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ANALYSIS OF LAND SURFACE TEMPERATURES IN THE "LOCAL CLIMATE ZONES" OF NOVI SAD (SERBIA)

Abstract: In this study, the Local Climate Zones (LCZs) in Novi Sad, the second largest city in Serbia, are analysed as to surface temperature differences. The LCZs were delineated on the basis of the GIS-based method created by Geletič & Lehnert (2016). Land Surface Temperatures (LSTs) were derived from the satellites Terra, sensor ASTER, and LANDSAT-8. The thermal images were provided at a similar time (at about 9.30 AM) between 2002 and 2008 (ASTER) and between 2013 and 2017 (LANDSAT-8). Statistical analyses, including the analysis of variance (ANOVA) and Tukey-HSD test, were employed to reveal LST differences between the LCZs. The results indicate that in 84% of cases there were significant differences in LST between pairs of LCZs. Temperature differences between LCZs were the most pronounced in the summer season. In general, 8 (large low-rise), 10 (heavy industry), 2 (compact midrise) and 3 (compact low-rise) LCZs had the highest surface temperatures in Novi Sad. Contrary to this, LCZs A (dense trees), B (scattered trees) G (water bodies) were the coolest zones.

Key words: urban climate, urban surface, Land Surface Temperature, Local Climate Zone, Novi Sad

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Introduction

Cities have heterogeneous surface features and complex energy fluxes, which results in an excessive heat accumulation in urban areas. As a consequence, it is possible to observe surface urban heat island (SUHI) or urban heat island (UHI) effects – where an urban area has a higher surface or air temperature than the urban hinterland or rural areas (Chen et al., 2016). Therefore, detailed information regarding the urban surface and built-up characteristics are essential in order to understand urban temperature processes.

One of the newest and most widely used methods in urban climate research is the concept of Local Climate Zones (LCZs), defined by Stewart & Oke (2012). The advantages of the LCZ concept lie in the facts that it is a global classification scheme with a limited number of classes (10 built and 7 land cover types) and that classes are defined by the measurable physical properties of the urban environment. Each LCZ has a uniform land cover, surface structure, construction materials and human activities that span from hundreds of meters to several kilometers on a horizontal scale. The LCZ system does not cover entirely the spatial heterogeneity of the thermal pattern because it is affected by far more numerous and complex processes. However, it describes the most important urban and natural features and can serve as a good basis for the study of climate on local and regional scales (Bechte et al., 2015; Lelovics et al., 2016; Cai et al., 2017). According to the LCZ classification concept, air temperature measurements may be best suited for the analysis of temperature contrasts among LCZs (Stewart et al., 2014); however, Geletič et al. (2016) have recently demonstrated that the concept is also convenient for the analysis of the Land Surface Temperature (LST).

Higher land surface temperatures (LSTs) in urban landscapes in comparison with surrounding (rural or natural) landscapes occur in particular response to lower albedo, higher degree of sealing and anthropogenic heat emission (Oke, 1982). Compact areas of increased LST in urban areas give rise to a phenomenon known as the "surface urban heat island" (SUHI), something that has been the subject of many studies in recent decades (Roth et al., 1989; Voogt & Oke, 2003; Peng et al., 2012). Several investigations have demonstrated that the intensity and character of SUHI greatly influence the air temperature conditions of a city, contributing to the formation of UHIs – air-temperature-based urban heat islands (Voogt & Oke, 2003; Peng et al., 2012; Schwarz et al., 2012; Majkowska et al., 2017; Zhou et al., 2017). The LST derived from satellite remote sensing techniques is an important factor in the study of urban climate (Voogt & Oke, 2003). Compared to in situ air measurements, the remote sensing method has advantages in providing continuous spatial coverage, high integrity and real-time data acquisition over large areas. Therefore, it can reveal the spatiotemporal variability of the urban thermal environment (Voogt & Oke, 2003; Fabrizi et al., 2010; Schwarz et al., 2012; Chen et al., 2016; Geletič et al., 2019; Rostam & Beck, 2019).

The main goals of this study are (1) to delineate LCZs in Novi Sad (Serbia) and (2) analyze spatial and seasonal differences of LCZs as to their LST in order to better understand the relationship between different urban surface features and the spatial LST variability in medium-sized Central European cities.

Research area, data and methods

Geographical characteristics of the research area

Novi Sad is the second largest city in Serbia, where approximately 330,000 inhabitants live in the built-up area covering 102 km^2 (as of 2019). The urban area is located in Central Europe, on the Pannonian Plain, between 80 and 130 m a.s.l. The Danube River flows through the southern and eastern edges of the urban area (260–680 m wide), and the narrow Danube–Tisza–Danube Canal passes through the northern section of the city. The south hinterland is Fruška Gora Mountain, the low mountain covered with mixed forests with various types of deciduous trees. The city's surroundings to the north, west and east is predominantly characterized by agricultural areas where low plants are prevailingly cultivated. According to the Köppen-Geiger climate classification (Kottek et al., 2006), the Novi Sad region has a Cfb climate (temperate climate, fully humid, and warm summers, with at least four Tmon ≥ +10 °C). The mean monthly air temperature ranges from -0.3 ºC in January to 21.8 ºC in July. The mean annual precipitation is 623 mm (based on data collected between 1949 and 2015). The temperature and precipitation data were provided by the meteorological yearbooks of the Republic Hydrometeorological Service of Serbia.

Local Climate Zones

The GIS-based method published by Geletič & Lehnert (2016) was employed to delineate LCZs in the studied area of Novi Sad. The method is based on the measurable physical properties of the environment and a clearly defined decision-making algorithm. The algorithm is derived from the basic physical parameters defined by Stewart & Oke (2012).

For the classification process, the urban and hinterland areas were divided into grid cells of 100 m × 100 m, where each cell exhibited defined physical parameters. In the first step, the cells were divided by a building surface fraction (BSF) into two basic classes: (1) building types and (2) natural land cover types. In the second step, the cells that had been categorized as building types (BSF ≥ 10%) in the first step were classified into particular LCZs based on the smallest deviation from the optimum interval, as defined by Geletič & Lehnert (2016), in terms of defined physical parameters. The industrial zones categorized as LCZs 8 and 10 were refined using the number of buildings. The cells categorized as land cover types in the first step were automatically classified into particular LCZs in the second step by means of the vector land-use geo-database (2016). After all cells had been assigned to an appropriate LCZ, the LCZ areas were delineated using a three-cell filter to smooth the results of classification. Each LCZ demonstrated approximately 90%-agreement with the areas defined on the basis of expert knowledge.

Land Surface Temperature

LSTs were obtained from two satellites, i.e. Terra (sensor ASTER) and LANDSAT-8. ASTER consists of three separate instrument subsystems, namely a visible near-infrared (VNIR; Bands 1-3, at 15 m resolution), a shortwave infrared (SWIR; Bands 4–9, at 30 m resolution) and a thermal infrared (TIR; Bands 10-14, at 90 m resolution) subsystem. LANDSAT-8 uses two instruments, i.e. an operational land imager (OLI) sensor and a thermal infrared sensor (TIRS). The OLI sensor has nine bands (Bands 1–7 and 9 at 30 m resolution and panchromatic Band 8 at 15 m resolution). The TIRS has two bands (Bands 10 and 11, collected at 100 m resolution and re-sampled to 30 m) (Geletič et al., 2016). In total, 20 thermal images were obtained for the urban and hinterland areas of Novi Sad (4 from ASTER and 16 from LANDSAT-8), between the 2002 and 2017. All scenes were recorded in morning daylight times, i.e. from 9:26 to 9:45 UTC (Tab. 1).

Tab. 1. Satellite imagery with the basic information used for LST spatial patterns in Novi Sad (Serbia)

City	Scene ID	Satellite	Date	UTC	Cloud cover*	Temperature conditions**
Novi Sad	AST_20021006	ASTER	06.10.2002	09:39:58	0.7 %	normal
	AST_20050903		03.09.2005	09:44:14	0.1 %	summer days
	AST_20070801		01.08.2007	09:39:13	0 %	summer days
	AST_20080623		23.06.2008	09:45:31	0 %	hot days
	LT8_20130901	LANDSAT-8	01.09.2013	09:29:30	0 %	summer days
	LT8_20140819		19.08.2014	09:27:32	0 %	summer days
	LT8_20150416		16.04.2015	09:26:51	0 %	summer days
	LT8_20150518		18.05.2015	09:26:30	0 %	summer days
	LT8_20150603		03.06.2015	09:26:36	0 %	hot days
	LT8_20150705		05.07.2015	09:26:54	0 %	hot days
	LT8_20150721		21.07.2015	09:27:02	0 %	extremely hot days
	LT8_20150806		06.08.2015	09:27:05	0 %	extremely hot days
	LT8_20150923		23.09.2015	09:27:27	0 %	summer days
	LT8_20160707		07.07.2016	09:27:21	0 %	summer days
	LT8_20160723		23.07.2016	09:27:27	0 %	hot days
	LT8_20160808		08.08.2016	09:27:29	0 %	summer days
	LT8_20160824		24.08.2016	09:27:36	0 %	summer days
	LT8_20170624		24.06.2016	09:26:57	0 %	summer days
	LT8_20170710		10.07.2017	09:27:00	0 %	extremely hot days
	LT8_20170811		11.08.2017	09:27:14	0 %	extremely hot days

Note: * cloud cover for study areas, not full-scene; ** temperature conditions for the selected days were defined according to Climate and Ocean – Variability, Predictability and Change – CLIVAR (http://www.clivar.org/organization/etccdi/indices.php)

Two algorithms were used to estimate LSTs: (1) split-window and (2) multispectral. The split-window technique used two thermal infrared (TIR) bands, typically located in the atmospheric window between 10 μm and 12 μm (Sobrino et al., 1996). The algorithm applied was based on the estimation of the top-of-atmosphere spectral radiance and at-satellite brightness temperature. LANDSAT-8 provided two thermal bands, Band 10 and Band 11 (USGS, 2016). LANDSAT-8 did not provide data for a surface emissivity calculation. Because of this, a land-surface emissivity (LSE) algorithm was used to estimate emissivity from the normalized difference vegetation index (NDVI) (Rozenstein et al., 2014).

The basic statistical methods were used in the analysis of the LST differences among LCZs. The LSTs of the LCZs were evaluated by the one-way variance analysis (ANOVA). If the ANOVA F-test indicated statistically significant differences in LST, the Tukey HSD test was used to analyse which LCZs were significantly different in terms of their mean LST. Boxplots were used to present the LST variability typical of each analysed LCZ.

Results and discussion

The pattern of Local Climate Zones

According to the applied method, 7 built types of LCZs were identified in the studied area: LCZ 2 – compact midrise, LCZ 3 – compact low-rise, LCZ 5 – open midrise, LCZ 6 – open low-rise, LCZ 8 – large low-rise, LCZ 9 – sparsely built, LCZ 10 – heavy industry; as well as 6 land cover types LCZs: LCZ A – dense trees, LCZ B – scattered trees, LCZ D – low plants, LCZ E – bare rock and paved, LCZ F – bare soil and sand, LCZ G – water.

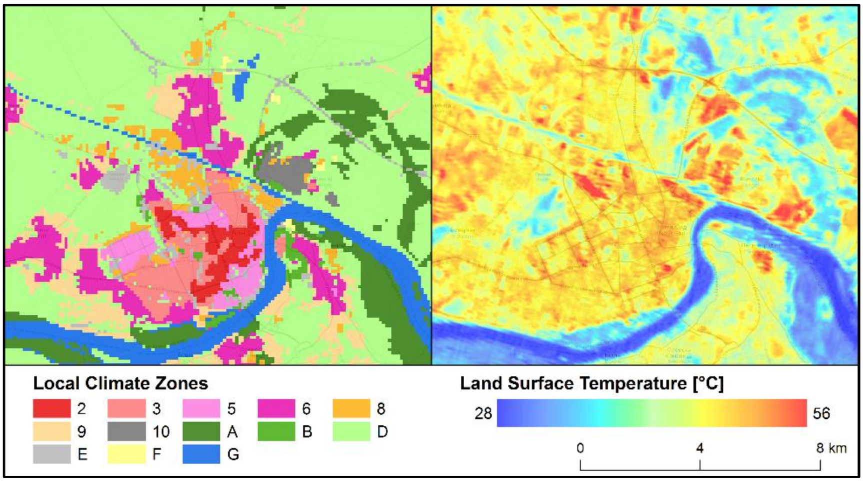

Fig. 1. Spatial distribution of LCZs in Novi Sad (left) and example of the LST pattern from LANDSAT-8, scene LT8_20170710 (right; for scene ID see Tab. 1) in Novi Sad's urban area and hinterland

The central parts of the city were the most built-up areas defined as LCZ 2 and surrounded by LCZ 5 and LCZ 3 types. Towards the outskirts, industrial areas were delineated as LCZ 8 and 10 (mostly in the northern areas), LCZ 6 and finally LCZ 9. Furthermore, LCZ 6 and 9 were typical of villages and farms around the city. The most dominant land cover type was LCZ D, due to the agricultural character of the city's hinterland, where the cultivation of low plants prevailed (wheat, maize, sunflower, soya etc.). Forests with dense trees, mostly concentrated near the Danube River, belonged to the LCZ A type, whereas urban parks and forests surrounding the historical fortress, characterised by scattered trees, fell into LCZ B. Roads around the city, graveyards and some industrial areas were classified as LCZ E, and waste dumps and major construction sites were denoted as LCZ F. LCZ G was the Danube River and the Danube–Tisza–Danube Canal. The spatial pattern of LCZs in Novi Sad is shown in Fig. 1 (left). The defined LCZ types and their spatial pattern for Novi Sad are similar to the results for other Central European cities, such as Prague, Brno, Olomouc and Hradec Králové in the Czech Republic (Geletič & Lehnert, 2016; Geletič et al., 2016), Hamburg (Bechtel & Daneke, 2012) in Germany and Szeged in Hungary (Lelovics et al., 2014).

Land Surface Temperature in Local Climate Zones

The variability of LSTs in the LCZs of Novi Sad is illustrated using the example of a summer day (10.07.2017) with a very high/extreme temperature (that day was within one of the heat wave period) (Fig. 1). The highest mean LST was observed in compact midrise (LCZ 2) and industry areas (LCZ 8 and 10). LCZ 3 and LCZ 5, as compact low-rise and open midrise areas, were the next warmest built-up zones. A very high LST was also observed in LCZ E and LCZ F but they had a smaller spatial coverage. The lowest LSTs were detected in water (LCZ G) and forested areas (LCZ A and LCZ B).

Individual scenes could not be compared directly as they represented different days within the period spanning from April to October. Therefore, a Tukey-HSD test was employed to analyse LST differences between pairs of LCZs as to their significance ("hits" – the number of multiple comparison tests indicating significant LST differences in a pair of LCZs). The examples of the test results for the three selected scenes are presented in Fig. 2a. Taking into consideration all 20 scenes analysed in this study, a generally greater number of "hits" was found for land cover types of LCZs, except for LCZ E (bare rock or paved), where the surface temperature resembled the LST of the built types of LCZs. As far as the built types of LCZs are concerned, the greatest number of hits was found for LCZ 10 (heavy industry) and LCZ 8 (large lowrise), where LSTs were frequently significantly higher than in other LCZs. Less hits were found for LCZs 2, 3, 5 and 6, where the surface temperatures were in some cases very similar; however, even for these LCZs, the relative number of "hits" was around 80%. These findings are in a good agreement with the results obtained in other two Central European Cities – Brno and Prague (Geletič et al., 2016; Geletič et al., 2019).

The relative numbers of "hits" calculated separately for each month from April to October indicate seasonal variations in LST differences between LCZs (Fig. 2b). In general, temperature differences among LCZs were more pronounced in the months when solar irradiance was the highest (June–July). Apparently, greater temperature differences between LCZ G or LCZ A and other LCZs could be observed in the summer. The LSTs for LCZ D were usually not significantly different from the LSTs of the built types of LCZs in April (before the growing period) and in September and October (after the harvest), whereas in the growing period (May, June, July), they were substantially lower (Fig. 2b). About LCZ G (water area) it is more complicated situation, because of the Danube River as floating water. Also, in some scenes the flow rate is not on the same high, i.e. some parts of riverbed are flooded in particular period of the year, but in another (mostly summer) these areas are dry surface. Furthermore, a few small lake areas near industrial buildings characterized with higher surface temperatures comparing to water temperature in Danube River.

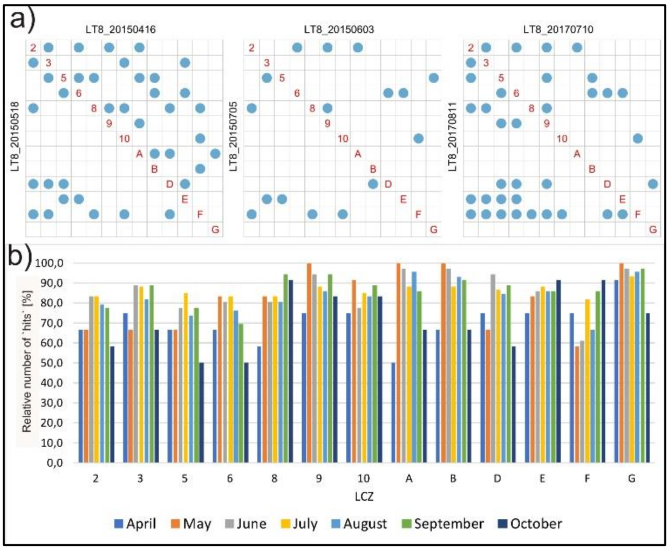

Fig. 2. a) Results of the Tukey-HSD test for all combinations of LCZ classes (red numbers and letters) and for the selected scenes in Novi Sad (for scene ID see Tab. 1); blue points indicate the pairs of LCZs for which LSTs were not significantly different (p > 0.05), while empty cells denote the LCZs pairs for which the average LSTs were significantly different; b) Relative number of multiple comparison tests indicating significant differences (p < 0.05) in LST ("hits") among LCZs in Novi Sad in the selected months

Conclusions

In this study, LCZs were delineated in Novi Sad (Serbia) and they were subsequently analyzed as to their LST. The spatial pattern of LCZs in Novi Sad (Serbia) corresponds to those of other medium-sized Central European cities; however, what makes it peculiar is the large extent of areas classified as LCZ 3. Statistical analyses confirmed that LCZs in Novi Sad significantly differed in terms of their LST in 84% of cases. It was shown that temperature differences between LCZs were the most pronounced in the summer. Therefore, seasonal variations must be considered in any further research dealing with temperature differences between LCZs. The highest LSTs were found in built-up areas with a significant share of concrete and other artificial materials – LCZs 2, 8 and 10. Contrary to this, LCZs G (water), A (dense trees) and B (scattered trees) had the lowest surface temperatures. Finally, the results of this study, as well the previous studies conducted in Brno and Prague (Czech Republic), indicate that this kind of research and the applied methodology can contribute to the further study of the relationship of temperature variability and urban surface types.

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АНАЛИЗА ТЕМПЕРАТУРЕ ПОВРШИНЕ ЗЕМЉИШТА У "ЛОКАЛНИМ КЛИМАТСКИМ ЗОНАМА" НОВОГ САДА (СРБИЈА)

Резиме: У овој студији представљене су анализе и резултати везани за кретање површинских температура (Land Surface Temperature - LST) у односу на различите типове урбанизације. Као улазни параметри коришћени су: (1) класификација локалних климатских зона (Local Climate Zones - LCZs) дефинисана од стране Stewart & Oke (Stewart & Oke, 2012); (2) термални снимци за временски период од око 9.30 UTC са ASTER-а (за период 2002-2008.) и LANDSTAT-8 (за период 2013-2017.). Истраживачко подручје представља урбана зона Новог Сада, другог града по величини у Србији са око 330.000 становника. Класификација LCZs у урбаној зони Новог Сада базирана је на GIS методама, које су креиране од стране Lelovics-Gál метода (Lelovics et al., 2014) и Geletič/Lehnert метода (Geletič & Lehnert, 2016). На основу представљене методологије класификације, дефинисано је седам различитих изграђених зона и 6 природних зона. За даље анализе карактеристика LST-а у различитим LCZs коришћене су статистичке методе и то: (1) анализа варијансе – ANOVA и (2) Tukei-HSD тест.

На основу тога, главни циљеви ове студије су: (1) дефинисање и разграничење LCZs у урбаној зони Новог Сада; (2) анализа просторних и сезонских разлика LST-а у различитим LCZs у циљу бољег разумевања односа између различитих типова урбанизације и површинских температура у градовима средње величине на простору Централне Европе.

Резултати показују да су у 84% случајева постојале значајне разлике у LST између парова различитих LCZs. Температурне разлике између LCZs биле су најизраженије у летњој сезони. Генерално, LCZ 8, LCZ 10, LCZ 2 и LCZ 3 имали су највише површинске температуре у Новом Саду. Са друге стране, LCZ A, LCZ B и LCZ G су се показале као најхладније зоне.