EVALUATION OF THE CLIMATE CHANGE EFFECTS TO THE PRECIPITATION PATTERNS IN THE SELECTED BOSNIA AND HERZEGOVINA CITIES

by

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Climate change effects are most often presented with ongoing and expected temperature increase and sea level rise, but also stressed is the shift in rainfall patterns, often difficult to distinguish because there is much natural variability in precipitation. Statistical process control presents application of statistical methods and procedures for monitoring and control of the selected process. It aims to evaluate two potential sources of a process variation: natural (common) and assignable (special) causes. Statistical process control was recently used to evaluate climate change/variation, using previous referential period as a benchmark for addressing the present variations (e. g. in temperature or precipitation) as being triggered by natural or special causes. This means that either variation statistically should have been expected or the natural processes "capability" changed and variations are higher than one could expect. This paper analytically compares specific precipitation pattern changes in the three cities of Bosnia and Herzegovina with different annual participation. The comparison is based on the assessment of statistical behaviour of the precipitation data during the periods of 1961-1990 and after 1990. Such comparison allows preliminary conclusions on the studied geographical distribution of specific climate change/variation impacts. The presented results show that climate variations effect the precipitation patterns change, but do not confirm that they are as high as they could not be statistically expected, based on previous precipitation data.

Key words: *climate change, precipitation patterns, monitoring data, statistical process control, control charts*

Introduction

Scientists define climate as the average weather for a particular region and time period, including temperature, precipitation, humidity, sunshine, cloudiness, and wind, where standard averaging period is 30 years [1]. It is really an average pattern of weather for a particular region. The term "climate change" is used to refer to the changes in the climate often considered to be caused by human activities, mostly during the 20th and 21st century. America's Climate Choices report of 2011 states that the average temperature of the Earth's surface increased by about 1.4 °F (0.8 °C) over the past 100 years, with about 1.0 °F (0.6 °C) of this warming occurring over just the past three decades. Most of the world scientists agree that global temperatures will continue to rise [2].

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The „Climate Change 2007: Synthesis Report" reports that the average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed faster than the oceans. Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3,000 m and that the ocean has been taking up over 80% of the heat being added to the climate system [3].

For the South-East European countries, including Albania, Bosnia and Herzegovina (B&H), Montenegro, Serbia, and Turkey, the impacts of climate change is forecasted to include: increased temperatures; a rise in the frequency of extreme weather events; increased coastal erosion, sea level rise, impacts on marine biodiversity, rising water levels in tidal rivers; increased flooding; severe pressure on water resources; increased forest and scrubland fires; changing agricultural landscapes, including crop failure; changes in habitat composition and species distribution, richness and diversity; and increasing problems caused by invasive alien species [4].

High-mountain and mountain ecosystems, on the basis of a research on global climatic changes in B&H, are expected to be exposed to the greatest impact. In other words, the areas of an altitude above 1,500 m will have a more rapid increase of average temperature. Besides that, extremes in temperature represent the biggest pressure being exerted on the areas, which is particularly visible in the warmer season of the year. It is leading to melting of snow and drying and, with it, a threat that many glacial and boreal relicts and their habitats will be destroyed [5].

Recent B&H meteorological data are in line with such predictions. Data show that the temperature increased by 0.6 °C during the period of 1925-2000 in the country. Seasonal mean temperature for the summer months June-August in the 1990s was higher for 1 °C compared with the mean value for 1961-1990, where in winter months December - February the increase was smaller (about 0.3 °C). The summer of 2003 was the warmest in B&H during last 100 years. The winter of 2006/2007 was the warmest in northern parts B&H during last 100 years, in the other parts it belongs to the three warmest winters during last 100 years. Next few decades could bring significant reduction of a number of days with snow, so as reduction of rainfall in warmer part of the year which would result in the reduction of soil humidity and availability of water resources [6]. The shift in precipitation is observed in strengthening of existing precipitation patterns (wet get wetter, dry get drier), so as in change in storm tracks, expected to move away from the equator and toward the poles as atmospheric circulation changes. Precipitation changes and consequently water regime changes could heavily influence local economy and such a possibility needs to be adequately addressed.

It is mostly accepted that climate change is real and its impacts can not be ignored any more. Increased temperatures as a result of expected global warming will lead to significant changes in atmospheric processes, including rainfall formation and occurrence. It is projected that more extreme events such as floods and droughts will occur so as that the rainfall seasons will change and rainfall variability will increase [7]. A number of researchers forecast that nearly all European regions will be adversely affected by the climate change. But the question is whether some of these changes can be described as statistically expected (including a way to define what may be statistically expected) and especially whether the water regime is really changed in a way that it makes a completely different pattern as compared to the previous meteorologically significant period. The paper is a potential response to the question if the precipitation pattern confirms the shift from former relevant period and if the natural processes "capability" has changed or the "precipitation regime process" is still as it could be expected (or "in-control" as defined within the Statistical Process Control concept and changes do not get out of the range of values that could be expected. These questions are addressed in this paper, using the statistical process control methods approach. It is based on the assessment of precipitation data for the period of 1961-1990 when "the process is considered to be in-control", and then used for evaluating behaviour of precipitation during the period of 2000-2010, all evaluated for the three B&H cities located in three different precipitation zones. Comparison of the precipitation pattern changes may provide indicative response to the above mentioned questions.

The paper is divided in six sections. Following the introduction, the next section reminds of the main aspects of climate change and its basis, as addressed during last decades. Section *Research results – control chart for precipitation data* introduces statistical process control concept, while the section *Discussion of the control charts* presents results of application of SPC i-chart to the series of precipitation data in Bihac, Sanski Most and, Sarajevo, all in B&H, during the periods of 1961-1990 and 2000-2010. Finally, the last section brings conclusions both on climate change effects and on the applicability of SPC in this area.

Used methodology – statistical process control concept

Vilfredo Pareto (1848-1923), who was trained as an engineer but is best known for his economic and sociological works, has set one of the basic optimization postulates of statistical process control. He noticed that many failures in a system result from a small number of causes and that in production process rarely some "general malaise" causes problems. Pareto found out that even though some companies show both diligence and hard work, and even strong motivation in some cases, the quality of the product or service is still poor. Thus, in order to improve such system, for production, management or providing services, it is required to find and correct those causes, also called "Pareto glitches" [8].

The SPC chart is an effective monitoring technique widely used in production processes. But recently SPC chart is increasingly used also in non-manufacturing sectors. An SPC control chart aims to assist in decision making to avoid the two potential types of errors:

- a decision for enhancement is made when the situation is actually still under control. Such a decision is referred to as a false alarm, which leads to unnecessary waste of resources, and
- a decision for a necessary and immediate action is delayed when the event already becomes out of control. Such an error may lead to serious or even disastrous consequences [9].

Walter Shewhart at Bell Laboratories during the 1920s developed basic theory of SPC – in 1924 Shewhart developed the control chart and the concept of a state of statistical control. It was later popularised worldwide by Edwards Deming who introduced SPC to Japanese industry after World War II. After early successful adoption by Japanese firms, statistical process control has been incorporated by organizations around the world as a primary tool to improve product quality by reducing process variation. Both Shewart and Deming noticed that repeated measurements of a single process will exhibit some level of variation. Even though Shewhart originally started working with manufacturing processes, both he and Deming understood that such observation could be applied to any sort of process. If a process is stable, its variation will be predictable and it is possible to describe it with some of several statistical distributions (where normal distribution is the most often used).

Inherent nature of any process has own common cause variations that can not be altered without changing the process itself. But there are also other causes, called *special* or *assignable* causes of variation, that present unusual process disturbances. Such causes should be recognized and removed. The key purpose of SPC is to distinguish between these two types of variation, aiming to avoid both over-reaction and under-reaction or even lack of needed response to the changed process. It assists in recognizing situations where reaction relates to the cause that has sufficient impact, and which is practical and economic to remove it in order to improve the quality [10].

Statistical process control approach is based on the Shewhart's finding that control limits placed at three standard deviations from the mean in either direction are giving reasonable trade off between the risk of reacting to a false signal and the risk of not reacting to a true signal, both being undesired, no matter what is the actual process statistical distribution. Thus if the process has a normal distribution, 99.74% of the population is under the related distribution curve at three standard deviations from the mean both sides. In other words, only 0.26% chance is to get a value beyond the three standard deviations, and thus it is considered that such a measured value indicates that the process has either shifted or become unstable.

Similarly, for the process with normal distribution, 95.44% of the population is under the related distribution curve at two standard deviations from the mean both sides, or 4.56% chance is to get a value beyond the two standard deviations, where such chance falls to only 0.21% is such two consecutive values appear. This was the basis to conclude that having one measured value beyond the two standard deviations could be understood as a warning signal for higher attention to the following value, while the two consecutive values beyond the two standard deviations indicates that the process has either shifted or become unstable.

Application of the statistical process control generally consists of three phases:

- provision of the process flowchart, clearly separating process steps,
- sampling and measuring, usually at regular temporal intervals, at different process steps, and
- creation of "control chart(s)" aiming to recognize *Pareto glitches*, aiming to discover and remove their causes. Control lines at these charts are derived at two (warning lines) and three (action lines) standard deviations from the mean, based on the above explained presumed normal distribution of the data.

The essence of statistical process control is to differentiate causes of process variation. Some variations belong to the category of chance or random variations, and are considered as inherent to the process. They could be removed only with the whole process revision. But other causes of variation, relatively large in magnitude and possible to be identified, are conveniently classified as *assignable* or *special* causes (or *Pareto glitches*). When special causes of variation are present, level of the variation is statistically unexpected and the process is classified as *unstable* or *out of statistical control*.

Thus SPC tries to respond to the two key questions, which are: (i) "Is the process in-control", and (ii) "What is the extent of the process variability". A response to these questions refers to potential presence of any assignable causes of variation, and clarifies if the existing variability may be assigned only to the natural process capability (when only common causes of variation are present).

A control chart has functions similar to the traffic signals. The green light is given when the process is running properly and does not need any adjustment (it is said that "the process is under control") – that means that only common causes of variation are present. Next level is like amber light, which signals that some discrepancy to the natural process could be possible and that increased attention is needed (warning lines at control chart). The red light clearly indicates that assignable or special cause(s) of variation appeared before the occurrence of such data and the process is out of control (action lines at control chart). Such control mechanism could be used only when the process itself is proved to be "in statistical control", meaning that it did not change its main behaviour characteristics.

Control charts are supposed to monitor production processes and are not widely used for controlling the natural processes, and authors are not aware of SPC application in water management or hydrological related studies by other researchers. Still, a few papers of the authors do refer to such use of control charts [11-13].

Research results – control chart for precipitation data

For this specific research data on precipitation of the meteorological stations in Bihac, Sanski Most, and Sarajevo were used. It is relevant to underline that these three cities belong to different precipitation zones - on average Sarajevo is classified within the zone of less then 1,000 mm per year, Sanski Most within the zone of 1,000-1,250 mm per year, and Bihac within the zone of 1,250-1,300 mm per year (fig. 1). The data provider is the Federal Meteorological Institute, legally responsible administration for the data collection. The data was available for the following two periods: the period of 1961-1990 and the period of 2000-2010. The gap of the period of 1991-1999 relates to the war in B&H and few post-war years when the data collection was not enabled due to major destructions in the monitoring system. Four years of the severe war activities destroyed both the technical aspect of the monitoring system, and the human resources being in charge for its management, and several post-war years were thus needed to establish the system again. That is the reason why the second period is much shorter, and the analysis results are expected to be of higher value once the data for equally lasting periods of 30 years would be available. But the ongoing climate changes already request adjustments in the agricultural practices, hydro-power production, reservoirs management and other and delay in addressing these changes can lead to irreversible consequences, thus awaiting for the period 2000-2030 to pass in order to get equally lasting period is not a reasonable option. Nevertheless, even this shorter period enabled appropriate analysis.

For each of the 12 months of the year, for each of the years and the selected cities, total monthly precipitation is calculated as a sum of daily recorded precipitation. Months are selected as appropriate units for hydrological comparison (it could be also *e. g.* periods of 10 consecutive days). Daily data are not appropriate to be used for SPC since for many of the days there was no precipitation recorded. Also, using average daily precipitation within the month or using total monthly precipitation and both is applicable, by the mathematical nature of the used method, have to lead to the same conclusions on expectance of the values, so the authors decided for the total monthly precipitation. That creates (monthly) sequences of values which are considered as an input for the creation of the i-chart (control chart for individual values) – average value CL and standard deviation SE are calculated for each sequence of values of the 12 months and separately for either of the two periods of data available, 1961-1990 and 2000-2010. The values for the period of 1961-1990, which is presumed as a period "when the process was in control", were used to calculate appropriate warning and action values for the control chart.

Data for the period of 2000-2010 were then inserted into this chart with such control lines in order to check if they still remain "being under control", meaning if they are still within the "green light zone" (between the two warning lines). Orange and red lines refer to warning and action lines – if no values of the period of 2000-2010 within any of the months are out of the range between the orange lines, that means that they are statistically expected (or if only one such value is between the orange and red lines, when higher attention was needed, but the next "green" value resets such attention). Values out of the range between the two red lines, or two consecutive values between the same orange and red lines, or six consecutive decreasing or increasing values, or six consecutive values below or above centre line, would indicate that the process is "out of control" or that such value could not be statistically expected.

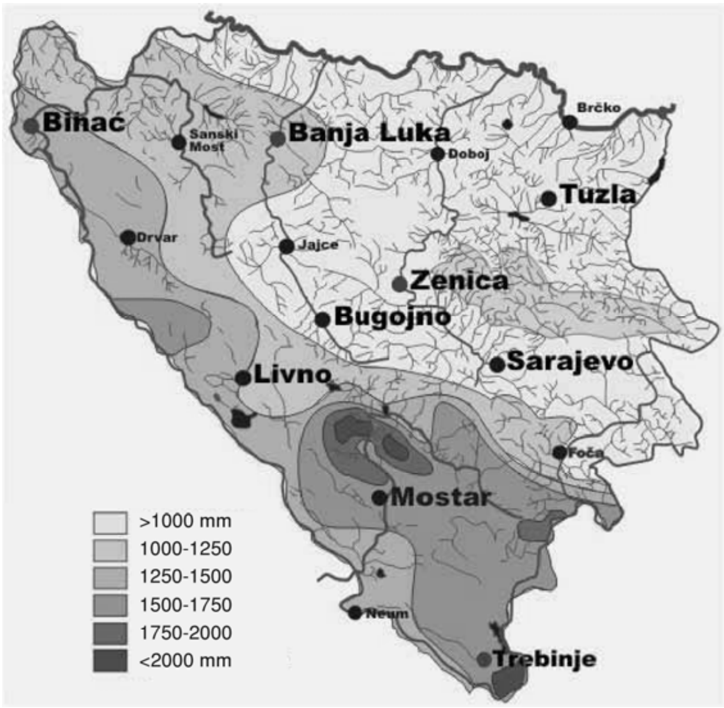

Figure 1. Annual precipitation distribution in B&H, with Bihac, Sanski Most and Sarajevo position (Source: Federal Meteorological Institute)

Created control charts as individual i-charts for each of the months and for each of the cities follow (figs. 2-13). At the end, figures showing comparison for the two periods of average monthly precipitation and related standard deviations (that show the level of variation) are presented. X axis is relating to the observed period, while the Y axis is adjusted for actual precipitation range for each of the months and for each of the locations, since there is no need for mutual comparison of the monthly precipitations, focus is just at the control lines.

Discussion of the control charts

The control charts (figs. 2-13) are individually observed in regard to the change in the precipitation pattern. All points outside the red lines, two out of three successive points between the red and orange lines (meaning between the warning and action lines) or eight points in a run on one side of the mean value would indicate that precipitation in that period was "out of control", or that it was not statistically expected. These rules were checked separately for each of the cities and compared for the same months.

The following abbreviations are used with the figs. 2-13 – LAL for Lower Action Line, LWL for Lower Warning Line, CL for Center Line, UWL for Upper Warning Line, UAL for Upper Action Line, Values for actual values, LAL, LWL, CL, UWL and UAL are all straight lines at the following figures parallel to X axes and positioned in line with their actual meanings, Values are represented by curves within these boundaries.

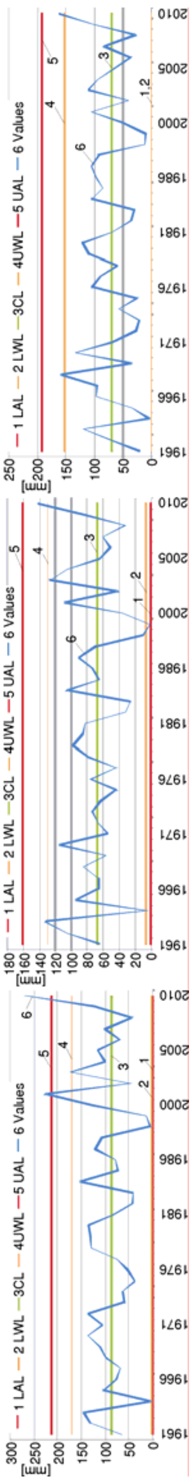

Figure 2. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – January (for color image see journal web site)

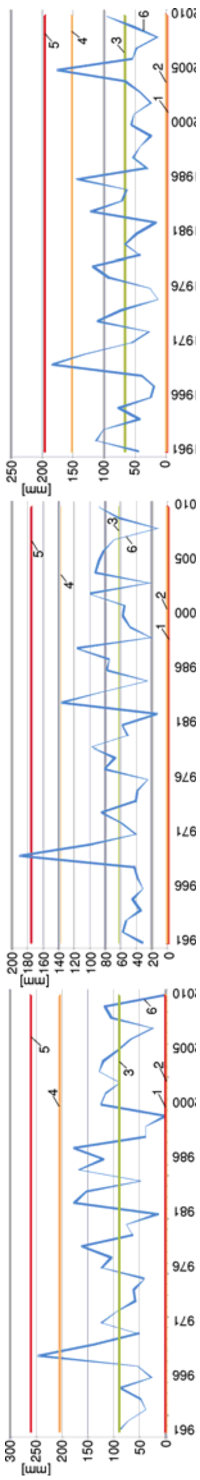

Figure 3. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – February (for color image see journal web site)

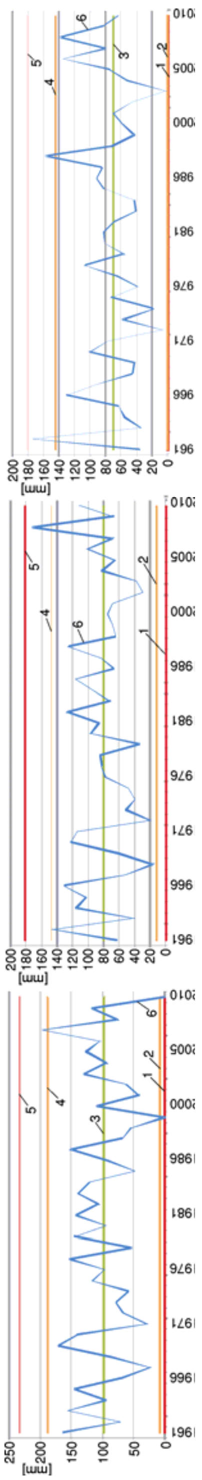

Figure 4. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – March (for color image see journal web site)

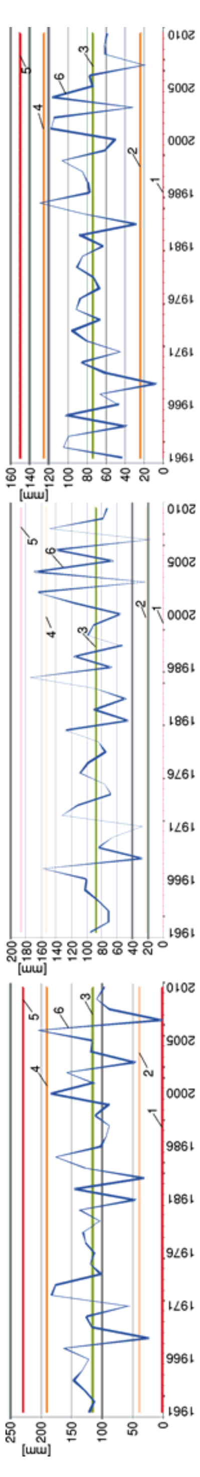

Figure 5. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – April (for color image see journal web site)

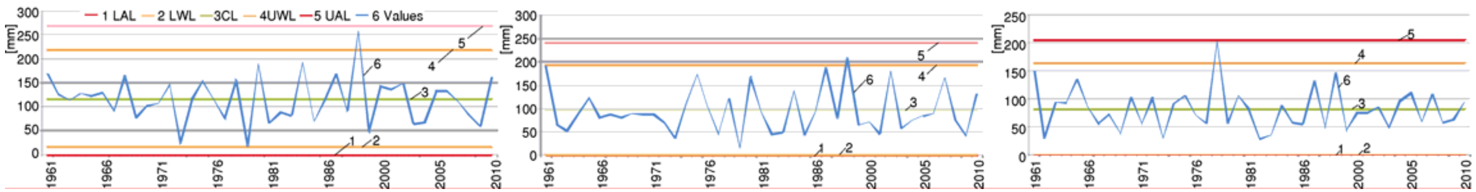

Figure 6. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – May (for color image see journal web site)

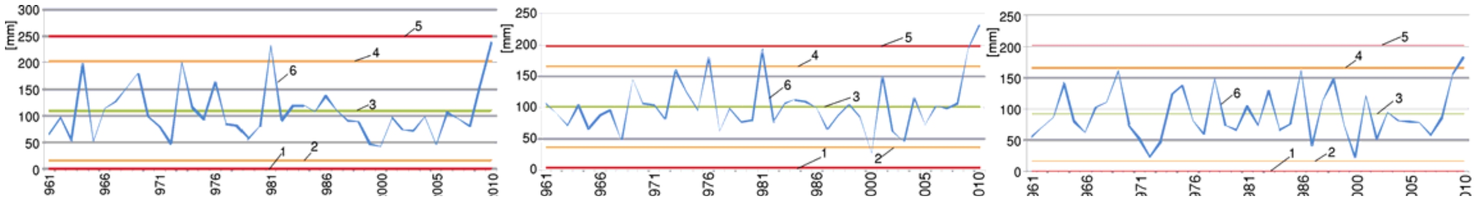

Figure 7. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – June (for color image see journal web site)

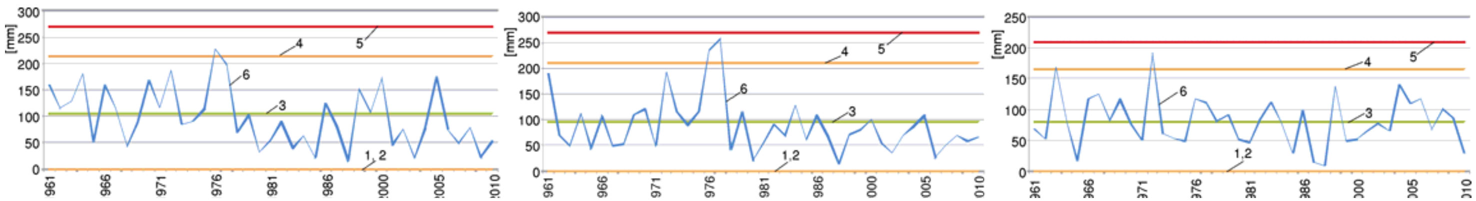

Figure 8. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – July (for color image see journal web site)

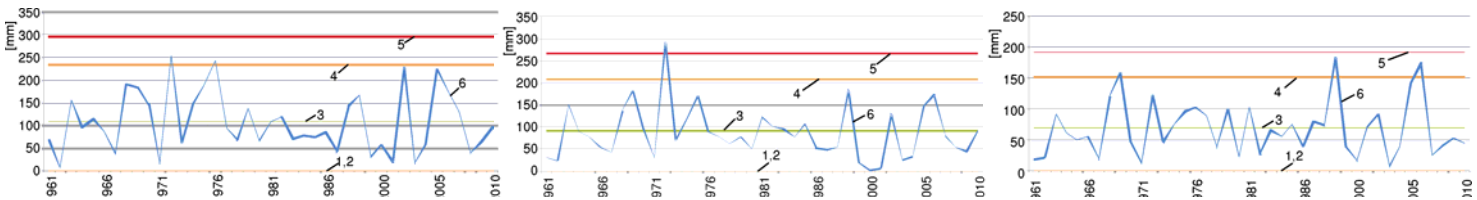

Figure 9. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – August (for color image see journal web site)

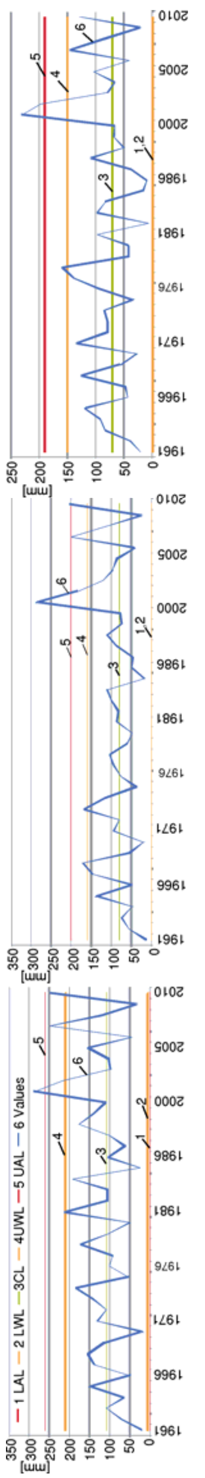

Figure 10. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – September (for color image see journal web site)

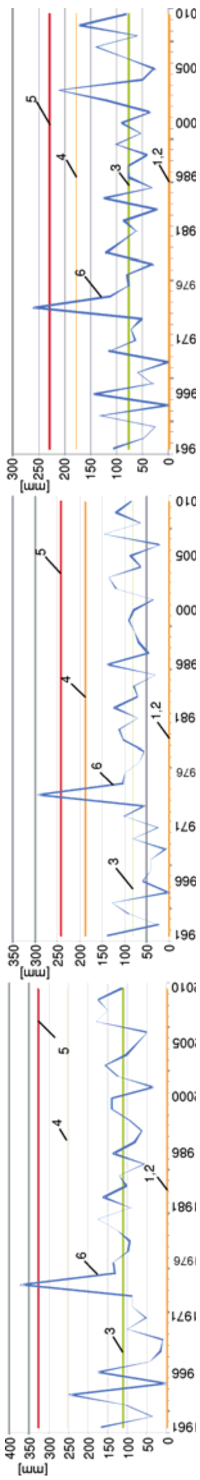

Figure 11. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – October (for color image see journal web site)

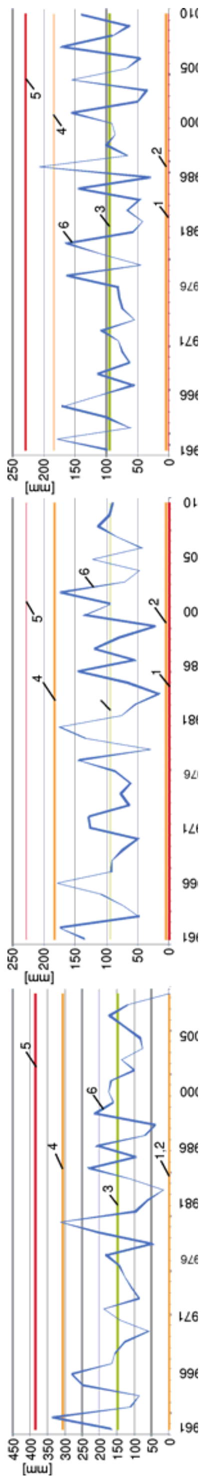

Figure 12. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – November (for color image see journal web site)

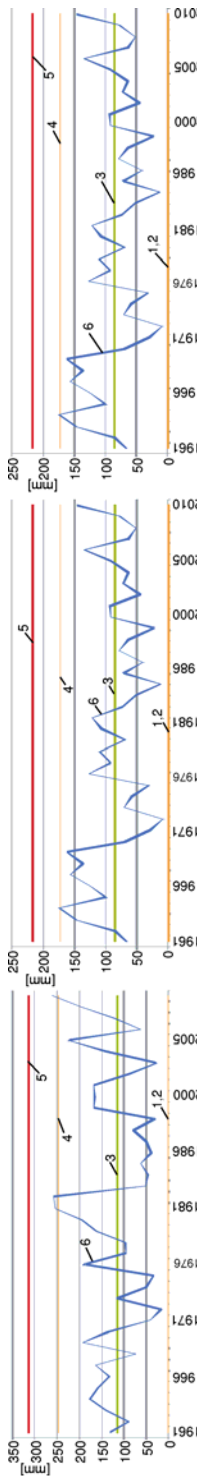

Figure 13. i-chart for precipitations for Bihac, Sanski Most and Sarajevo – December (for color image see journal web site)

It can be noted that very few months/years fall under any of these categories. None of the months for any of the cities have a series of 6 consecutive years for the same month below or above the Center Line, so there is no constant increase or decrease of precipitation in these periods. There is a number of points within the warning zones, but never two consecutive ones in the same zone (*e. g.* for Bihac these were January 2002 at upper warning zone, March 2006 at upper warning zone, March 2010 at lower warning zone, then April 2006, April 2007, June 2010, September 2007 and 2010, December 2010; for Sanski Most these were January 2010, March 2008, April 2002, 2004 and 2007, June 2009, September 2002 and 2007, December 2005; for Sarajevo these were January 2010, February 2005, April 2007, June 2010, August 2006, October 2003).

Therefore, the only months within these cities to be classified as statistically unexpected (since those are outside of the red action control lines) are the following: January 2000 and 2010 for Bihac, June 2010 for Sanski Most, September 2001 for Bihac, Sanski Most and Sarajevo, September 2010 for Sanski Most. Thus this test, with the exception of the above mentioned months and years for the three selected cities, shows that changes in total monthly precipitation may be labelled as statistically expected. It is worth to note that during the observed period 2000-2010 there was only one month, which is September 2001, when all three cities had precipitation higher than it could be expected by the three standard deviations rule. It should also be underlined that the level of variation of monthly precipitation during the referenced period 1961-1990, and consequently related standard deviation, was such that actually lower action lines would have been set to zero, which prevents situations when the actual precipitation in the observed period 2000-2010 is statistically unexpected (while the "warning" situations for low precipitation were included into the above list).

Table 1. Comparison of average monthly precipitations data for Bihac, Sanski Most and Sarajevo for the two observed periods

Months	Bihac			Sanski Most			Sarajevo		
	Average '61-'90	Average '00-'10	Difference [%]	Average '61-'90	Average '00-'10	Difference [%]	Average '61-'90	Average '00-'10	Difference [%]
January	85.84	126.00	46.8%	67.63	77.25	14.2%	69.443	79.436	14.4%
February	89.61	89.20	–0.5%	62.20	66.06	6.2%	67.017	62.182	–7.2%
March	97.61	95.65	–2.0%	79.94	79.49	–0.6%	70.347	72.609	3.2%
April	115.03	112.43	–2.3%	88.11	95.46	8.3%	74.340	70.845	–4.7%
May	116.27	112.19	–3.5%	95.70	92.53	–3.3%	81.630	79.327	–2.8%
June	109.02	99.84	–8.4%	100.77	109.70	8.9%	90.970	91.482	0.6%
July	105.91	76.93	–27.4%	96.01	65.65	–31.6%	80.153	82.400	2.8%
August	109.45	100.89	–7.8%	93.00	71.91	–22.7%	69.590	63.818	–8.3%
September	107.92	150.94	39.9%	80.32	129.65	61.4%	70.270	105.491	50.1%
October	109.55	117.69	7.4%	80.06	86.15	7.6%	76.657	96.936	26.5%
November	146.17	118.98	–18.6%	93.74	84.46	–9.9%	94.040	96.818	3.0%
December	113.56	144.74	27.5%	83.89	99.54	18.7%	84.673	83.430	–1.5%
Total	1,305.95	1,345.48	3.03%	1021.37	1057.85	3.57%	929.130	984.775	5.99%

Another comparison is done for the average monthly precipitation during the two mentioned periods (tab. 1). For Bihac there is a high increase of 46.8% in the average total monthly precipitation in January, relevant increase also in September and December (39.9% and 27.5% respectively), but also relevant decrease of the average monthly precipitation in July and November (for 27.4% and 18.6%, respectively). Other differences are below 10% level.

For Sanski Most there is a high increase of 61.4% in the average total monthly precipitation in September, relevant increase also in January and December (14.2% and 18.7% respectively), but also relevant decrease of the average monthly precipitation in July and August (for 31.6% and 22.7%, respectively). Other differences are below 10% level.

For Sarajevo, there is a high increase of 50.1% in the average total monthly precipitation in September, relevant increase also in January and October (14.4% and 26.5% respectively), but no relevant decrease in the average monthly precipitation higher than 10% (fig. 14).

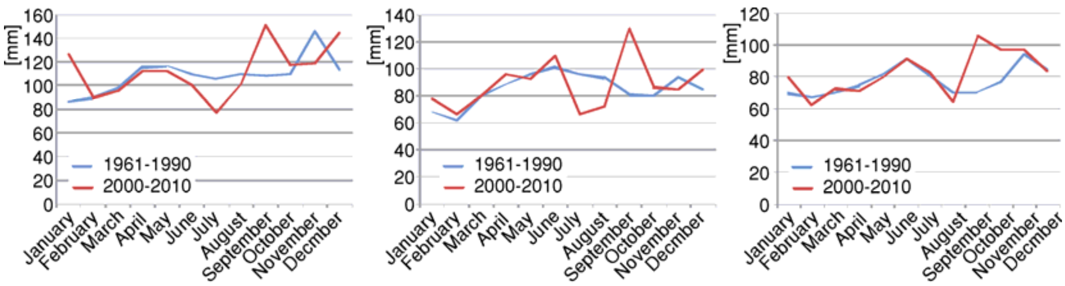

Figure 14. Comparison of average monthly precipitations for Bihac, Sanski Most, and Sarajevo for two observed periods

It is to be noted that January and September are months with a high increase of precipitation in all three cities (October also has increase, but of lower level), which means that the precipitation in May and August is decreased in all of the cities (July is exempt for Sarajevo which records a slight increase, while the other two cities record a high decrease in the same month).

The total average yearly precipitations during the period 2000-2010, in comparison to the total average yearly precipitations during the period 1961-1990, have increased in all three cities by 3.03%, 3.57% and 5.99%, respectively, but are also redistributed differently per months, as it can be seen in fig. 14 and as already underlined above.

Conclusions

The paper proves the usability of SPC methods in the assessment of climate change level and more specifically in the precipitation patterns change, and if likewise applied to different regions, the method allows a comparison analysis.

The noticed changes, especially for the period July-September should be taken into account when preparing spatial plans, strategies for agriculture or hydro-power development, reservoirs management plan and similar.

It is also worth to say that this method with the above results proves the present climate variations effect to the precipitation patterns change, but does not confirm that they are as high as they could not be statistically expected, based on the previous precipitation data. Of course results will be more relevant after the year 2020, for areas where the two (or more) complete 30-years period data would be available for a similar analysis.

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