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SEASONAL DISTRIBUTION OF URBAN HEAT ISLAND INTENSITY IN BELGRADE (SERBIA)

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Abstract: The aim of this study is to quantify the intensity of the urban heat island in Belgrade through the seasons. Air temperature observations from 23 meteorological stations in Serbia in the period 1949–2008 were analyzed. Using cluster analysis, we identify the group of stations which the data from the meteorological station Belgrade are the most similar to. It has been shown that, through all the seasons, air temperatures in Belgrade are significantly higher than the average in the wider surroundings. The greatest difference is in winter (1.4 °C), and the smallest is in summer, when it is 0.9 °C. It is greater in fall (1.2 °C) than during spring months, when it is 1.0 °C. Although the contribution of air temperatures in Belgrade to the increase of the average value of air temperature in its cluster is statistically significant, it is without any practical significance.

Keywords: Belgrade; Serbia; urban heat island; seasonal air temperature

Introduction

Due to its geographical position, dissected relief and exposure to air masses of various characteristics, and also due to the impact of other climatic factors, Serbia is characterised by a greatly pronounced variability. Milovanović, Stanojević, and Radovanović (2020) stated that the northern plain part of Serbia, the border of the Pannonian Plain, lower parts along the river valleys, and the mountainous terrains of the western, central and eastern Serbia, as well as the valleys and ravines in the south of Serbia, are characterised by mean annual air temperatures between 10 °C and 12 °C. In the highest parts of the mountains of southeastern Serbia, air temperatures range from 2 °C to 4 °C, while they are below 2 °C in the mountains on the southwest and south at altitudes above 1800 m a.s.l. They also state that, as the result of the urban heat island, the mean annual temperature in Belgrade for the period 1961–2010 was 12.3 °C.

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Urban Heat Island (UHI) is generally described as a higher average air temperature in cities compared to their less urbanized surrounding areas. Many factors influence the UHI intensity, including local and synoptic weather, season, time of the day, size of the city and its geographical location, urban morphology and anthropogenic heat release (Oke, Mills, Christen, & Voogt, 2017). It is well known that the UHI intensity is strong on clear and windless nights and exhibits diurnal and seasonal variations (Kim & Baik, 2005). The examination of UHI can be very important in many fields of climatology and connected scientific disciplines. For example, Huang and Lu (2015) examined the effects of UHI on the Yangtze River Delta urban agglomeration and showed that the warming rates of average air temperature of huge cities, megalopolises, large cities, medium-sized cities, and small cities are 0.483, 0.314 ±0.030, 0.282 ±0.042, 0.225 ±0.044, and 0.179 ±0.046 °C/decade, respectively, during the period of 1957–2013. The average warming rates of huge cities and megalopolises are significantly higher than those of medium-sized cities and small cities, indicating that the UHI effect has a significant impact on regional-scale climate warming (*t*-test, $p < .05$), thus urbanization has a measurable effect on the observed climate warming aggravating the global climate warming. Besides the effects on rainfall patterns, worsening air pollution, increasing flood risk, and decreasing water quality, the most direct effect on health from the UHI is due to heat risk, which is exacerbated in urban areas, particularly during heat waves (Heaviside, Macintyre, & Vardoulakis, 2017). Due to this, according to the data for the area of Belgrade, 2000–2010, it is evident that the increasing mean daily temperature also increases the number of deaths due to heat impact on health (Stanojević, Stojilković, Spalević, & Kokotović, 2014).

In previous studies it has been shown that Belgrade as the capital and the largest city in Serbia represents an UHI (i.e., Anđelković, 2003, 2005; Milovanović, 2015) which is on average warmer than the surrounding area by approximately 1.0 °C.

Bearing in mind the previously mentioned, it seems important to answer the following questions:

1. What is the seasonal distribution of Belgrade UHI?
2. Does Belgrade UHI affect conclusions about air temperature in the (wider) surrounding area?

Table 1
The list of the analyzed stations—their coordinates and height above sea level (m a.s.l.)

Station name	φ°N	λ°E	Height (m a.s.l.)
Palić	46°06'	19°45'	102
Sombor	45°46'	19°08'	88
Novi Sad	45°19'	19°49'	84
Kikinda	45°50'	20°27'	81
Zrenjanin	45°23'	20°22'	80
Vršac	45°08'	21°18'	84
Sremska Mitrovica	45°00'	19°33'	82
Belgrade	44°48'	20°28'	132
Loznica	44°33'	19°14'	121
Valjevo	44°17'	19°55'	176
Veliko Gradište	44°45'	21°31'	82
Smederevska Palanka	44°22'	20°57'	122
Kragujevac	44°02'	20°56'	185
Ćuprija	43°56'	21°22'	123
Negotin	44°14'	22°33'	42
Zaječar	43°53'	22°17'	144
Zlatibor	43°44'	19°43'	1028
Kruševac	43°34'	21°21'	166
Sjenica	43°16'	20°01'	1038
Niš	43°20'	21°54'	201
Dimitrovgrad	43°01'	22°45'	450
Vranje	42°29'	21°54'	432
Prizren	42°13'	20°44'	402

Data and methods

The data of mean monthly and seasonal air temperatures from 23 meteorological stations (listed in Table 1) for the period 1949–2008 were analyzed. The stations are evenly distributed over Serbia, with the exception of Kosovo and Metohija where we had access only to the data only from station Prizren. Void filling of the missing data is shown in details in Milovanović, Schuster, Radovanović, Ristić Vakanjac and Schneider (2017). In homogeneity testing of the data we relied on the results of Tošić (2004) and Milovanović (2015, 2017). The mentioned studies used Standard Normal Homogeneity Test (SNHT) and showed that the time series from those 23 meteorological stations in Serbia are homogenous.

For grouping of the stations, hierarchical (joining tree) cluster analysis was used. We chose Pearson's correlation coefficient as a measure of similarity/distance (actually, dissimilarity because it is calculated as 1-Pearsons *r*). According to Everitt, Landau, Leese, and Stahl (2011), the use of a correlation coefficient can be justified for situations where all the variables have been measured on the same scale and the precise values taken are important only to the extent that they provide information about the subject's relative profile. Agglomerative hierarchical clustering method of weighted average linkage was used. In this method of clustering, points in small clusters weighted more highly than points in large clusters which is useful if cluster sizes are likely to be unevenly distributed (Everitt et al., 2011).

Since *t*-tests have been thoroughly described in many textbooks (e.g., the conditions under which they can change, their advantages and disadvantages, and the ways of statistical calculations), here it will only be mentioned what they were used for. For the significance testing of the difference between air temperature in Belgrade and average air temperature in the cluster which it belongs to (but without Belgrade in it), a *t*-test for independent samples was used. For the significance testing of the difference between average air temperatures in the cluster with and without Belgrade included, *t*-test for dependent samples was used. In the inferential statistics, besides the information on the statistical significance, the analysis of the effect size is very useful but rarely used. Effect size can be considered as an index of the extent to which the research hypothesis is true, or the degree to which the findings have practical significance in the study population. In other words, effect size is an index that quantifies the degree to which the study results should be considered negligible, or important, regardless of the size of the study sample (Hojat & Xu, 2004). Tenjović and Smederevac (2011) stated that another important characteristic of data regarding the effect size is the possibility of creating the basis for more specific subsequent hypotheses. For the estimation of the difference in average air temperatures between Belgrade and its surroundings, or effect size estimation, Cohen's *d* (Cohen, 1988) was chosen (Equation 1).

$$d = \frac{M_1 - M_2}{SD} \tag{1}$$

where M_1 is mean of group 1, M_2 is mean of a group 2, and SD is pooled standard deviation according to Equation 2:

$$SD = \sqrt{\frac{(SD_1^2 - SD_2^2}{2}} \tag{2}$$

with SD_1 as the standard deviation of group 1, SD_2 the standard deviation of group 2. Cohen (1988) provided the distribution of the effect size according to Table 2.

Table 2
The effect size compared to the value of Cohen's d

Cohen's d	Size effect
0.2	Small
0.5	Medium
0.8	Large

Note. Adapted from *Essentials of behavioral research: Methods and data analysis* (3rd ed., p. 361), by R. Rosenthal and R. L. Rosnow, 2008, New York, NY: McGraw-Hill. Copyright 2008 by the McGraw-Hill Companies, Inc.

Results and discussion

Based on the data from Table 3 it can be concluded that Belgrade (listed as Beograd in Table 3) is warmer in all the seasons than most of the other analyzed stations. The exceptions are Prizren (warmer than Belgrade by 0.3 °C) and Negotin (warmer than Belgrade by 0.2 °C) in the summer. When Prizren is concerned, even though it has a higher altitude than Belgrade, it should be taken into consideration that this is the most southern station in the sample, and that it is exposed to the maritime impact by the valley of the river Drim (Milovanović et al., 2020). The station Negotin is located about half a degree more to the south than Belgrade, and its altitude is 90 m lower.

Table 3
Seasonal values of air temperatures in the analyzed stations

Station name	Spring (°C)	Summer (°C)	Fall (°C)	Winter (°C)
Belgrade	12.3	21.7	12.5	2.2
Ćuprija	11.2	20.5	11.3	1.0
Dimitrovgrad	9.8	19.2	10.5	0.3
Kikinda	11.4	21.0	11.3	0.5
Kragujevac	11.3	20.7	11.7	1.6
Kruševac	11.3	20.7	11.5	1.1
Loznica	11.5	20.5	11.5	1.6
Negotin	11.6	21.9	11.4	0.7
Niš	11.8	21.3	12.1	1.6
Novi Sad	11.4	20.9	11.5	0.8
Palić	11.2	20.8	11.1	0.3
Prizren	12.0	22.0	12.5	1.9
Sjenica	6.2	15.3	7.2	–3.1
Smederevska Palanka	11.5	20.9	11.6	1.4
Sombor	11.2	20.6	11.0	0.6
Valjevo	11.2	20.5	11.4	1.3
Veliko Gradište	11.4	20.8	11.5	0.9
Vranje	10.9	20.6	11.6	1.0
Zaječar	10.9	20.9	10.7	0.3
Zlatibor	6.8	16.3	8.3	–1.8
Zrenjanin	11.5	21.0	11.6	0.7
Vršac	11.8	21.0	12.2	1.6
Sremska Mitrovica	11.4	20.5	11.3	0.9

Taking into consideration the differences in the position of the stations (primarily their differences in altitude), the comparison of the seasonal air temperature in Belgrade with the values of each of the remaining stations would not be justified. Thus, a hierarchal cluster analysis was used to determine to which of the stations Belgrade has the most similar annual air temperature pace, and also a more detailed overview of the position of these stations is presented. According to the data from Table 4 it can be concluded that, in all of the seasons, Belgrade is in the group with the following stations: Sombor, Palić, Zrenjanin, Kikinda, Sremska Mitrovica, and Novi Sad. All the mentioned stations are located at a larger latitude (from Sremska Mitrovica, which is 12′ more to the north, to Palić, which is 1° 18′ further to the north) and lower altitude than Belgrade (the differences range from 30 m to 52 m). In summer, this cluster is "joined" by Loznica (15′ more to the south and 11 m lower altitude in comparison to Belgrade) and Valjevo (31′ more to the south and 44 m higher altitude in comparison to Belgrade), and in winter by Loznica, Valjevo, and Smederevska Palanka (26′ more to the south and 10 m lower altitude in comparison to Belgrade). Based on the abovementioned, it can be concluded that there are no significant differences between the altitudes and latitudes of the stations in the cluster.

Table 4
Seasonal division of the stations according to clusters

Season	Members of the cluster which Belgrade belongs to
Spring	Sombor, Palić, Zrenjanin, Kikinda, Belgrade, Sremska Mitrovica, Novi Sad
Summer	Sombor, Palić, Zrenjanin, Kikinda, Belgrade, Sremska Mitrovica, Novi Sad, Loznica, Valjevo
Fall	Sombor, Palić, Zrenjanin, Kikinda, Belgrade, Sremska Mitrovica, Novi Sad, Loznica, Valjevo
Winter	Sombor, Palić, Zrenjanin, Kikinda, Belgrade, Sremska Mitrovica, Novi Sad, Loznica, Valjevo, Smederevska Palanka

In all the seasons, the air temperature in Belgrade is significantly higher than the value of this climatic element at the stations in its surroundings (i.e., in the stations in the cluster which Belgrade belongs to). The greatest difference is in winter (1.4 °C), and the lowest is in summer, when it is 0.9 °C. Also, it is greater in fall (1.2 °C) than during spring months, when it is 1.0 °C (Table 5). These values are large by themselves and they are statistically significant (p = .01) in all the seasons. However, here it should be taken into account that the p-value represents the probability, *if the zero hypothesis is true*, to obtain such or more extreme value of the statistics for testing the zero hypothesis on the same size as used in the given research. A very small p-value (e.g., $p \leq .05$) can be used by researchers as an empirical argument for the justification of their doubt in the correctness of the zero hypothesis, i.e., for its rejection (Tenjović & Smederevac, 2011). Thus, the differences in the mean air temperatures in Belgrade and its surroundings are also presented through the seasonal effect size (Table 6). The greatest values of Cohen's *d* are in fall and spring when they exceed the limit of 0.8. The effect sizes in winter and summer are in the class of middle or almost high. It is interesting that the differences in the air temperature in Belgrade and its surroundings are largest in winter, but the data variability is the highest then as well, so the effect size that can be assigned to Belgrade's UHI is smaller than in other seasons.

Table 5.
Seasonal differences between the mean air temperatures in Belgrade and the mean air temperatures in the station cluster which Belgrade belongs to

Season	Cluster name	Average air temperature (°C)	Difference (°C)	Standard deviation	*t*-value	*p*
Spring	Belgrade	12.34	1.0	1.24	4.7	.01
	Cluster without Belgrade	11.34		1.10		
Summer	Belgrade	21.68	0.9	1.22	4.4	.01
	Cluster without Belgrade	20.76		1.07		
Fall	Belgrade	12.53	1.2	1.09	6.2	.01
	Cluster without Belgrade	11.32		1.02		
Winter	Belgrade	2.15	1.4	1.89	3.9	.01
	Cluster without Belgrade	0.79		1.93		

When discussing the seasonal differences between the mean air temperature of the station cluster with Belgrade and the station cluster without Belgrade, the values range from 0.12 °C in spring and summer to 0.18 °C in winter (Table 7). All the differences show statistical significance (p = .01). However,

Table 6
Seasonal distribution of the effect size of Belgrade urban heat island

Season	Cohen's *d* value
Spring	0.853
Summer	0.787
Fall	1.146
Winter	0.712

it should be taken into consideration that the values of the significance level are greatly dependent on the sample size and the variability of the analyzed set. With a large sample and a small variability of the observed sets, statistically significant differences may be obtained despite the fact that such small variations are not of practical consequence. Also, if we take into account that the *Guide to Meteorological Instruments and Methods of Observation* (World Meteorological Organization, 2008) sets the required accuracy of the measurement system at ± 0.1 K for air and sea surface temperature measurement, with an achievable operational accuracy of ± 0.2 K, the obtained differences clearly imply to have no practical significance.

Table 7
Seasonal differences between the mean air temperatures of the station clusters with and without Belgrade

Season	Cluster name	Average air temperature (°C)	Difference (°C)	Standard deviation	*t*-value	*p*
Spring	Cluster with Belgrade	11.46	0.12	1.12	37.6	.01
	Cluster without Belgrade	11.34		1.10		
Summer	Cluster with Belgrade	20.88	0.12	1.08	–23.1	.01
	Cluster without Belgrade	20.76		1.07		
Fall	Cluster with Belgrade	11.46	0.14	1.03	–45.1	.01
	Cluster without Belgrade	11.32		1.02		
Winter	Cluster with Belgrade	0.96	0.18	1.93	–34.8	.01
	Cluster without Belgrade	0.78		1.93		

The formation and intensity of an UHI is influenced by an extremely large number of factors, such as city size, morphology, land-use configuration, geographic setting (e.g., relief, elevation, regional climate), its geographic extent, orientation, and its persistence through time (Brazel & Quatrocchi, 2005; Oke et al., 2017). An abundance of additional scientific (sub)questions arises when we take into consideration that the effect of an UHI can be examined in various temporal (hourly, daily/nightly, diurnal, monthly, annually, and multi-annually) and spatial resolutions (from mesoscale, in which a city is observed as a whole, and localscale, in which certain urban zones with specific climate can be distinguished within a city, to microcsale, in which the climate of individual streets and objects can be considered). However, for a more detailed spatio-temporal research, a much larger number of stations would be needed, in and around the city, where also variables other than air temperature could be continuously recorded. A relatively scarce set of data about the mean monthly air temperatures that we had at our disposal in this study (based on which the seasonal values were calculated) limited the scope of this contribution to the quantification of a seasonal "pace" of the Belgrade UHI at the mesoscale and in comparison to its wider surroundings. Nevertheless, the information obtained according to this dataset may serve as an initial step in defining the research questions, purpose, aims, issues, and resources necessary for their solving in future research of the Belgrade UHI.

Conclusion

The average seasonal air temperatures in Belgrade in the period 1949–2008 are the most similar to those observed in the stations in its wider surroundings. Even though the differences in the latitude and altitude as important factors which affect air temperature between Belgrade and these stations are negligible, Belgrade shows a much higher temperature in all the seasons. The greatest difference is in winter (1.4 °C), and the smallest is in summer, when it is 0.9 °C. It is greater in fall (1.2 °C) than during spring months, when it is 1.0 °C. These differences are statistically significant (p = .01), and they also have a practical importance since they can be used as an "entrance" for the experts in the field of energetics, urbanism, construction, etc. in order to account for the UHI effects in future planning. Even though the difference in air temperature in Belgrade compared to its wider surroundings is the greatest in winter, the effect size (Cohen's d) of Belgrade urban heat island on the air temperature is the smallest in that period. In summer, this indicator is slightly larger than during winter months, and its highest values are in fall and spring. The seasonal differences between the mean air temperatures of the station clusters with Belgrade included and the same cluster of stations without Belgrade range from 0.12 °C in spring and summer to 0.18 °C in winter. Even though they show statistical significance, since they are within the acceptable measuring error, these values have no practical implications for the overall temperature time series of Serbia. Nevertheless, we may conversely conclude that, other than for most stations in the surrounding area of Belgrade, any air temperature trend derived from air temperatures recordings in Belgrade itself is superimposed by a non-negligible UHI effect. This is important since the Belgrade UHI possibly also has an increasing trend due to the urban growth of Belgrade over the 20th century and in the 21st century as well.

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