia. The advantage of applying the method of cumulative sums and the „bootstrapping“ in the analysis of time series in relation to the method of linear trend has been emphasized. Periods when precipitation was below average or above average for the entire analysed period were defined. Also, a spatial differentiation of change in precipitation for the period of 60 years in Serbia has been noticed.

Key words: annual sums of precipitation, Serbia, linear trend, the cumulative sum method

Introduction

Analysis of precipitation trends for the past several decades as part of climate changes has been the topic of many studies. Knowledge of the precipitation regime and the hydrological cycle in general has significant scientific and practical importance. This study seeks to answer the question of whether and how precipitation changed in Serbia in the period of 60 years (1951-2010) by analysis of the annual amount of precipitation for 27 stations.

Several authors studied changes in the values of climate elements in the second half of the 20th century in Serbia (Radovanović & Ducić, 2004; Ducić & Luković, 2005; Milovanović, 2005; Ducić, Luković & Milovanović, 2009; Milovanović, Radovanović & Jojić-Glavonjić, 2010; Unkašević & Tošić, 2011). The paper aims to determine the time periods when amounts of precipitation were below, that is above the average for the entire analysed period and the timing when the change occurred. In order to achieve that, the method of

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cumulative sums and the ‘bootstrapping’ method were used and their advantage in the analysis of time series in relation to the method of linear trend has been emphasized. Stanojević (2011) used the mentioned methods in the analysis of seasonal temperatures in Serbia for the period 1949-2009.

Data and Methodology of the Research

This paper analyzes annual sums of precipitation for 27 stations in Serbia in the period 1951-2010 (Table 1). The selected stations are those that have the status of major meteorological stations in Serbia according to the meteorological yearbook from 2010[2], and for which the time series of 60 years are available. Missing values for individual stations were interpolated using the two neighbouring stations and the time series completed. In the first step, the average sums of precipitation were calculated for the entire period, as well as the standard deviation, coefficient of variation and coefficient of skewness for the series of annual sums of precipitation. Mean annual precipitation was also calculated for the climate normal period 1961-1990 and difference in relation to the whole period was obtained. Also, annual precipitation minima and maxima were singled out, that is, years with the highest and lowest amount of precipitation. The goal has been to gain a detailed insight into the data set available and, in the second step, to approach the calculation of trends in order to determine whether it came to the increase or decrease in annual precipitation in the observed period.

The results of trend analysis provide an unambiguous assessment of the changes that have occurred (+ for increase, and - for the decrease). To gain further insight into changes over time, the method of cumulative sums was applied, that is, series of the cumulative sum of differences of all values in the range of arithmetic mean of the whole series. Decline (increase) of the value in a series of cumulative sums indicates that the values i.e. precipitation was below (above) the average for the entire period. Also, the difference between maximum and minimum values in a series of cumulative sums (S_{diff}) is calculated. This method is suitable for detecting the time at which the change occurs, that is, a value decline (increase) begins. The statistical verification of this moment is determined by the method of „bootstrapping“. This means generating the new samples from the existing series (in this case the number of new samples is obtained as the factorial of the number 60, that is 60!), and then re-calculating the series of cumulative sums and differences obtained (S^0_{diff}) are compared with the determined difference in the original series. Compliance with the

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[2] http://www.hidmet.gov.rs

conditions that the newly obtained difference is less than the difference from the original series ($S^0_{diff} < S_{diff}$) is used to determine the level of confidence that the change occurred, where the ratio is the number of cases when the difference is less to the total number of cases (obtained ratio is multiplied by 100 and expressed in %). The program that has been used in the paper for this calculation is Change-Point Analyzer 2.3[3].

Table 1. Stations with geographic coordinates, altitude (above the sea level) in m and the time period used in the analysis

Station	λ	φ	Alt.	Period
Palić	46 ° 06 ’	19 ° 46 ’	102	1951-2010
Kikinda	45 ° 51 ’	20 ° 28 ’	81	1951-2010
Sombor	45 ° 46 ’	19 ° 09 ’	87	1951-2010
Zrenjanin	45 ° 24 ’	20 ° 23 ’	80	1951-2010
Rimski Šancevi	45 ° 20 ’	19 ° 51 ’	86	1951-2010
Vršac	45 ° 09 ’	21 ° 19 ’	84	1951-2010
Sremska Mitrovica	45 ° 01 ’	19 ° 33 ’	82	1951-2010
Beograd	44 ° 48 ’	20 ° 28 ’	132	1951-2010
Veliko Gradište	44 ° 45 ’	21 ° 31 ’	80	1951-2010
Loznica	44 ° 33 ’	19 ° 14 ’	121	1951-2010
Smederevska Palanka	44 ° 22 ’	20 ° 57 ’	121	1951-2010
Valjevo	44 ° 17 ’	19 ° 55 ’	176	1951-2010
Negotin	44 ° 14 ’	22 ° 33 ’	42	1951-2010
Kragujevac	44 ° 02 ’	20 ° 56 ’	185	1951-2010
Ćuprija	43 ° 56 ’	21 ° 22 ’	123	1951-2010
Zaječar	43 ° 53 ’	22 ° 17 ’	144	1951-2010
Požega	43 ° 50 ’	20 ° 02 ’	310	1951-2010
Zlatibor	43 ° 44 ’	19 ° 43 ’	1028	1951-2010
Kraljevo	43 ° 43 ’	20 ° 42 ’	215	1951-2010
Kruševac	43 ° 34 ’	21 ° 21 ’	166	1951-2010
Niš	43 ° 20 ’	21 ° 54 ’	204	1951-2010
Kopaonik	43 ° 17 ’	20 ° 48 ’	1711	1951-2010
Sjenica	43 ° 16 ’	20 ° 00 ’	1038	1951-2010
Kuršumlija	43 ° 08 ’	21 ° 16 ’	383	1951-2010
Dimitrovgrad	43 ° 01 ’	22 ° 45 ’	450	1951-2010
Leskovac	42 ° 59 ’	21 ° 57 ’	230	1951-2010
Vranje	42 ° 33 ’	21 ° 55 ’	432	1951-2010

Source: Meteorological yearbooks, The Republic Hydrometeorological Service of Serbia

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[3] http://www.variation.com/

The Research Results

Average values of annual sums of precipitation in the period 1951-2010 range from 554 mm for Kikinda station to 972.5 mm for Zlatibor station and 977.1 mm for Kopaonik (Table 2). The highest values are found for stations located at higher altitudes and it is quite clear as to why Kopaonik and Zlatibor. Kikinda and generally other stations located in northern Serbia (Palić 560.3 mm, Sombor 607.2 mm, Zrenjanin 583.7 mm, Rimski Šančevi 625.6 mm, Vršac 659.6 mm and Sremska Mitrovica 629.2 mm) have the lowest values of precipitation, followed by stations in the east and the southeast of Serbia (Veliko Gradište 637 mm, Negotin 652.6 mm, Zaječar 611.1 mm, Niš 592.9 mm, Dimitrovgrad 645.7 mm, Leskovac 627.7 mm, Vranje 611.8 mm), while relatively higher values are recorded at stations in central Serbia (Belgrade 698.2 mm, Kragujevac 635.8 mm, Smederevska Palanka 646 mm, Kraljevo 763.7 mm, Kruševac 648.4 mm), and the highest ones are in the west and southwest of Serbia (Loznica 844.8 mm, Valjevo 806.6 mm, Požega 737.1 mm, Sjenica 734.5 mm). Also, the standard deviation value is the lowest for the station with the least mean perennial precipitation (106.6 mm for Kikinda), while the highest values are for Kopaonik (171.9 mm), Zlatibor (142.7 mm), Valjevo (165.1 mm) and Rimski Šančevi (150.3 mm). However, quite uniform values of the coefficient of variation (in the range of 0.15 for Loznica and Kraljevo to 0.24 for Rimski Šančevi) indicate that the average deviation for all stations was about 20% of the arithmetical mean (Table 2). The coefficient of skewness does not exceed the absolute value of 0.50, which means that all stations show a symmetrical arrangement, that is, have a normal distribution. Differences from normal (1961-2010) range from relatively small negative values for three stations (Valjevo -2.7 mm, Požega -2.4 mm and Vranje -2.3 mm) to positive values that in most stations range from 2.4 mm (Kraljevo) to 27.1 mm (Zrenjanin), with a maximum of 48.6 mm for Rimski Šančevi. One gets the impression that for most stations changes in average perennial precipitation are negligible or relatively small in the period 1951-2010 compared to the normal 1961-1990.

The linear trend analysis shows negative values for stations that are for the most part located in the northeast, east and southeast part of Serbia (Kikinda -0.247 mm/year, Veliko Gradište -0.657 mm/year, Negotin -1.878 mm/year, Zaječar -1.38 mm/year, Kruševac -0.807 mm/year, Kuršumlija -0.063 mm/year, Vranje -1.055 mm/year, Dimitrovgrad -0.022 mm/year), while other stations show an increase in precipitation for the analyzed period (Table 3). However, in most cases the trend is poorly expressed and without statistical significance. Statistically significant positive trend on the risk level of 0.05 was obtained for stations Palić (1.906 mm/year), Loznica (1.951 mm/year), Zlatibor

(3.751 mm/year) and Sjenica (1.944 mm/year). However, the question arises as to whether the changes in the analyzed period are poorly expressed, that is, whether something major happened with precipitation in Serbia for a period of six decades.

Table 2. The mean value (X) for the period 1951-2010 in mm, mean value (x) for the period 1961-1990 in mm, the difference for the entire period and normal (d = X-x), standard deviation (S), coefficient of variation (Cv) and coefficient of skewness (Cs) for the analyzed annual series of precipitation in the period 1951-2010

Station	X	x	d	S	Cv	Cs
Palić	560.3	539.2	21.1	123.9	0.22	0.46
Kikinda	554.0	535.3	18.7	106.6	0.19	-0.25
Sombor	607.2	583.5	23.8	128.4	0.21	0.65
Zrenjanin	583.7	556.6	27.1	120.1	0.21	0.17
Rimski Šančevi	625.6	577.0	48.6	150.3	0.24	0.55
Vršac	659.6	647.2	12.4	137.3	0.21	0.20
Sremska Mitrovica	629.2	615.0	14.3	126.1	0.20	0.16
Beograd	698.2	685.0	13.2	131.4	0.19	0.10
Veliko Gradište	637.0	615.0	22.0	126.0	0.20	-0.23
Loznica	844.8	819.6	25.1	125.0	0.15	-0.08
Smederevska Palanka	646.0	638.5	7.5	113.9	018	-0.06
Valjevo	806.6	809.3	-2.7	165.1	0.20	1.84
Negotin	652.6	642.9	9.7	126.8	0.19	-0.21
Kragujevac	635.8	632.5	3.3	111.3	0.18	0.10
Ćuprija	662.6	649.5	13.1	118.5	0.17	0.35
Zaječar	611.1	600.1	11.0	120.8	0.18	0.11
Požega	737.1	739.6	-2.4	116.2	0.20	-0.05
Zlatibor	972.5	963.2	9.3	142.7	0.16	0.08
Kraljevo	763.7	761.4	2.4	122.5	0.15	0.22
Kruševac	648.4	634.7	13.8	135.4	0.16	0.90
Niš	592.9	588.2	4.7	97.4	0.21	0.01
Kopaonik	977.1	963.9	13.2	171.9	0.16	1.03
Sjenica	734.5	707.1	27.4	122.1	0.18	0.25
Kuršumlija	660.0	639.9	20.0	119.8	0.17	0.30
Dimitrovgrad	645.7	636.9	8.8	108.5	0.18	-0.45
Leskovac	627.7	602.8	24.9	108.3	0.17	0.29
Vranje	611.8	614.0	-2.3	110.8	0.17	-0.06

If selected annual maximum and minimum precipitation amounts for a period of 60 years are observed, it can be seen that the 2000 is the year with the lowest precipitation for most stations, that is, years in the last decades of the period, while at the maximum annual values of precipitation those are the initial decades of the period (Figures 1 and 2). The question is whether it is isolated years about or implication that larger amounts of precipitation are characteristic of the first decade in relation to the last decade of the analysed period. Some of the answers were obtained in further research.

Table 3. Annual sums of precipitation linear trend for the period 1951-2010. Asterisks placed next to the name of station indicate statistically significant trend for the risk level of 0.10 (*) and 0.05 (**) for that station by Student's t-test.

Station	Trend line	R^2
Palić**	y = 1.906x + 502.1	0.072
Kikinda	y = -0.247x + 561.4	0.001
Sombor	y = 1.044x + 575.3	0.020
Zrenjanin	y = 0.483x + 568.9	0.005
Rimski Šančevi	y = 1.719x + 573.1	0.039
Vršac	y = 0.130x + 655.6	0.000
Sremska Mitrovica	y = -0.352x + 640	0.002
Beograd	y = 0.516x + 682.4	0.004
Veliko Gradište	y = -0.657x + 657.0	0.008
Loznica**	y = 1.951x + 785.2	0.074
Smederevska Palanka	y = 0.640x + 626.4	0.009
Valjevo	y = 0.622x + 787.6	0.004
Negotin*	y = -1.878x + 709.9	0.067
Kragujevac	y = 0.220x + 629.0	0.001
Ćuprija	y = 0.743x + 639.8	0.012
Zaječar	y = -1.385x + 653.3	0.040
Požega	y = 0.230x + 730.1	0.001
Zlatibor**	y = 3.751x + 858.0	0.210
Kraljevo	y = -1.019x + 794.8	0.021
Kruševac	y = -0.807x + 673.0	0.010
Niš	y = 0.378x + 581.3	0.004
Kopaonik	y = 1.657x + 926.5	0.028
Sjenica**	y = 1.944x + 675.2	0.077
Kuršumlija	y = -0.063x + 661.9	0.000
Dimitrovgrad	y = -0.022x + 646.3	0.000
Leskovac	y = 0.690x + 606.6	0.012
Vranje	y = -1.055x + 643.9	0.027

By using the methods of cumulative sum and „bootstrapping“, an insight into what happened with precipitation series over time is provided. Application results of these methods are shown in such a way that the stations are grouped as follows: the Figure 3 shows the obtained results for the stations that are located in northern Serbia (Palić, Sombor, Kikinda, Zrenjanin, Rimski Šančevi, Vršac, Sremska Mitrovica), the stations in the east, south and southeast of Serbia are in the Figure 4 (Veliko Gradište, Negotin, Zaječar, Niš, Kuršumlija, Leskovac, Dimitrovgrad and Vranje), the stations that are found in most of central Serbia (Belgrade, Smederevska Palanka, Ćuprija, Kragujevac, Kraljevo and Kruševac) are in the Figure 5 and the Figure 6 shows the stations that are mostly in the west and southwest of Serbia (Loznica, Valjevo, Požega, Zlatibor, Kopaonik and Sjenica).

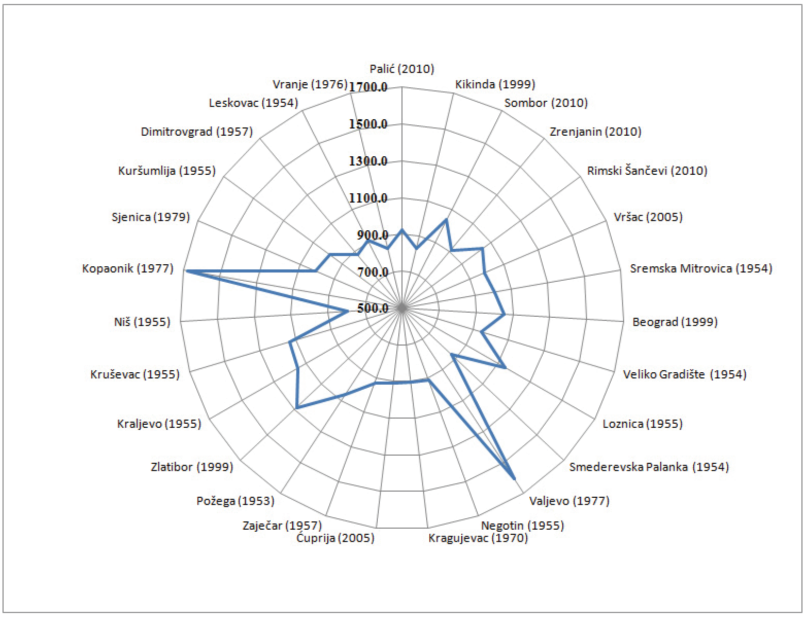

Figure 1. Annual precipitation maxima (mm) with the year of appearance, period 1951-2010.

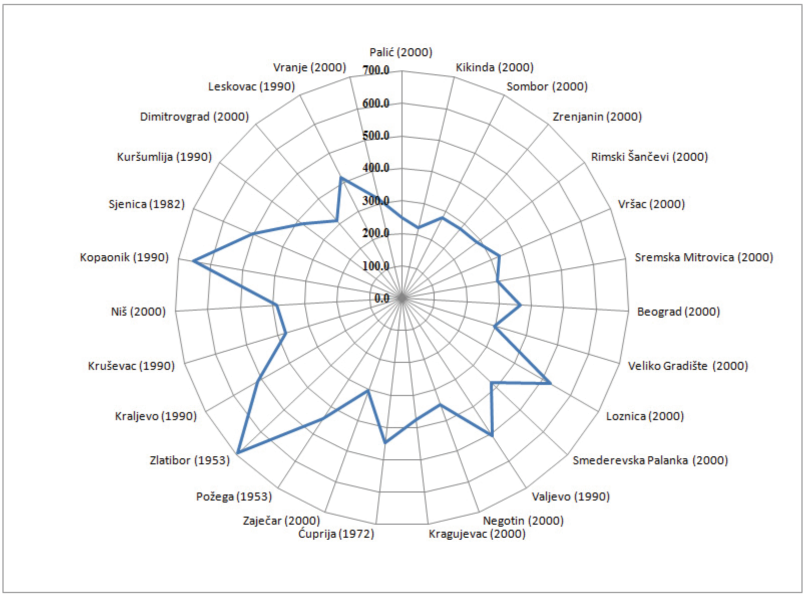

Figure 2. Annual precipitation minima (mm) with the year of appearance, period 1951-2010.

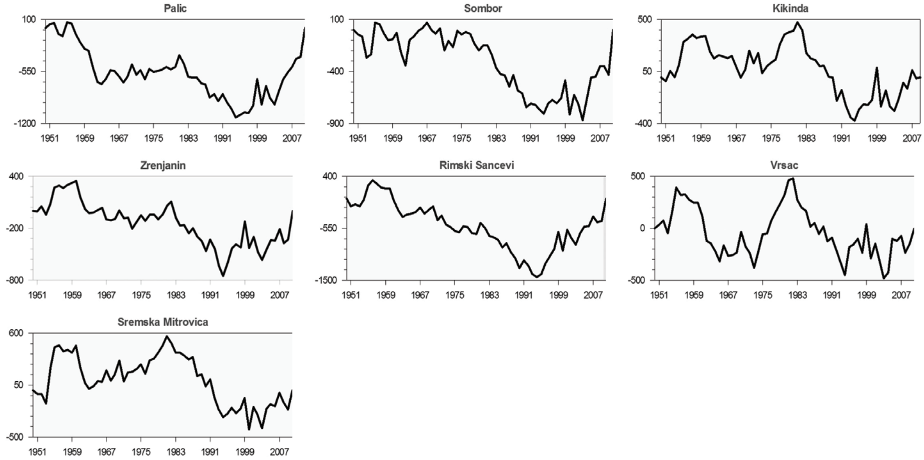

Figure 3. Cumulative sums for stations in the north of Serbia, the period 1951-2010.

It can be noticed that for the stations in northern Serbia, annual sums of precipitation are greater or they increased compared to the average for the entire period during the first few decades, with the maxima during the first decade and the 1970s, after which a decline occurred, followed by a new sharp increase from the mid-1990s (Figure 3).

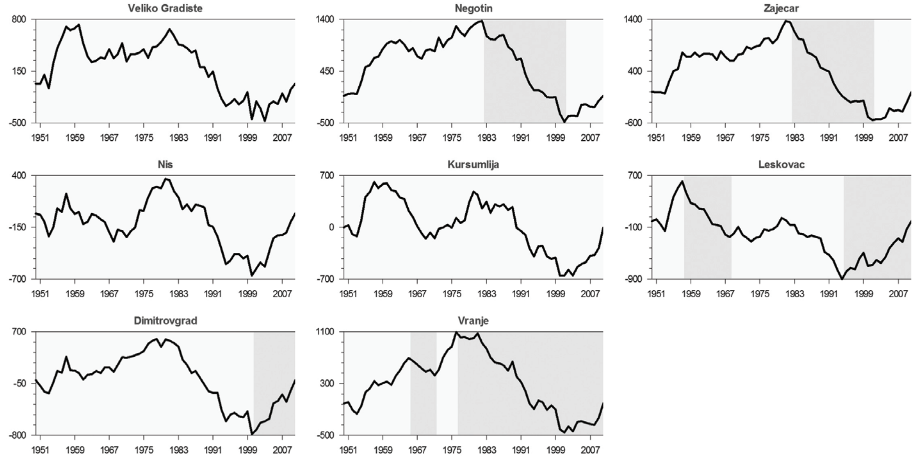

Figure 4. Cumulative sums for stations in the east, south and southeast of Serbia, the period 1951-2010.

Stations in the east and south/southeast of Serbia (Figure 4) are characterized by precipitation at the beginning of the period that are lower than average, followed by an increase, with a maximum during the 1970s, after which lower than average values followed by the end of the 1990s and early 2000s, and the rapid growth again by the end of the analysed period. In the Figure 4, grey parts which indicate that the change over a certain period of time is statistically significant can be observed for some stations. Thus, there are two separate years, 1983 and 2002, singled out for the station of Negotin as the time moment when changes have occurred. The average annual precipitation value was 695.7 mm up to 1983, in the period from 1983 to 2002, 555 mm, and by the end of the period the value was 705.3 mm. The significance level for the first year was 99%, and 92% for the second. The same years have also been singled out for Zaječar, and the average was 653.3 mm up to 1983, from 1983 to 2002, 511.4 mm, and 641.4 mm by the end of the period. The significance level was 100% and 98%. For Leskovac, years that have been singled out are 1958 (change from 715.2 mm to 549.3 mm, 98% confidence level), 1969 (change from 549.3 mm to 602.8 mm, 95% confidence level) and 1995 (from 602.8 mm to 683 mm, 97% confidence level). For Dimitrovgrad, statistically significant moment of change is 2001, the former average of precipitation of 630.1 mm increased to 723.9 mm by the end of the period (97% confidence level). For Vranje, the most significant change occurred in 1977 when the precipitation decreased from 744.8 mm on the average to 567.1 mm (93% confidence level). The trend of precipitation increase was only in the second half of the last decade.

Figure 5. Cumulative sums for stations in central Serbia, the period 1951-2010.

In the territory of central Serbia, several periods are clearly differentiated; the increase to the middle of the first decade, then precipitation lower than average until the mid-1960s, then re-increase to the mid-1980s followed by a decrease of annual sums of precipitation until the middle or end of the 1990s when an increase in precipitation occurred (Figure 5). Statistically significant time moment of changes was found for Smederevska Palanka and Kruševac. In the first case, 1961, 1968 and 1982 were selected (100% confidence level for all three years), while for Kruševac, 1961 (98% confidence), 1966 (100% confidence level) and 1982 (100% confidence level).

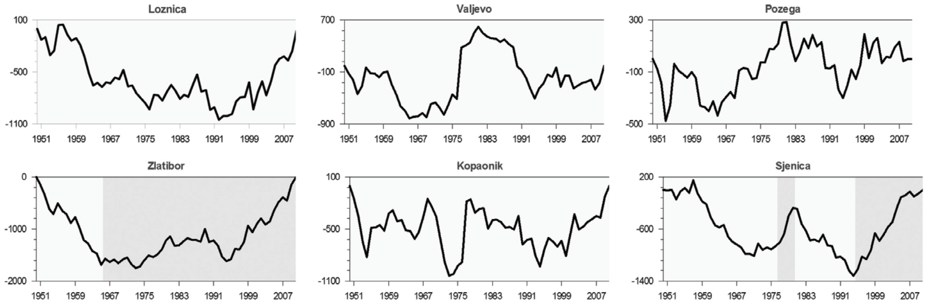

Figure 6. Cumulative sums for stations in the west and southwest of Serbia, the period 1951-2010.

West and southwest of Serbia are characterized by annual sums of precipitation that are lower than average from the beginning of the period with the less pronounced growth during the mid-1980s and further decline up to the 1990s, followed by an increase in precipitation in relation to the average of 1951-2010 (Figure 6). For station Zlatibor, the 1966 has been singled out when the average precipitation from 860.1 mm increased to 1009.9 mm by the end of the period (96% confidence level). In Sjenica, the time moments of changes are 1977 (98% confidence), 1981 (95%) and 1995 (99%). The most significant change occurred in 1995 when the average precipitation increased from 659.4 mm up to 1995 to 816.9 mm after this year.

These results indicate the advantage of using the method of cumulative sums in understanding the changes that have occurred over time. Also, it is important to note that this approach is not mutually excluded from the method of linear trend, but both methods can be complementary in the analysis of time series.

Discussion and Conclusion

Based on the analysis of annual sums of precipitation in Serbia in the period of 60 years (1951-2010), one can draw a number of conclusions. The lowest values of mean perennial precipitation were obtained for the stations in northern Serbia, while the highest values are for the stations at higher altitudes and in western and south-western Serbia. Generally, the total annual amount of precipitation decreases from west to east, that is, follows the spatial distribution in Serbia which gave Ducić and Radovanović (2005), analyzing the data for the period 1961-1990. Coefficient of variation for the series of annual precipitation indicates an average of 20% of data deviation from the mean value for the entire period (1951-2010). Analysis of linear trend indicates negative trend values for stations in the northeast, east, south and southeast of Serbia, while the rest of Serbia shows the increase in precipitation. However, the cumulative sum method showed that the method of linear trend generalized the changes that occurred. Calculation of the series of cumulative sums and implementation of „bootstrapping“ allowed detailed insight into changes over time and determination of the time moments when a particular phenomenon occurred. Thus, at the stations in the north of Serbia, the initial decades of the analysed period had the values of annual precipitation above the average, but after the 1970's there was a decrease with the lowest values during the 1990s and the rapid growth in the last decade. The stations in the east and south/southeast of Serbia, after the highest values in the 1970s compared to the average of the whole period showed significantly lower values, and the growth came in the last years of the period. Precipitation above average during the first decade, then during the middle and at the end of the analysed period, and a visible decrease in the decade of the 1960 and the 1990 is the characteristic of time series for the stations of central Serbia. West and southwest of Serbia are characterized by lower annual precipitation than average from the beginning of the period with the less pronounced growth during the mid-1980s and further decline until the 1990s, followed by an increase in precipitation compared to the average of 1951-2010. Bearing in mind these results, the calculated values of the linear trend become clearer: the increase of precipitation for the stations in the east and south/southeast (stations where precipitation has negative trends) is recorded only in the last few years of the period, that is, a little later than other stations where the increase of precipitation is present since the mid-1990s. Also, for most of the stations in the west and southwest of Serbia in the 1980s, there has not been recorded so intense precipitation decline as in other stations, and this part of Serbia has the most positive values of the linear trend. For stations (Kopaonik, Zlatibor) at higher altitudes, precipitation have different course of changes.

There are several studies on the possible causes of precipitation variability on the territory of Serbia. Ducić, Luković and Stanojević (2010) analyzed the relationship between changes in precipitation on the seasonal and annual level and the circulation of the atmosphere presented by Hes-Brezovsky circulation types. One of the conclusions is that the circulation of the atmosphere is an important factor of precipitation variability and regional climate differences. Tošic (2004) analyzed the main characteristics of spatial and temporal variability of winter and summer temperatures and precipitation on the example of 30 stations in Serbia and Montenegro for the period 1951-2000. It has been pointed to the importance of atmospheric circulation to changes in precipitation, that is, a strong correlation between the NAO (North Atlantic Oscillation) index and winter precipitation. Also, spectral analysis revealed quasi-cycle variability of precipitation for 16 years for the winter season, that is, 3 years for the summer season. Djordjević (2008) analyzed trends in annual and seasonal precipitation and temperatures, as well as indexes of extremes of these elements for the station Belgrade in the period 1888-2006, that is, Serbia for the period 1961-2006. It was found that the annual sums of precipitation for Belgrade showed increase, while the number of days with precipitation reduced for all seasons except summer when it was raised. Also, the increased frequency of extreme precipitation events was established for the stations of Belgrade, Zlatibor, Kikinda, Sombor, Kragujevac, Loznica, Smederevska Palanka, Požega, Novi Sad, Niš and Ćuprija. Unkašević and Radinović (2000) in the statistical analysis of monthly precipitation and maximum daily precipitation for Belgrade in the period 1888-1995 indicate the importance of weather types for these events, the maximum daily precipitation most common events are associated with cold fronts followed by torrential rain and storm and cyclones over the East Mediterranean, with centres in the area of south-western Black Sea. Ducić, Luković, Burić, Stanojević and Mustafić (2012) associated the indices of precipitation extremes at the station Crkvice (Krivošije, Montenegro) with particular trajectories of air masses and the position of the action centres on the territory of Europe.

This study, as the studies of other authors, points to the complexity of the problem of determining the changes in precipitation series over time, and also revealing the causes of changes. In this context, of great importance is the knowledge of changes as on the annual, so the seasonal or monthly basis, but also in the direction of research on change of the number of days with precipitation, that is, intensity of precipitation events.

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