STATISTICAL ANALYSIS OF TEMPERATURE REGIME CHANGE ON THE EXAMPLE OF SOKOBANJA BASIN IN EASTERN SERBIA

by

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The changes and oscillations in air temperature during the second half of the 20th and in the early 21st century, have become one of the major concerns of almost all scientific disciplines. Such changes are noticeable both at the local and global level. The objective of this paper is to point out that the changes of this climate element can also be detected at the local level. The research underlying this paper is, in terms of territory, limited to the Sokobanja basin in Eastern Serbia. The analysis relies on the data on air temperature for the period 1946-2012 taken from the Meteorological weather station located in Sokobanja. The obtained data were processed in line with the recommendations of the World Meteorological Organization. The evidenced statistically significant changes in air temperature were examined using the following statistical tests: Pettit test, Standard Normal Homogeneity test, Buishand range test, and von Neumann test.

Key words: *air temperature, trend, statistical homogeneity tests, Eartern Serbia, Sokobanja*

Introduction

The undergoing changes and increase in global air temperature constitute a special segment of numerous debates among scientists. Such changes affect not only man's life, but also all other aspects of man's natural environment, starting from the local and regional levels going as far as national and global levels. The Intergovernmental Panel of Climate Change (IPCC) presented on several occasions their assessments of the possible impact of human activity on the global increase in air temperature. One of the reports of the European Environmental Agency (EEA) [1] shows a worrisome trend of air temperature increase. Summing up the statistical data on air temperature for the period 1850-2007, the EEA asserted that there was an increase warm-

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ing of temperature on the European continent both at annual and seasonal levels, particularly during spring and summer months. According to the data of the Global Historical Climate Network (GHCN) resulting from the surface meteorological measurements performed across Europe, there is a statistically significant increase in air temperature of 0.13 °C per decade in the period 1949-2006 [2]. The examinations carried out so far, indicate significant changes in variability and increased extreme weather frequency [3-5].

The research that has been undertaken so far in Serbia, as well as in other countries of the region, manifestly indicates annual average temperature increase [6-9]. Quite a few authors were focused on the issue of oscillations of air temperature on the territory of Serbia. Radovanović *et al*. [10] point to a perceivable trend of air temperature increase, but only in the last decade of the 20th century and in the early 21st century. According to Ducić [2] the changes in air temperature have been stated as such and found compliant with the global changes, but not as statistically significant. Almost all authors conclude that an increase in air temperature is evident across the territory of Serbia, but it varies spatially. The regions with the greatest increase in temperature are Eastern Serbia and the region Vojvodina. Numerous studies also point out that there is a tendency of annual average air temperature increase at the microregional level. This, too, confirms the fact on global warming.

The research aimed to determine the temperature regime of the Sokobanja basin was based on the consideration of the data from the Sokobanja Meteorological Weather Station (300 m altitude; 43°38'22"N and 21°52'10"E) for the period 1946-2012. Mean annual and monthly data were used to identify general trends in the temperature regime. This data were provided by the Republic Hydrometeorological Service of Serbia. The objective of the research was to examine homogeneity of the data during the period of observation, and to pinpoint the components of a trend in the data on annual average air temperature. This would allow determination of the moment t_c, if any, marking a shift of the annual average air temperatures, implicating a statistically significant difference between the average temperatures in the period before and after the break-point t_c.

Map 1. Sokobanja basin

Territory

The Sokobanja basin is located in Eastern Serbia. It covers an area of 515.5 km^2 and ranks among larger basins of the central part of the Balkan Peninsula (map 1). It is in the boundary zone between the Carpathian and Balkan parts of Serbia.

From a climatic point of view, the Sokobanja basin is marked by certain peculiarities conditioned by its position and tectomorphogenesis. It is fully enclosed by tall mountains: Rtanj, Ozren, Bukovik, Slemen, Krstatac. The basin is southwardly open towards the valley of the South Morava river, exposing it to the continental influences from the

North. Eastwardly, it is open to the influence of the continental air masses which reach this area from the Eastern and Northern Europe through the Wallachian plain and Timok river basin. According to the climatic regionalization of Serbia [11] the Sokobanja basin is classified as Carpathian, *i. e.* Sokobanja-Knjazevac climatic region, featuring long, hot summers, and cold, snow-abundant winters [12]. The area has temperate continental climate which, in terms of certain climate elements, allows a slight inflow of mild Mediteranean influences [13]. Due to such circumstances, the Sokobanja basin differs significantly from other parts located outside the ravine, but not very far from Sokobanja.

Methodology and data basis

Four test methods have been used to test and to identify general trends in the temperature regime of the Sokobanja basin. Such an analysis involved the following statistical tests: Pettitt's test [14], Standard normal homogeneity test (SNHT) [15], Buishand range test (BR) [16], and von Neumann test [17]. Under alternative hypothesis, SNHT, BR test, and Pettitt test assume the series consisted of break in the mean and considered as inhomogeneous. These three tests are capable to detect the year where break occurs. Meanwhile von Neumann test is not able to give information on the year break because the test assumes the series is not randomly distributed under alternative hypothesis.

The annual results of the Pettitt, Buishard range, and a SNHT tests goal to temperature data series show that the change points were detected 1991 and 1997. Two of the tests (the Pettitt and Buishand tests) show the 1991 shift point as the year at the change occurs at the Sokobanja station.

The Pettitt's test is a non-parametric test, meaning that its application requires no assumption about the distribution of data. This test provides assessment of the null hypothesis H_0 implying that the data are homogeneous throughout the period of observation, *i. e.* that the data have been obtained from a single or several distributions with the same location parameter (average values). The alternative hypothesis H_1 implies presence of a non-accidental component among data causing a shift of the location parameter at a particular moment. Aside from providing for a data homogeneity check, the Pettitt's test also determines – if the alternative hypothesis happens to be accepted – the change-point when a shift of the location parameter occurred. The test statistics (K_T) used in this test is:

$$K_T = \max_{1 \le t \le T} \left| U_{t,T} \right| \tag{1a}$$

where

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} D_{ij} \tag{1b}$$

$$D_{ij} = \text{sgn}(X_i - X_j) \tag{1c}$$

$$\text{sgn}(r) = \begin{cases} -1, & r < 0 \\ 0 & r = 0 \\ 1 & r > 0 \end{cases} \tag{1d}$$

The SNHT homogeneity test is a statistical test which also checks if the data originate from the same population with the same distribution or indicate presence of a significant difference in the location parameter between the data before and after a specific change-point t_c bringing an increase or decrease of the value of the observed feature. The null hypothesis in this test H_0 implies that the data are homogeneous, *i. e.* that they originate from the same population, while the alternative hypothesis H_1 implies presence of a significant difference in the location parameter in the period before and after the moment t_c. The SNHT test determines the moment of change of the location parameter t_c. The test statistics used in this test runs as follows:

$$T_0 = \max_{l \le t < T} \left| t_c \overline{X_1}^2 + (T - t_c) \overline{X_2}^2 \right| \tag{2a}$$

where $\overline{X_1}$ and $\overline{X_2}$ are the average values of the observed feature before and after t_c:

$$\overline{X_1} = \frac{1}{t_c} \sum_{i=1}^{t_c} X_i \tag{2b}$$

and

$$\overline{X_2} = \frac{1}{T - t_c} \sum_{i=t_c+1}^{T} X_i \tag{2c}$$

The Buishand range test is also a non-parametric test checking presence of a change-point in the given data marking a change of the location parameter (average values) distribution. The null hypothesis H_0 implies data homogeneity in terms of the location parameter, *i. e.* absence of a change regarding the said parameter over time. The alternative hypothesis H_1 implies presence of a change-point involving an increase or decrease of the average value of the observed feature. There are two variants of this test. The Buishand range test with a quotient range R does not reveal the moment when the location parameter occurs. Follows the test statistics used:

$$Q = \max_{j \le t < T} \left| S_t^{**} \right| \tag{3a}$$

and

$$R = \max_{l \le t < T} (S_t^{**}) - \min_{l \le t < T} (S_t^{**}) \tag{3b}$$

$$S_t^{**} = \frac{S_t^*}{\overline{S_n}} \tag{3c}$$

is the ratio of the value S_t^* and the sample standard deviation:

$$S_t^* = \sum_{i=1}^{t} (X_i - \overline{X_T}), \; t = 1, 2, \ldots, T \tag{3d}$$

is the difference of the value in the moment t from the sample mean, $S_0^* = 0$;

$$\overline{X_T} = \frac{1}{T} \sum_{i=1}^{T} X_i \tag{3e}$$

and

$$\overline{S_T} = \sqrt{\frac{1}{T} \sum_{i=1}^{T} (X_i - \overline{X_T})^2} \tag{3f}$$

represent the sample mean ($\overline{X_T}$) and the sample standard deviation ($\overline{S_T}$).

The von Neumann test also tests the null hypothesis H_0 implying data homogeneity in terms of the location parameter and absence of its change over the period of observation, as opposed to the alternative hypothesis H_1 implying presence of the moment t_c when the change of the location parameter occurs. If the alternative hypothesis is accepted, the von Neumann test cannot pinpoint the moment t_c marking the change of the location parameter. Follows the test statistics used in this test:

$$N = \frac{1}{T\overline{S_n}} \sum_{i=1}^{T-1} (X_i - X_{i+1})^2 \tag{4a}$$

where

$$\overline{S_n} = \sqrt{\frac{1}{T}\sum_{i=1}^{T}(X_i - \overline{X_T})^2} \tag{4b}$$

is the sample standard deviation.

For the application of the mentioned tests, Microsoft Office Excel 2007 and its XLStat were used.

Discussion

On the basis of the observed sample, the following descriptive average annual temperature statistics was obtained for the period 1946-2012 (tab. 1).

Table 1. Descriptive statistics for temperature on the entire sample

Variable	N	Minimum	Maximum	Mean value	St. deviation
Avg. temp.	67	8.7	12.3	10.536	0.762

Table 2 shows the results of the Pettitt's test.

Table 2. Pettitt's test results

Variable	K_T	t_c	Average value (mu1) before t_c	Average value (mu2) after t_c	p-test significance
Avg. temp.	574	1991	10.278	11.1	0.002

Being that test significance $p = 0.002$ is smaller than the significance level $\alpha = 0.05$, the alternative hypothesis is accepted, *i. e.* it can be concluded that there was a change-point when the average temperature increased. This test indicates that the change in average temperature occurred in 1991. Figure 1 shows that the mentioned change-point brought about an increase of average temperatures.

The results of the SNHT test are shown in table 3.

The significance of the SNHT test, $p < 0.001$ indicates that the alternative hypothesis should be accepted, *i. e.* leads to a conclusion that average annual temperatures in the observed period are not homogeneous in terms of the location parameter. This test identifies 1997 as the year when an increase in temperature occurred. This can also be noticed in the following fig. 2.

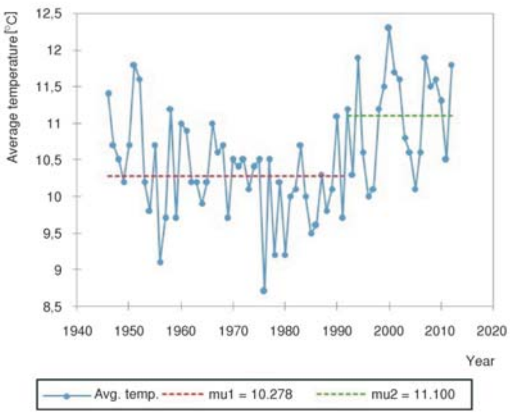

Figure 1. Change-point of average temperature by Pettit test

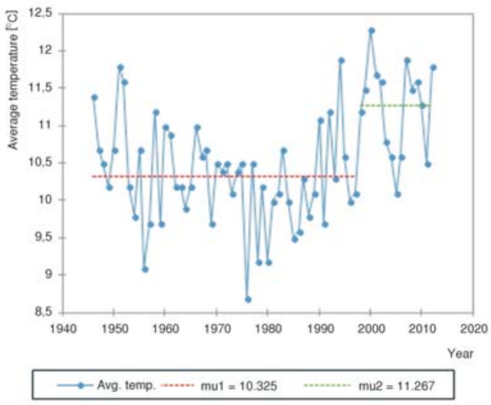

Figure 2. Change-point of average temperature by SNHT test

Table 3. The SNHT test results

Variable	T_0	t_c	Average value (mu1) before t_c	Average value (mu2) after t_c	p-test significance
Avg. temp.	17.801	1997	10.325	11.267	<0.001

Table 4. Buishand test results (Q variant)

Variable	Q	t_c	Avrage value (mu1) before t_c	Average value (mu2) after t_c	p-test significance
Avg. temp.	15.676	1991	10.278	11.1	<0.001

Table 5. Buishand test results (R variant)

Variable	R	p-test significance
Avg. temp.	19.842	<0.001

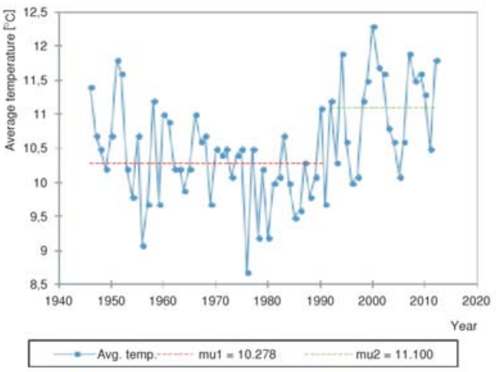

Figure 3. Change-point of average temperature by Buishand test

Table 6. Van Neumann test results

Variable	N	p-test sinificance
Avg. temp.	1.273	0.001

The results of the Buishand tests are shown in tabs. 4 and 5.

With regard to the test significance $p <$ 0.001 which is smaller than the significance level $\alpha = 0.05$, the alternative hypothesis is accepted, *i. e.* it can be concluded that there is a change-point marking occurrence of the change in average temperature. The Buishand test identifies 1991 as a moment when temperature increase occurred. Figure 3 shows this change in a graphical form.

The Buishand range test with a quotient range R cannot identify the change point marking occurrence of average temperature change, but the test significance indicates presence of a change in the location parameter of temperature distribution.

So, the results of the van Neumann test of homogeneity, too, call for acceptance of the alternative hypothesis, *i. e.* lead to a conclusion that in the series of average annual temperatures there is a change-point regarding the location parameter. The results are shown in tab. 6.

Conclusions

Today the climate changes potentially constitute a major threat to the environment and the human sustainable development. Even relatively small in the means and in variations of air temperature can induce a considerable change in the variability or in the severity of extreme events. Their manifestations are expressed by the impacts affecting the natural resources and the whole of life sectors.

The analysis of air temperature recorded over 50-year period for the station located in the Sokobanja (Eastern Serbia). On the basis of the statistical tests used, it can be concluded that there is a change-point marking occurrence of an increase in average air temperature in Sokobanja. The data analysis conducted and presented in the paper, as well as a comparison with the results of previous research carried out for the Sokobanja area, disclosed that global meteorological conditions are dominant over local conditions. The annual results of the Pettitt, Buishard range, and a SNHT tests goal to temperature data series show that the change points were detected 1991 and 1997. Two of the tests (The Pettitt and Buishand tests) show the 1991 shift point as the year at the change occurs at the Sokobanja station.

The tests applied in the research indicate that the year of 1991, *i. e.* the last decade of the 20th century is a break point, *i. e.* a moment marking occurrence of temperature increase. Depending on the test used, different values regarding the year of temperature break have been obtained.

The von Neumann test indicates that in the series of average annual temperatures in the last decade of the 20th century, there is a change-point marking occurrence of an increase of annual average air temperature. The Pettitt and Buishand tests identify the year of 1991 as a moment marking increase of annual average air temperature, while the SNHT test singles out the year of 1997 as the year of air temperature increase.

Statistical testings of the Sokobanja ravine temperatures indicate an increase of mean annual values in the last decade of the 20th century. Piticar and Ristoiu [18] obtained similar results for the temperatures in Romania, where 1988, 1995, and 1998 were detected as break-point years. The obtained results are also compliant with numerous other researches carried out in Europe [19-21], as well as with the last two reports of the Intergovernmental Panel of Climate Change [22, 23].

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