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Original Scientific Paper

ANALYSIS OF AIR TEMPERATURE TRENDS: CITY OF PODGORICA (MONTENEGRO)

NIKOLA BAČEVIĆ[1*], ALEKSANDAR VALJAREVIĆ[1], DUŠAN KIĆOVIĆ[2], NIKOLA MILENTIJEVIĆ[1], MARKO IVANOVIĆ[1], MELIHA MUJEVIĆ[1]

[1]Faculty of Natural Sciences and Mathematics, University of Priština, Kosovska Mitrovica, Serbia
[2]The College of Tourism, Academy of Applied Studies, Belgrade, Serbia

ABSTRACT

This paper presents the results of the analyzed trends for three categories of parameters: average annual air temperature (YT), average maximum air temperature (YTx) and average minimum air temperature (YTn) for the Podgorica Meteorological Station in the Republic of Montenegro. The aim of this paper is to present possible climate changes based on the results obtained from the analyzed air temperature trends. The methodology is based on the application of: a) linear trend equations, b) trend magnitudes and c) Mann-Kendall trend test. The data from the respectable meteorological station in Podgorica for the period from 1947 to 2018 were used in order to estimate the trend. The obtained results indicate a statistically significant positive trend for all analyzed time series. Analyzing the trend test hypotheses, it was concluded that in all three cases the Ha hypothesis prevails. Average annual air temperature in Podgorica increased by 1.4°C, average maximum air temperature increased by 2.5°C and average minimum air temperature increased by 0.6°C. In accordance with the trends analyzed, the increase in air temperature is dominant in the capital of the Republic of Montenegro.

Keywords: Climate changes, Air temperature, Mann-Kendall test, Podgorica, Montenegro.

INTRODUCTION

The trend of increasing average annual air temperature has been identified worldwide. However, the spatio-temporal distribution of the increase in global air temperature is not uniform on Earth. The rise in air temperature varies by region. A higher rise in air temperature was observed in the northern hemisphere. Regional differences in terms of increasing average global air temperature are in the range of 0.65°C 1.06°C. This is indicated by various reports given by the International Panel on Climate Change (IPCC, 2007; IPCC, 2014; IPCC, 2018). Also, in Europe there is a statistical trend of increasing average annual air temperature. The data obtained from various meteorological stations across Europe, (Klein et al., 2002) indicated an upward trend. The same rising trend in Europe has been observed with average seasonal air temperatures (Brázdil et al., 1996; Brunetti et al., 2004; Feidas et al., 2004; Brunet et al., 2007). Therefore, trends in the increase of air temperatures in the greatest part of Europe were recorded during the 20th century. They were most pronounced during the 1990s (Kovats et al., 2014). A similar trend continued in the next century, so the four warmest years since instrumental measurements were recorded in the second decade of the 21st century - 2015, 2016, 2017 and 2018 (WMO, 2019). Previous research into climate change in the wider region and in Southeast Europe has addressed similar issues (Jovanović et al., 2002; Unkašević & Tošić, 2013; Tosić et al., 2016; Trbić et al., 2017; Gavrilov et al., 2015; Gavrilov et al., 2016; Gavrilov et al., 2018; Ivanović et al., 2016; Popov et al., 2017; Popov et al., 2018; Vukoičić et al., 2018; Papić et al., 2019) and aridity as an indicator of climate change (Hrnjak et al., 2014; Bačević et al., 2017; Radaković et al., 2017; Milentijević et al., 2018). A statistically significant upward trend in the average annual air temperature was also observed in the urban area (Savić et al, 2013; Bačević et al., 2018). This paper analyzes recent trends for average, average maximum and average minimum air temperatures in the urban area of Podgorica. The problem of climate in the study area was addressed by numerous authors (Vujević, 1953; Radinović, 1981; Burić et al., 2007; Burić et al., 2011; Burić et al., 2013; Burić et al., 2014; Burić et al., 2015; Burić et al., 2018; Burić et al., 2019).

MATERIAL AND METHODS

Study area

In geomorphotectonic sense, the area of Podgorica is part of the mid-Montenegrin valley. The valley is an area that extends from the Gatačko Field in Herzegovina to Lake Skadar, while the river Bojana opens to the Adriatic Sea. The valley consists of: Golija and Duga (800 to 1000 m of a.h.), Niksic Field (600 to 660 meters), Bjelopavlić plain (40 to 56 meters) and Podgorica-Skadar Valley (6 to 67 meters). North of Skadar Lake (as part of the Podgorica-Skadar basin) is the Zeta plain. It covers the lower course of the Morača River. This is the largest continental lowland of Montenegro, measuring about 240 km². The plain is low in altitude (except for limestone mounds) and is slightly sloping from northeast to southwest and south. In its northern part is Podgorica. The administrative center and capital of Podgorica is located in the central part of the Republic of

* Corresponding author: nikola.bacevic@pr.ac.rs

Montenegro. The urban area covers an area of about 1500 km², which represents 10.5% of the total territory. In the north and northwest, the municipalities of Podgorica are bordered by the municipalities of Kolašin, Andrijevica and Danilovgrad, and in the south and southwest by the municipalities of Bar, Ulcinj and Cetinje. To the east, the municipality borders with the Republic of Albania. Podgorica Weather Station is located in Golubovci, 10 km from the city center (Burić et al., 2007). According to Kepen's climate classification, Podgorica and its surroundings belong to the *Csa* subtype. It is characterized by warm and dry summers and moderate and rainy winters. The average temperature of the coldest month is between -3℃ and 18℃. Summer is the warmest period of the year, with the warmest monthly temperature > 22℃ (Burić et al., 2014).

Data

This paper uses data for average annual, average maximum and average minimum air temperatures, published in the Meteorological Yearbooks of the Republic Hydrometeorological Institute of the Republic of Montenegro from the meteorological station in Podgorica, for the period from 1947 to 2018 (http://www.meteo.co.me/). Coordinates of defined study area are: φ=42°26′00″ N, λ=19°17′00″ E and 49 m of altitude. The geographical location of the Podgorica meteorological station is shown in Map 1. The technical and critical control of these measurements was realized by the Republic Hydrometeorological Institute of the Republic of Montenegro. Long time climate series used for analyses are influenced by inhomogenieties. They are caused by few factors: a) relocation of the meteorological station, b) the replacement of instruments or/and observers, c) changes in observation rules, d) changes in the environment of the meteorological station, etc. planting or/and uprooting of trees and grass, e) human errors in data processing. Many authors presented different homogeneity test: a) standard normal homogeneity test (SNHT; Alexandersson, 1986; Alexandersson & Moberg, 1997); b) Pettitt's test (Pettitt, 1979); c) Von Neumann ratio test (Von Neumann, 1941). If these inhomogenieties are not detected and treated adequately, results of climate analyses will be inaccurate. In paper Savić et al. (2012) homogenisation test provided relatively low break point magnitudes and adjustment values (from ±0.03 to ±0.26°C), probably caused by small territory of Vojvodina Province, not too large distance among weather stations and the geographical area with a gentle relief, so generally, the climate is free from orographic effects. Furthermore, these stations are a group of higher-rank stations (main stations) which probably resulted in higher quality of observations. Homogenisation process show relatively low differences of mean monthly (from 0°C to 0.12°C) and trend (from 0°C to 0.001°C/per year) air temperature values between raw and homogenised time series. Similarly, here are dominantly factors as small territory of Podgorica Municipality, plain relief, one main station in study area. For this reasons, in this paper weren't applied none of mentioned homogeneity tests.

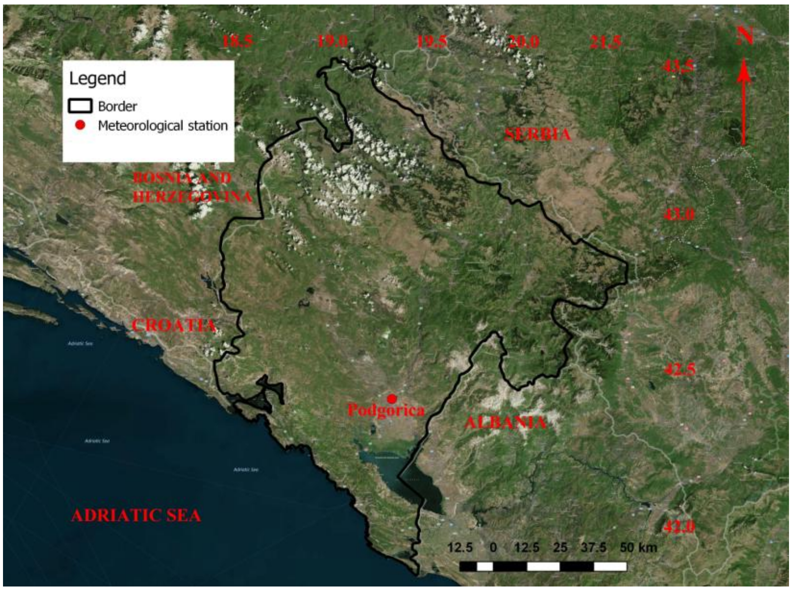

Figure 1. Physical-geographical map of the Republic of Montenegro and the geographical location of the capital Podgorica, marked in red.

Method

The paper uses three statistical approaches in order to analyze air temperature trends. The trend equation is the first statistical approach, which is of utmost importance for the analysis, evaluation and distribution of short-term climate change. Another statistical approach consists in determining the magnitude of the trend (Mann, 1945; Kendall, 1938). Whereas, the third statistical approach is to test the MK trend test, for each time series separately (Gavrilov et al., 2016). Air temperature trends were determined using EXCEL, which is part of the MICROSOFT OFFICE XLSTAT software package, used to calculate value levels, *p*, and to test hypotheses (https://www.xlstat.com/en).

The trend equation

The linear trend is a statistical procedure, which is of great importance in the analysis and evaluation of changes in air temperatures (Hrnjak et al., 2014). The equation takes the following form:

$$y=ax+b \quad (1)$$

where y represents the air temperatures in ℃ and a is the magnitude of the slope, x is the time series, while b is the temperature at the beginning of the period. The value of the trend of air temperature is in function of the slope size. There are three possible scenarios: a) the slope size is greater than zero - the trend is positive; b) equal to zero - no trend; v) less than zero - the trend is negative.

Trend Magnitude

Trend magnitude is determined according to the trend equation (Gavrilov et al, 2015), i.e.:

$$\Delta y=y(1948) - y(2018) \quad (2)$$

where Δy represents the trend magnitude expressed in ℃, y (1948) in the equation is the value of the variable at the beginning of the period and y (2018) represents its value at the end of the period. When it comes to trend magnitude, there are three possible scenarios here: a) when it is greater than zero - the trend is negative; b) when Δy is less than zero - the trend is positive; c) when equal to zero – there is no trend.

RESULTS AND DISCUSSION

Trend parameters

The results are presented as average annual air temperatures (P-YT), as average annual maximum air temperatures (P-YTx) and as average annual minimum air temperatures (P-YTn). The MK trend test analysis is presented for a total of three time series for the Podgorica meteorological station. Figure 2 show the average annual, average maximum and average minimum air temperatures, trend test equations and linear trend for the Podgorica Meteorological Station for the observed period from 1947 to 2018. Trend magnitudes, Δy (℃) and trend probability *p*, for each of the three time series are presented in Tables 1 and 2.

Table 1. The trend equation y, the trend magnitude Δy, and probability *p* of the confidences for 3 time series.

Time series	Trend equation	Δy (℃)	*p (%)*
P-YT	*y=0.0196x+15.044*	1.4	< 0.0001
P-YTx	*y=0.035x+25.757*	2.5	< 0.0001
P-YTn	*y=0.0087x+5.0861*	0.6	0.0176

Table 2. The main results of the analysis of temperature trends for 3 time series.

Time series	Trend equation	Classical MK test
P-YT	*positive trend*	*positive significant trend*
P-YTx	*positive trend*	*positive significant trend*
P-YTn	*positive trend*	*positive significant trend*

Trend evaluation

The obtained MK trend test results for average air temperatures in Podgorica are shown in Table 2 for the observed period from 1947 to 2018. Of the three time series, in all cases the MK trend test analyzes showed a statistically significant positive trend. Also, a positive statistical trend is shown by all numerical parameters and graphical representations (Figure 2).

For the P-YT and P-YTx time series for Podgorica Meteorological Station, the *p* value is <0.0001. For both time series above, the same values of the Mk trend test analysis apply. As the computed *p*-value is lower than the significance level alpha =0.05, they should reject the null hypothesis H0, and accept the alternative hypothesis Ha. The risk to reject the null hypothesis is Ha, while it is true is lower than 0.01%.

For the P-YTn time series for the Podgorica Meteorological Station, the *p* value is 0.0176. As the computed p-value is lower than the significance level alpha = 0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha. The risk to reject the null hypothesis Ha while it is true is lower than 1.77%.

Individually observed in Podgorica, the highest temperature increase of 2.5°C was noticed in the P-YTx time series. This is followed by an average air temperature increase of 1.4°C for the P-YT time series. Whereas, the least average temperature increase of 0.6°C was observed for the P-YTn time series. In all three cases, a statistically positive trend was observed, where the Ha hypothesis prevails. According to the IPCC (2018) report on a global average annual average, the average maximum and minimum air temperatures of 0.6°C to 1.8°C are significantly more pronounced in the Montenegrin capital. Similar results were observed in Bosnia and Herzegovina (Mostar and Bileća). In Mostar, the average annual temperature rose by 0.9 °C and in Bileća by 1.7°C. Average maximum temperatures in Mostar and Bileća increased by 1.9°C and 1.3°C, respectively, and average minimum temperatures increased by 1.4°C and 0.7°C (Papić et al., 2019). Also, a positive trend of increasing air temperature is noticed in Vojvodina (Gavrilov et al., 2015), Novi Sad as an urban environment (Savić et al., 2013), and Kosovo and Metohija region (Gavrilov et al., 2018). The average air temperature increased by 1.2°C. Such results confirm that there are tendencies that suggest an increase in average air temperature on regional and national levels.

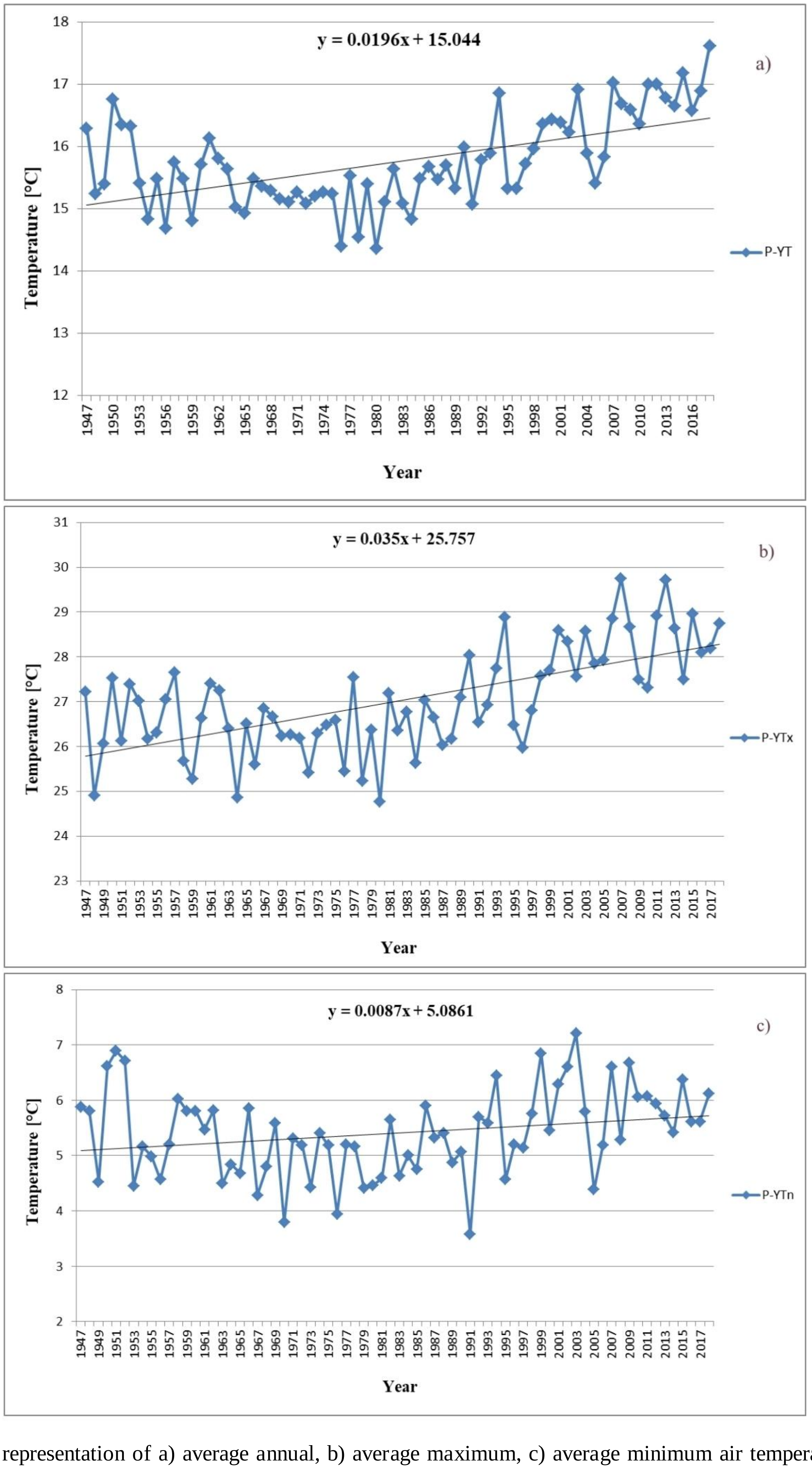

Figure 2. Graphical representation of a) average annual, b) average maximum, c) average minimum air temperature, trend equation and linear trend for the observed period from 1947 to 2018 in Podgorica.

CONCLUSION

Analyzing the trend equation, trend magnitude and MK trend test for average annual, average annual maximum and average annual minimum air temperature in Podgorica, a significant increase in air temperature was observed in all time series. Hypothesis Ha is prevalent, with a very low risk of rejecting the hypothesis. Positive trends for the Podgorica Meteorological Station represent a manifested pattern of climate change globally in line with the conclusions of the International Panel on Climate Change (IPCC, 2018). Unfortunately, this global problem has not, in scientific terms, been given much attention in the Republic of Montenegro. Future research should be focused on monitoring and analyzing climate extremes in the future. Also, it should be borne in mind that the analysis of trends was carried out on the basis of the parameters from the only station in the city territory. The presented results, due to the large heterogeneity of the space, show the general state of the selected parameters. There are many factors that influence the existence of microclimate differences in the area: degree of urbanization, terrain hypsometry, hydrographic objects, vegetation. For these reasons, monitoring of the required parameters through automatic weather stations would be necessary. This is possible if an AMS network is organized in the city. Climate change leads to numerous socio-economic consequences such as extreme climate events (aridity, drought - an unfavorable circumstance in agriculture), consequences for human health, reduction or even the disappearance of terrestrial and marine ecosystems.

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