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Heat wave risk assessment and mapping in urban areas: case study for a midsized Central European city, Novi Sad (Serbia)

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Abstract   Risk assessment and mapping methodologies for heat waves as frequently occurring hazards in central and southeastern Europe were applied in this study, and the impact of heat waves on the mortality of urban populations was determined as part of the assessment. The methodology for conducting the heat wave risk assessment is based on European Commission's Guidelines for Risk Assessment and Mapping. The Novi Sad (Serbia) urban area was studied during summer 2015, which was one of the hottest summers in the last few decades. In situ air temperature measurements from urban stations and mortality of urban populations were used. Nocturnal urban heat island (UHI) intensity values between the various built-up zones and natural surrounding areas were used for the hazard level calculation. Temperature data from 9 p.m. to 5 a.m. were used because during the night, the UHI intensity reached its maximum values. The average daily number of deaths by LCZs was used to define the impact level of the vulnerability index. Calculations for both hazard levels were completed during two intensive heat waves (in July and August 2015) when it was expected that there may be a high level of risk. The results and maps show that the urban area is complex, and the heat wave risk on the population is not uniform. The most densely built-up areas (LCZs 2, 5 and 6) have very high or high risk values that are influenced by a higher rate of mortality. The obtained results and maps can be used by local authorities to prevent and mitigate climate-related hazards, for medical institutions as well as urban planners and for ancillary local, regional or national services. According to these results, the local authorities could define hot spots where they can place medical and rescue teams and install points with water supplies, etc.

Keywords   Heat wave · Risk assessment · Air temperature · Human mortality · Local climate zones · Novi Sad

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1 Introduction

Climate change-related hazards have been increasing in frequency and intensity over the last few decades, and these increases are expected to continue during the twenty-first century. In Europe, the number of extreme precipitation events is expected to increase in the future, droughts will intensify, and heat waves will become more frequent and longer (IPCC 2012; Alcantara-Ayala et al. 2015). Therefore, risk assessment analysis is very important to define the vulnerability of the elements at risk to a specific hazard (Papathoma-Köhle et al. 2016a). In this study, the focus is on heat wave risk assessments, as heat waves are one of the most frequent climate change hazards in central and southeastern Europe. Furthermore, the emphasis on heat wave risk assessments will be particularly important for urban areas, which are regions with modified climate impacts and, unfortunately, are substantially affected by high temperatures.

The Intergovernmental Panel on Climate Change (IPCC) classified heat waves as one of the extreme weather events associated with climate change (Field et al. 2012). Heat wave frequency, intensity and duration have increased on a global scale (Perkins et al. 2012), as well as in southeastern Europe (Tomczyk 2016), and they will continue to increase over the twenty-first century at a global level (Clark et al. 2006), as well as in North America, Europe (Meehl and Tebaldi 2004) and Australia (Alexander and Arblaster 2009; Perkins and Alexander 2013). Furthermore, according to the Fifth Assessment IPCC Report (IPCC 2013), more frequent and intense extreme heat waves can be expected in the near future in response to recent climate change. The northwestern USA and western, central and southeastern Europe could see increases in heat wave intensity with serious impacts because these areas are not currently well adapted to heat waves (Meehl and Tebaldi 2004).

Heat waves have strong negative impacts in urban areas due to large areas of rough artificial surfaces (densely built-up areas), local and regional climates, and the lack of trees and green spaces leading to the modification of air temperatures and creating intensive urban heat islands (UHI) (Wilhelmi and Hayden 2010; Doborvolny and Krahula 2015; Skarbit et al. 2015; Gál et al. 2016; Hamdi et al. 2016; Lelovics et al. 2016; Skarbit et al. 2017). The UHI represents the difference in temperature between cities and the surrounding rural areas (Depietri et al. 2011), and the UHI intensity is positive in urban areas (Memon et al. 2009). According to Memon et al. (2009), air temperature-based UHI intensities were higher and positive during the night but lower and negative during the day. Tzavali et al. (2015) presented a detailed literature review related to UHI intensity in urban areas of Europe and other continents.

An increasing number of studies have documented that the frequency, intensity and duration of heat waves are significantly associated with human mortality (Muthers et al. 2017; Baccini et al. 2008; Le Tertre et al. 2006). Due to these results, heat-related mortality is recognized as one of the most important hazards to public health. The negative health impacts also depend on a number of factors that affect the sensitivity of the population to increased temperatures (health condition, occupation, age) as well as their ability to respond to and cope with the heat exposure (Wilhelmi and Hayden 2010). Vulnerable population groups to heat waves include the elderly, socially isolated and people with chronic diseases (Baccini et al. 2008; Muthers et al. 2017). Especially vulnerable are people who have a low socioeconomic status, who are socially isolated and who are homeless (IPCC 2012). According to UN data (UN 2014), over the past six decades, the world population has faced rapid and intensive urbanization, and since 2007, more than half of the total population of the world lives in urban areas. Furthermore, intensive urbanization

will continue into the next decades, and urban populations are expected to grow, i.e., the world population will be two-thirds urban by 2050 (UN 2014). Therefore, heat waves are expected to have more severe impacts in the future not only due to climate change but also due to the increase in urban and ageing populations (Senf and Lakes 2011). As a solution, local authorities and emergency services must be able to identify and locate vulnerable groups of people or urban areas where medical intervention is required (Buscali et al. 2012). Finally, heat waves have garnered more attention in research on climate change, urban environments, sustainable development plans, public health and heat-related fatalities in populations (Hatwani-Kovacs et al. 2016).

Climate change is expected to increase the existing risk levels associated with not only with heat waves but also with other natural hazards, and risk assessments should be the starting point for managing and reducing these risks. Due to the significant impacts of extreme air temperatures, the effects of heat waves would require systematic integration of risk assessment outcomes in central and southeastern Europe (Marković et al. 2016). Furthermore, the Spatial Plan of the City of Novi Sad (investigated area in this study) does not consider climate change scenarios, projected temperatures or future risk scenarios. Hence, it emphasizes the priority of the development of natural disaster protection and real-time warning systems. The European Commission's Guidelines (EC 2010) emphasize the necessity of disaster management activities based on risk assessments and mapping and offer alternatives to overcome common deficiencies such as the lack of data and documentation of past events. Through the South-East Europe Transnational Cooperation Programme project called "Joint disaster management risk assessment and preparedness in the Danube macro-region" or SEERISK project (developed from 2012 to 2014), a generic and adaptable risk assessment methodology for the Danube macro-region was developed and tested. The methodology served as a theoretical framework for a risk mapping process and has been adapted for five climate change-related hazard types: flood, drought, heat wave, wildfire and extreme wind (SEERISK 2014). Papathoma-Köhle et al. (2016a, b) conducted a heat wave risk assessment for the urban area of Arad (Romania) based on a number of paramedic interventions and UHI data. The results show the highest risk to the health of populations in the most urbanized areas.

The goal of this paper is to perform a heat wave risk assessment and risk mapping for the urban area of Novi Sad (Serbia) based on data from summer 2015. The methodology calculations were based on highly frequent spatiotemporal in situ measurements of air temperature (T_a), and the difference in the air temperatures between the built-up areas and land covered areas (UHI intensity index) and the average daily number of deaths (M_{avg}) as the impact level. The final calculation of assessment shows the risk level of high temperatures in different urban surface areas on residents. Finally, this heat wave risk assessment will help local authorities to identify vulnerable groups of people and hot spots in urban areas, and this methodology can be used for other cities that are different sizes and that have different development patterns, topographies, climates and population densities.

2 Description of the risk assessment and mapping methodology

In 2009, the EU emphasized that hazard and risk identification and analysis, impact analysis, risk assessments and matrices, scenario development, risk management measures and regular reviews were major components of the EU disaster prevention framework.

Therefore, at the national level, guidelines on the methods for hazard and risk mapping, assessments and analysis were made by the EU (EC 2010).

The risk assessment and mapping methodology was developed as a neutral framework (Papathoma-Köhle et al. 2016b), and within the SEERISK project, it has been adapted for five climate change-related hazard types (flood, drought, heat wave, wildfire and extreme wind) for the areas of central and southeastern Europe (SEERISK 2014). "The methodology has been developed in order to improve the consistency in risk assessments among countries and provide the local authorities and other end-users with a tool that will enable them to conduct risk assessments and mapping for a range of hazard types, focusing on different scales and elements at risk" (Papathoma-Köhle et al. 2016a). Figure 1 shows a flow chart of the methodology that has three steps: (1) definition of the context and risk, (2) risk analysis and (3) risk evaluation. The following subchapters will present each step in detail.

2.1 Identification of the risk

Risk identification is the first step of the methodology where working groups and end users identify the context and the basis of the risk assessment (Papathoma-Köhle et al. 2016b). The important stage of the risk assessment is defining the risk criteria that will eventually show if a risk is acceptable and/or tolerable or not (e.g., number of deaths, number of medical interventions, material damages, financial losses). The basis of a risk assessment could be defined by the type of hazard, the scale of the assessment (e.g., local, regional, specific site), the elements at risk, such as people, and the risk metric that is used to express risk (Papathoma-Köhle et al. 2016a). In this paper, the focus is
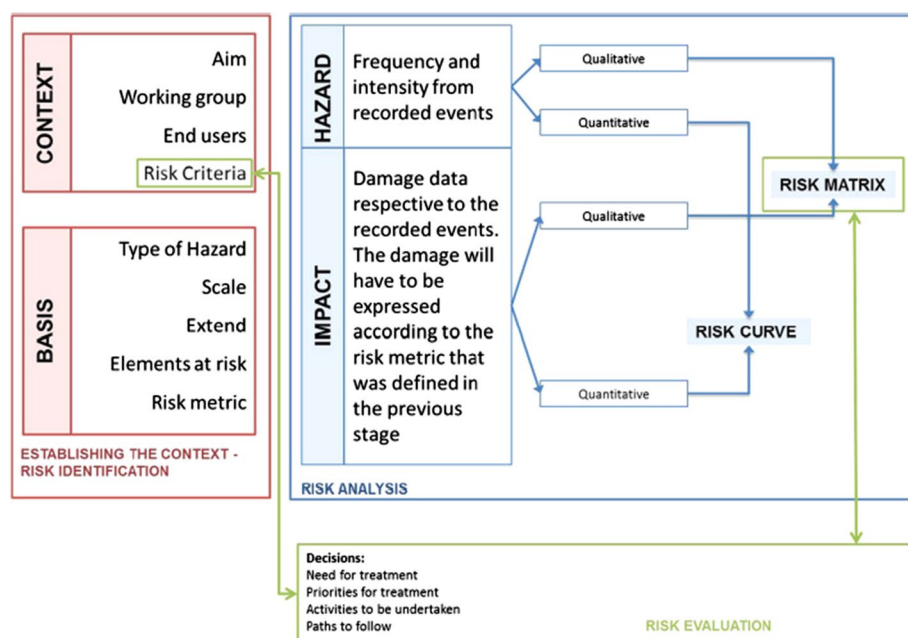

Fig. 1 Schematic flowchart of the developed SEERISK common risk assessment methodology (SEERISK 2014)

on the deaths of urban populations during heat waves (periods with extremely high air temperatures) as a serious hazard in central and southeastern Europe. The risk metric is M_{avg} based on different built-up zones (zones with different levels of urbanization) within the urban area.

2.2 Risk analysis

Risk analysis is the second step of a risk assessment and contains the hazard analysis, impact analysis and risk analysis.

The hazard values show spatial and temporal recorded data from the past to obtain information on the probability of occurrence or the intensity of potential events or measurements (SEERISK 2014). The data collected for a hazard analysis could concern the frequency and duration of measurements, spatial area of the hazard, hazard intensity, etc. In this study, the hazard analysis is based on urban heat island (UHI) intensity data, i.e., the air temperature differences between urban and non-urbanized areas.

The impact analysis is focused on the consequences of the potential hazardous events on the elements at risk (Papathoma-Köhle et al. 2016a). The identification of the elements at risk in the study area and their characteristics that affect their vulnerability must be included in the impact analysis (SEERISK 2014). In this paper, the impact analysis is based on the number of deaths, i.e., M_{avg}, in the urban population for each LCZ.

Risk analysis is a process to describe the nature of the risk and determine the risk level (EC 2010). The results of the hazard and impact analyses can be displayed on a risk matrix. The risk rating and intervals of the risk matrix mainly depend of the type of the risk assessment (Papathoma-Köhle et al. 2016a). The risk analysis may be qualitative, where risk is described as high, medium or low, or quantitative, where risk is described by a specific previously defined risk metric (e.g., number of deaths, costs, losses) (Papathoma-Köhle et al. 2016b). In this paper, a heat wave risk assessment based on UHI intensity as the hazard level and M_{avg} as the impact level is analyzed.

2.3 Risk evaluation

In the third step of the risk assessment, the results of the risk analysis and risk criteria are compared. Risk evaluation is the procedure of deciding which risk is acceptable or tolerable and which risk needs to be addressed (SEERISK 2014). The risk evaluation procedure must start during the risk identification process. The working groups, local authorities or end users implementing the risk assessment will need to define the risk assessment criteria to identify a risk as high, medium or low. Furthermore, decisions must be made regarding the acceptance of the different risk levels, and these risk levels need to be translated into actions (Papathoma-Köhle et al. 2016b). In cases where there is a lack of the data required for the development of a heat wave risk assessment and map, the local authorities or other end users can use alternative steps for qualitative and quantitative risk assessments (see the workflows in Papathoma-Köhle et al. 2016a, b). In the quantitative risk assessment, the risk rating is expressed as a number, whereas in the qualitative risk assessment, a qualitative description (very high, high, medium, low) is used (Papathoma-Köhle et al. 2016a). Figure 2 presents the risk assessment and mapping procedures for heat waves based on quantitative or qualitative data and risk rating.
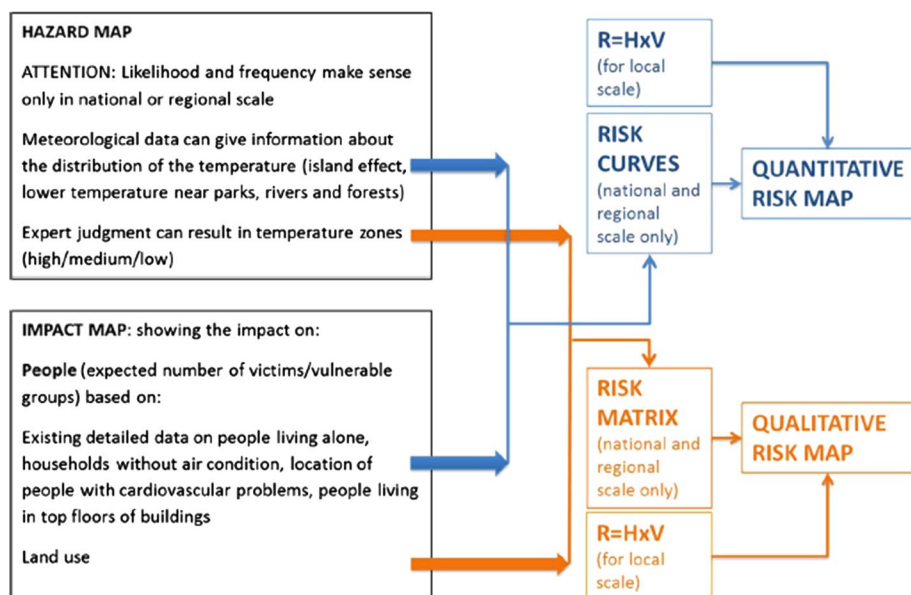
Fig. 2 Risk assessment and mapping procedure for heat waves (SEERISK 2014)

3 Research area and data

3.1 Geographical characteristics of Novi Sad city

The focus of this research is the City of Novi Sad, the second largest urban area in the Republic of Serbia, with 112 km^2 built-up area and population of 325,000 (data from 2016) (Fig. 3). It is located in Central Europe on a Carpathian Basin, and most of the built-up areas are on relatively gentle relief between 80 and 86 m a.s.l. The southeast outskirts of the city (Petrovaradin and Sremska Kamenica districts) are on a higher altitude, i.e., up to 130 m a.s.l. This southeast built-up area is settled on the edge of the northern slope of the low mountain Fruška Gora (higest peak 539 m a.s.l.) and separated from most built-up urban area by Danube River (river width from 260 to 680 m). Through the northern portion of the city passes the narrow Danube-Tisza-Danube Canal between industrial zones, Klisa, Salajka and Slana Bara districts in the north and most built-up areas in the south.

   Novi Sad region has a Cfb climate (temperate climate, fully humid and warm summers, with at least four $T_{mon} \geq + 10$ °C) according to Köppen–Geiger climate classification (Kottek et al. 2006). The mean monthly air temperature ranges from − 0.3 °C in January to 21.8 °C in July, and the mean annual precipitation is 622.8 mm (based on data registered from 1949 to 2015).

3.2 Built-up types and stations spatial patterns

Novi Sad has a densely built central area with medium-wide streets and avenue-boulevard roads network connecting different areas of the city (Unger et al. 2011). Built-up
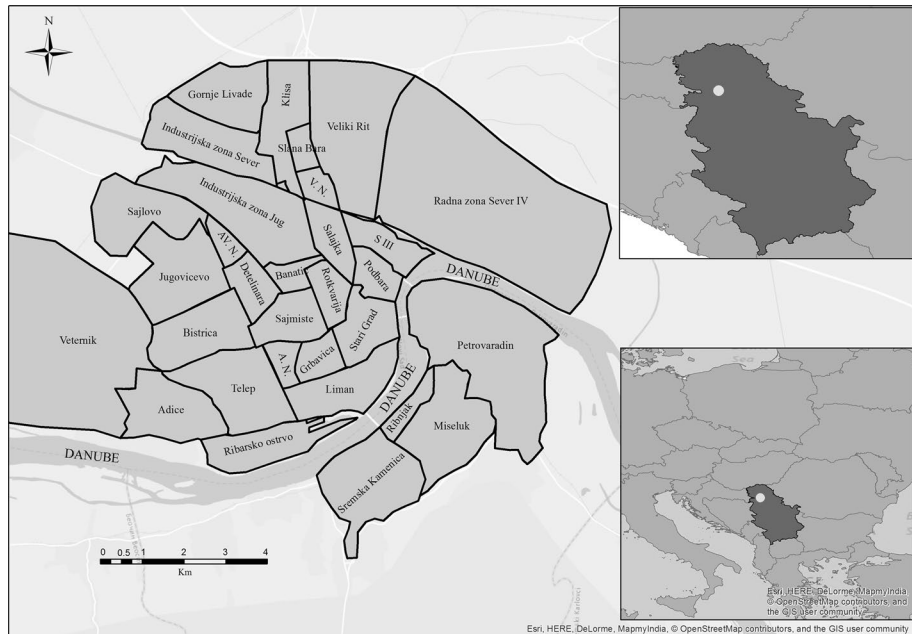
Fig. 3 Novi Sad urban area with marked districts and its location in Serbia and Europe. *AV.N.* Avijaticarsko naselje, *A.N.* Adamovicevo naselje, *V.N.* Vidovdansko naselje, *S III* Radna zona Sever III

area contains a lot of midrise building blocks (mostly from 4 to 8 stories) mixed with 1–3 buildings with 16–18 stories (for instance in: Podbara, Liman 1-4, Bistrica and Banatic districts), low-rise residential areas or park areas. Warehousing and industrial zones are concentrated in northern suburban areas, which is in some cases mixed with low-rise residential areas (for instance in: Salajka and Klisa districts). Green areas are spread along the banks of the Danube River, in park areas and in the city's outskirts. Hence, Novi Sad is complex urbanized city.

The definition and delineation of different built-up areas are based on the local climate zones (LCZ) classification system (Stewart and Oke 2012) (Table 1), the Lelovics-Gál methodology (Lelovics et al. 2014) (Fig. 4) and guidance for representative meteorological observations at urban sites (Aguilar et al. 2003; Oke 2004; Muller et al. 2013). According to the built-up patterns of Novi Sad and the local knowledge of researchers, the seven built LCZ classes are detected: 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 and LCZ 10—heavy industry (Figs. 5a, 6). Additionally, the land cover classes A, D and G representing dense trees, low plants and water, respectively, have been detected in Novi Sad and its surroundings. The Lelovics-Gál methodology for LCZ classification was created within URBAN-PATH project (HUSRB/1203/122/166) that was realized by University of Novi Sad, Faculty of Sciences together with colleagues from University of Szeged. Novi Sad and Szeged are first cities that this LCZ classification method was applied. According to surface parameters in Fig. 4, Novi Sad urban area is divided in 47.000 lot area polygons (each building with surroundings is one lot area polygons) and defined the LCZ type. The next step is aggregation of lot area polygons based on methodology described in

Table 1 Names and designation of the local climate zone (LCZ) types (Stewart and Oke 2012)

Built types	Land cover types	Variable land cover properties
LCZ 1—Compact high-rise	LCZ A—Dense trees	b—bare trees
LCZ 2—Compact midrise	LCZ B—Scattered trees	s—snow cover
LCZ 3—Compact low-rise	LCZ C—Bush, scrub	d—dry ground
LCZ 4—Open high-rise	LCZ D—Low plants	w—wet ground
LCZ 5—Open midrise	LCZ E—Bare rock/paved	
LCZ 6—Open low-rise	LCZ F—Bare soil/sand	
LCZ 7—Lightweight low-rise	LCZ G—Water	
LCZ 8—Large low-rise		
LCZ 9—Sparsely built		
LCZ 10—Heavy industry		
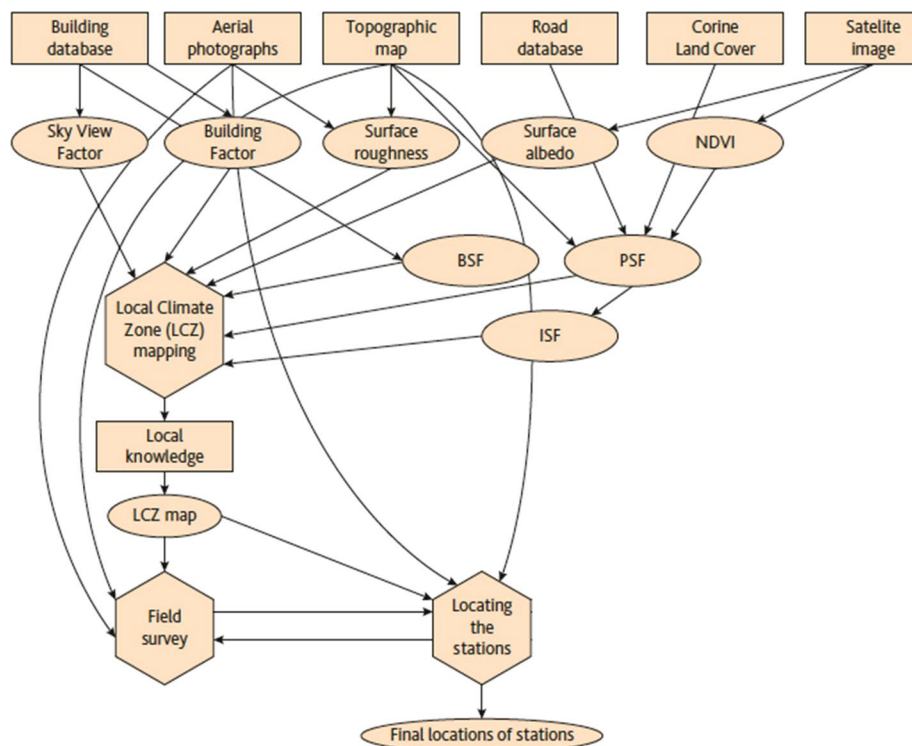
Fig. 4 Process of identifying and delineating LCZs and selecting the representative station sites for urban monitoring network in Novi Sad, Serbia (Lelovics et al. 2014); in pattern is excluded calculations that is not used for LCZs in Novi Sad. *NDVI* Normalized Difference Vegetation Index, *BSF* Building Surface Fraction, *PSF* Pervious Surface Fraction, *ISF* Impervious Surface Fraction
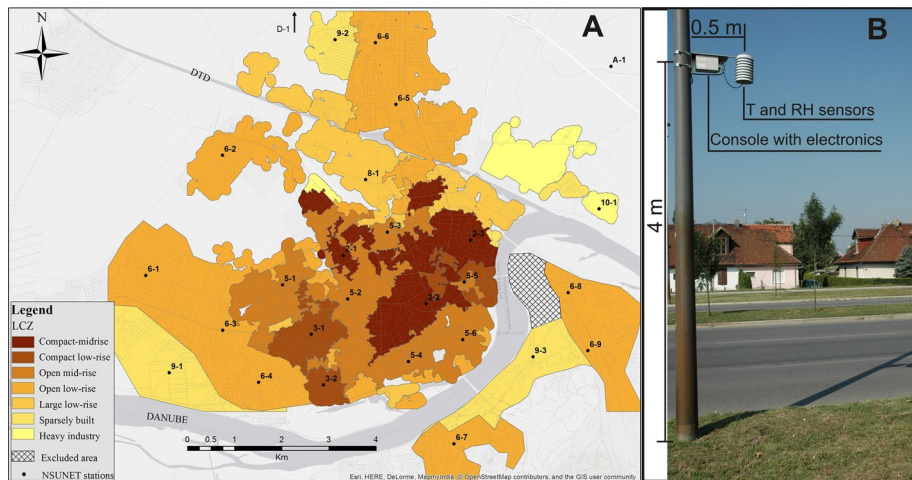
Fig. 5 **a** LCZ pattern and station locations in urban area of Novi Sad (Serbia), **b** example of station (5-2) with air temperature and relative humidity sensors inside radiation protection screen mounted on a lamppost

Lelovics et al. (2014). Final pattern of LCZ in Novi Sad (Fig. 5a) should represent that in each LCZ area is exactly or similar thermal features based on surface characteristics. The excluded area is historical fortress located about 50 m higher than urban area of Novi Sad and based on methodology is not represented area. The advantages of LCZ system are that it is a global classification scheme with limited number of classes and the classes are separated by the main thermal characteristic of the urban surface. The LCZ system does not cover entirely the spatial heterogeneity of the thermal pattern because it is affected by far more and complex processes. However, it describes the most important urban and natural features and can be a good basis for local and regional scale climate models in order to estimate the UHI intensity and intra-urban temperature patterns (Bechtel et al. 2015; Lelovics et al. 2016). Hence, the developed LCZ is a comprehensive climate-based classification system of urban and non-urbanized areas for temperature studies (Stewart and Oke 2012) and can be used for mapping and spatial analysis as well as for the characterization of measurement sites (Lelovics et al. 2016).

Novi Sad urban network (NSUNET) was created in 2014 with 25 stations installed in seven built LCZs and two stations in land cover A and D LCZs (Fig. 5a). The stations are equipped with air temperature and humidity sensors (ChipCap 2) in radiation protection screens (200 × 240 mm) to obtain long-term and effective measurement data within the Novi Sad urban area. The accuracy of the air temperature sensor is ± 0.3 °C, and of the relative humidity, (RH) sensor is ± 2% (20–80% RH). The sensors and all equipment were installed at least 4 m above the ground (with exceptions ± 0.2 m) on arms (50 cm long) fixed to selected lampposts (Fig. 5b). Two stations in the land cover areas were installed at 2 m above the ground. The stations are activated each minute to perform data measurements, and each 10 min they send the averaged readings to the main server installed at University of Novi Sad (Faculty of Sciences). Stations use Universal Time coordinated (UTC) as the system time, which is synchronized with the main server (Šećerov et al. 2015).

Fig. 6 Urbanization type for each defined LCZ in Novi Sad and built-up surroundings for nine selected stations; LCZs, local climate zones types by Stewart and Oke (2012); Station ID, Example of NSUNET stations from where were taken low-level and aerial photographs. The low-level photograph for station 10-1 is not available because it is forbidden to take a picture inside the industrial area

LCZs	Station ID	Low-level photo	Aerial photo radius of 250 m
2	2-1		
3	3-1		
5	5-4		
6	6-9		
8	8-1		
9	9-2		
10	10-1		
D	D-1		
A	A-1		

3.3 Air temperature data

Summer 2015 was characterized by hot and dry conditions with significant increases in temperature extremes and heat waves over central Europe. It was one of the hottest summers in the last few decades, and the magnitude of warming was comparable with previous hot summers in Europe, such as in 2003 and 2010 (Dong et al. 2016). According to the monthly reports of the Republic Hydrometeorological Service of Serbia (RHS), six heat wave periods occurred during summer 2015 in Serbia (RHS 2015a, b, c). Two heat waves occurred in each summer month, and the total number of days with these extreme temperatures was 42. Hence, the summer of 2015 was chosen for further analysis as an adequate period for a heat wave risk assessment in the urban area of Novi Sad.

Additional criteria (defined by the authors) were applied to select the days within very strong and intensive heat wave periods. The criteria are as follows: (1) The heat wave lasted ≥ 5 days; (2) the maximum daily T was ≥ 5 °C than the average daily temperature and (3) the maximum daily $T \geq 8$ °C than the average monthly (June, July or August) temperature. Two intensive heat wave periods were recognized based on additional criteria, i.e., from 17 to 25 July (e.g., average daily T_a from 27.6 to 29.5 °C; maximum daily T_a from 36.2 to 37.9 °C) and from 4 to 15 August (e.g., average daily T_a from 26.4 to 28.9 °C; maximum daily T_a from 33.5 to 38.2 °C).

The analysis in this study was performed using air temperature (T_a) data with a high temporal resolution, i.e., 10-min T_a data from the NSUNET system, for the selected heat wave events. The time of the T_a measurement was converted to local standard time in Novi Sad (i.e., Central European Time—CET). The next step was to define the daily period when the UHI intensity remains relatively strong. According to the new results for midsize central European cities (Fortuniak et al. 2006; Doborvolny and Krahula 2015; Gál et al. 2016), strong UHI intensity appears during the early night (Oke 1981; Alcoforado and Andrade 2006; Hart and Sailor 2009), i.e., at 1 h after sunset, and lasts for 9 h. Hence, T_a data were analyzed from 21 p.m. (current day) to 5 a.m. (next day), i.e., 8 h per day. The final T_a database contains 30618 measurements. Since there was only a small amount of missing data, i.e., 0.07% (21 missing measurements), there was no significant bias of the final results.

3.4 Population data

The total number of the populations by LCZs is based on data from the population register of the city of Novi Sad. A database for mortality for summer 2015 was obtained from the Institute for Public Health of Vojvodina Province, Republic of Serbia. For the purpose of this research, the daily number of deaths from all causes (ICD-version 10) of death was used, and the final analysis was performed on 559 deaths. The number of deaths was recorded daily (24-h) for the selected heat wave periods. The analysis for the specific part of day (e.g., night, afternoon or morning) is limited due to the lag effects. Only the permanent residents of the city who died in Novi Sad were included in the analysis. Using data on the residences for each person, spatial delineations of the deaths were calculated for different built-up areas, i.e., LCZs.
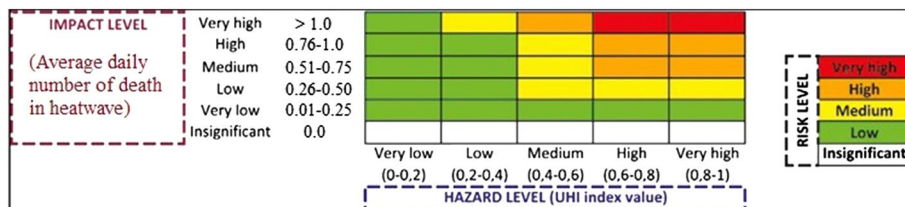
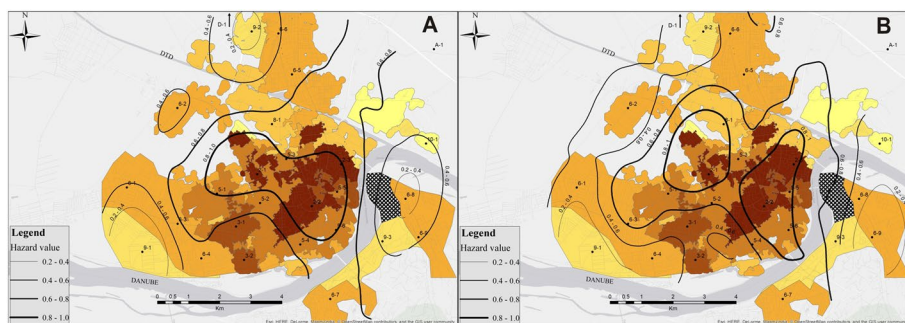**Fig. 7** Heat wave risk matrix for the urban area in Novi Sad

Fig. 8 Heat wave hazard maps for the urban area of Novi Sad: **a** from July 17 to 25, 2015, and **b** from August 4 to 15, 2015; Color patterns represent LCZs (see legend in Fig. 5a)

4 Application and results of the heat wave risk assessment and mapping methodology

The main purpose of this study is to calculate heat wave risk assessments for different built-up zones in the Novi Sad urban area and heat wave risk on mortality of the local population. Based on daily mortality data for the summer of 2015 and UHI intensity for two extreme heat wave periods, a risk matrix was developed for Novi Sad (Fig. 7). The heat wave risk matrix was previously created as a part of the SEERISK project (SEERISK 2014) and the analysis of Papathoma-Köhle et al. (2016a), and it is based on paramedic interventions per day and UHI differences. In this study, the vertical axis shows the impact level expressed as M_{avg}, and along the horizontal axis, the hazard level is expressed as a standardized UHI intensity index value (Fig. 7). Furthermore, the element at risk that was considered for risk mapping was the urban population of Novi Sad, and the risk metric was the number of deaths by each LCZ. In the heat wave risk matrix, the hazard and impact levels are scaled from insignificant to very high, and the risk level has five levels (insignificant, low, medium, high and very high). The following subchapters will explain the analysis procedure in detail.

4.1 Hazard pattern outcomes

Heat wave hazard maps (Fig. 8) are based on nocturnal air temperature differences between the diverse built-up LCZs (i.e., urbanized areas) and land cover (i.e., non-urbanized areas) LCZs. The results of previous studies showed the highest T_a differences between densely built LCZs and land cover LCZs (Unger et al. 2011; Skarbit et al. 2015; Lelovics et al. 2016; Wei et al. 2016) during nocturnal hours (Doborvolny and Krahula 2015; Lemonsu et al. 2015; Gál et al. 2016; Geletič et al. 2016; Skarbit et al. 2017), and these outcomes are similar to our findings. Therefore, during the selected intensive heat waves, the number of successive tropical nights (minimal night temperature $T_a \geq 20$ °C) in all the built areas in Novi Sad was higher than the number in the land cover areas (based on data from NSUNET system). These consecutive tropical nights led to heat risks for urban populations (health and mortality) and the environment (Meehl and Tebaldi 2004; Marković et al. 2016). Numerous UHI studies used the LCZ scheme to assess T_a differences in different cities. These studies showed that during summer nights LCZs with high impervious/building cover in cities such as Berlin (Fenner et al. 2014), Szeged and Novi Sad (Unger et al. 2011; Gál et al. 2016; Lelovics et al. 2016; Skarbit et al. 2017), Nancy (Leconte et al. 2015) and Dublin (Alexander and Mills 2014) have higher T_a values of up to 6.0, 4.0, 4.4 and 4.2 °C, respectively, than areas in these cities with high pervious/vegetated cover (Milošević et al. 2016). A recent publication (Papathoma-Köhle et al. 2016a) reported that the higher values on a heat wave hazard map of Arad city covered a wider area during the night compared to the day.

In this study, the air temperature was obtained from a relatively dense NSUNET station network (27 in situ stations) located in the urban area of Novi Sad with 10-min measurement frequencies. The UHI intensity index was obtained by subtracting the minimum value of the domain from each station temperature. In the next step, the index was standardized by dividing each difference with the maximum. The highest difference corresponds to the maximum UHI intensity effect, and its value is 1 (Fig. 7). The time period used for the UHI intensity hazard calculation is explained in subchapter 3.3. This study is the first time that a heat wave hazard map used data from monitoring stations. The previous studies (SEERISK 2014; Papathoma-Köhle et al. 2016a) used land surface temperature (LST) for their UHI index calculations.

Figure 8 shows the spatial distribution of the UHI intensity hazard maps between the urban and non-urban stations. The heat wave in July (Fig. 8a) shows UHI intensity values from 0.8 to 1.0 that cover most of the densely built-up areas, i.e., LCZs 2 and 5. Hence, the highest T_a differences between the built and land cover areas are the following urban districts: Stari Grad, Liman I and II, Detelinara, Podbara, Banatic and Grbavica. Most of the industrial areas (LCZ 8) and peripheral parts of the densely built-up areas (Liman III and IV, Sajmiste and western part of Bistrica district) have a UHI intensity index from 0.6 to 0.8. The city districts mostly characterized by moderately dense built-up zones (LCZs 3, 6, 8 and 10) have values between 0.4 and 0.6. Only the outskirts in the north, southwest and southeast (LCZ 9) have UHI intensity values lower than 0.4. The spatial pattern of hazard values during the August heat wave shows very similar results (Fig. 8b). There are slight differences in the spatial distribution of UHI intensity values from 0.8 to 1.0; that is, some parts of the industrial zones are covered by the highest hazard level, and the Banatic district has hazard values between 0.6 and 0.8.

4.2 Impact level pattern

Heat wave hazards have important influences on urban populations, particularly on vulnerable groups of people such as elderly people, children, people with chronic diseases and disabled people. The impact map used the average daily number of deaths (M_{avg}) as the impact index for the selected heat wave periods in the summer of 2015. Because the lag effect for heat-related mortality is 0–3 days (Yu et al. 2011; Huang et al. 2014; Bao et al. 2016), heat wave periods covered the days of the heat wave and three subsequent days. The indicators for the impact level are limited to only the total number of deaths for all causes because the analysis covers weather periods with extreme temperatures in a midsized city.

In the first step, the total number of deaths in each LCZs for the heat wave periods was obtained. In the second step, the number of days for both heat wave periods was determined, i.e., in July 12 days and in August 15 days. Finally, the calculation of M_{avg} was conducted using the total number of deaths and the number of days for the heat waves. This calculation was done for each LCZ. Figure 7 presents the impact level scale of M_{avg}, where the values that are > 1 have a very high impact level, and the impact is lower as the values are closer to 0. The minimum value of the impact level was defined (0.01) if at least one person died compared to the total number of deaths during the observed period. Figure 9 shows very high impact level values in the central and western part of the city, which are represented by dense midrise buildings (LCZ 2—Stari Grad, Podbara, Grbavica and Detelinara districts), and there is an open arrangement of midrise buildings in the western and southeastern urban areas (LCZ 5—Bistrica and Liman I-IV districts). LCZ 6 and LCZ 3 represent moderately dense buildings with high and medium impact levels, respectively. Near the outskirts of the city, there are less urbanized areas (LCZ 9) with very low impact
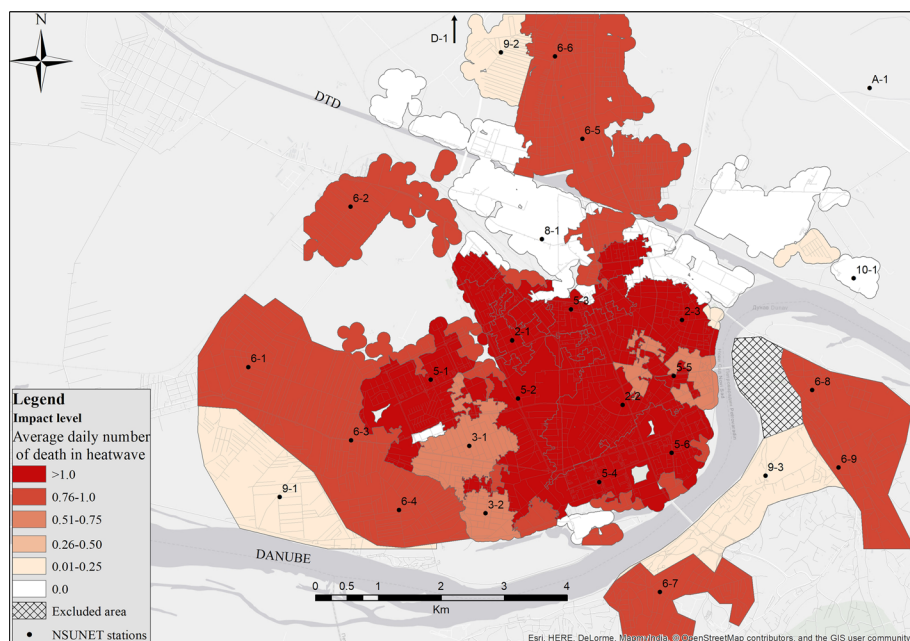

Fig. 9 Impact level pattern in the urban area of Novi Sad

levels. LCZs 8 and 10 are excluded from the impact level analysis because these areas do not have buildings where people live.

4.3 Heat wave risk assessment

Risk analysis is a process that involves understanding the risk and determining its level (EC 2010). Risk analysis involves an assessment of the probability of occurrence of a hazard and an assessment of its impact on the elements at risk (SEERISK 2014; Marković et al. 2016). In this study, the risk matrix was created based on the hazard level of the UHI intensity and the impact level of the M_{avg} from the heat wave periods in the summer of 2015 (Fig. 7). The risk map was generated based on the equation *risk value = 10 × hazard level + impact level*. The calculated risk values were reclassified to risk levels (insignificant, low, medium, high, very high) according to the coloring of the risk matrix, and these were used to develop the risk maps (Perge et al. 2014).

Figure 10 presents the heat wave risk assessment for the two periods from July (from the 17th to 25th) and August (from the 4th to 15th). The very high risk level is in most urbanized areas (Stari Grad, Podbara, Grbavica, Detelinara, Banatic, Sajmiste, Liman I-IV and Bistrica districts), which are represented by LCZs 2 and 5. The high risk levels are mostly in LCZ 3 (Telep district) and some parts of LCZ 6 (Slana Bara, Petrovaradin and Sremska Kamenica districts) that represent densely built houses and low buildings. LCZ 9 has a low risk level and represents the outskirts of the city. The spatial patterns of heat wave risk levels in July and August are very similar and can be seen in Fig. 10a, b. In comparison with August, the high risk levels covered larger urban areas (mostly LCZ 6) during the heat wave in July, which can be explained by the difference in the intensity of the heat waves. Based on the risk level maps, the urban areas characterized as having complex surfaces need more detailed impact level information for their risk hazard assessments.

5 Discussion

In this paper, the research focused on heat wave risk assessments in the urban area of Novi Sad (Serbia) during the very long and intensive heat waves in the summer of 2015. Moreover, the risk assessments were based on the air temperature differences between the various built-up areas (LCZs) and non-urbanized surroundings and the impacts on population
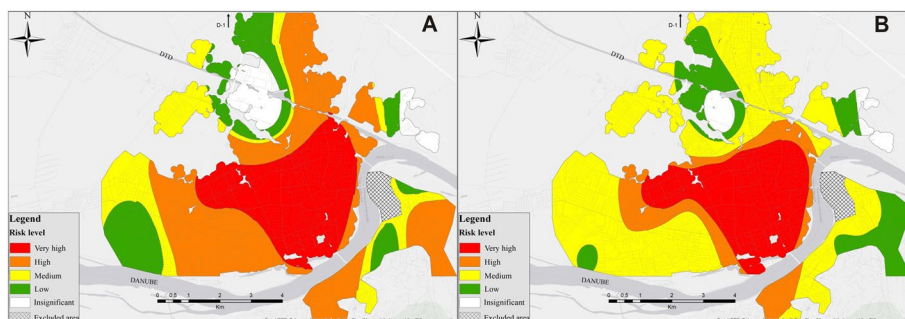

Fig. 10 Heat wave risk mapping for the urban area of Novi Sad: **a** July 2015 and **b** August 2015

mortality. Urban areas with primarily artificial, impervious surfaces are characterized by higher air temperatures compared to their surrounding, natural areas (the so-called UHI effect). Furthermore, the temperature difference values are known as UHI intensity. This UHI intensity is visible during the day, but it is the highest and intense during the night, particularly during periods of heat wave events. Unfortunately, these modified extreme temperatures during heat waves have negative influences not only on urban environments and infrastructure but also on population health and quality of life. When there are a few successive tropical nights (minimal night temperature $T_a \geq 20\ °C$), which often occur during the heat waves in the cities of central and southeastern Europe, the consequences on vulnerable groups of people can be fatal. In the further analysis of this study, the results demonstrated that different LCZs have different UHI intensity features. Hence, the urban area did not have uniform heat wave risk levels, but the levels were based on ratios of building density and height, traffic infrastructure, green areas, water bodies, and other factors, and the risk assessment levels were different. The results show that in LCZs 2 and 5, heat wave hazard risks have the highest values. At the same time, in these LCZs, the elderly people and people with chronic diseases are presented with a significant ratio in comparison to whole population. LCZ has the oldest population, i.e., the average age is 4.2 years more than average age of whole city. In both LCZs, cardiovascular disease is the leading cause of death (more than half of all recorded deaths).

Furthermore, in LCZ 2, the population is not the oldest compared to other LCZs, but the vulnerability to risk is very high according to the built-up type of development, i.e., dense buildings patterns and many impervious surfaces. This situation leads to a higher mortality rate, which is in line with the highest risk level. Similar results, based on the number of paramedic interventions needed in the city of Arad (Papathoma-Köhle et al. 2016a), show that in most urbanized parts of cities the negative effect of heat waves on population health was higher. According to heat wave risk assessment and map of urban areas, the local authorities and institutions who are in charge of preventing climate change-related hazards could use these results during the creation and implementation of mitigation and prevention strategies. Furthermore, local medical and rescue teams may use these results and maps to locate temperature hot spots in urban areas and identify the most vulnerable people with a higher need for intervention during heat waves (Papathoma-Köhle et al. 2016a). Finally, based on the information in the risk assessment, local authorities and rescue teams could plan prevention and mitigation actions more effectively.

According to the risk assessment, local authorities and end users could decide which kind of specific actions must be taken based on high, medium or low risk levels. In general, very high or high levels mean serious actions are needed, such as to put medical and rescue teams on hot spots, install points with water supply, provide constant information on local and regional media or even evacuate the population as a final measure. A medium risk might mean only giving alerts on the situation, and a low risk might mean no actions are necessary (SEERISK 2014).

The benefit of the heat wave risk assessment methodology is that it can be applied in urban areas with different climates and topography, as well as sizes, levels of development and population densities. The heat wave risk matrix could be adjusted for other cities based on T_a differences between various built-up and land cover areas as well as hazard values, population data and impact values. In this analysis, the spatial and temporal pattern of temperature measurements in the urban area as a background have an important role on the accuracy of the hazard level that leads to a precise final risk assessment. Finally, this methodology could provide analysis for other segments of the urban environment, such as other climate extremes (extreme precipitation or drought), water management (pluvial floods),

problems with populations (mortality, population ageing, health) and sustainable urban planning.

There are some limitations and disadvantages of the methodology. The hazard calculation had a better result based on the dense meteorological station network in the urban area and the high frequency of temporal and spatial measurements. Unfortunately, it is a very rare situation that urban areas in Europe or other continents have adequate urban meteorological networks (UMNs) (Muller et al. 2012, 2013; Unger et al. 2015). On the other hand, the car traverse measurements or land surface temperatures (LST) could be useful, but with some temporal or spatial limitations. There are some problems with the standardization of the impact level data, mostly if population data such as mortality data (in this study) or paramedical data were used (SEERISK 2014; Papathoma-Köhle et al. 2016a). Still, it is a serious challenge for impact level calculations to use all necessary parameters, such as population density, causes of death (or only chronic diseases), calculation of all paramedic cases (or only with death cases), socioeconomic data. However, despite this challenge, these data provided general information on the risk of vulnerable groups in the population, which is the main reason for the risk assessment methodology. Furthermore, energy efficiency data or money losses might be easier factors to define for determining the impact level values. The best definition of borders of an urban area is still under consideration. The delineation based on the district level (SEERISK 2014; Papathoma-Köhle et al. 2016a) or different built-up areas had some logical results, but further research with higher spatial resolution (i.e., by building blocks) would contribute to a more precise risk assessment.

In light of all the advantages and disadvantages, the heat wave risk assessment and mapping could be a starting point for developing adaptation strategies for climate change and contribute to better quality of life in urban areas. Furthermore, this methodology has implications for the future and could be further developed (Papathoma-Köhle et al. 2016a). Additional improvements to the hazard impact could include outdoor human thermal indexes (Papathoma-Köhle et al. 2016a) such as the Universal Thermal Climate Index (UTCI) or the physiologically equivalent temperature (PET) (near air temperature, the relative humidity, wind speed and radiation are necessary data). The outdoor human thermal indexes have significant impacts on populations related to public health and mortality. Furthermore, a heat wave risk assessment could be focused on energy efficiency in urban areas. The amount of energy consumption (in W) could be varied in different built-up areas according to population densities and the types of buildings. The results show (Savić et al. 2014) that energy consumption is higher than average during heat waves, particularly during the day with air temperatures > 30 °C and during the night with temperatures > 20 °C. The risk assessment rates could vary in different built-up areas based on socioeconomics, the ratio of people aged 65 +, the type of buildings (age, materials), the number of air conditions, etc. Finally, risk maps of energy consumption, water consumption, traffic, gas emission, noise, etc. could be part of urban environmental or infrastructure strategies.

6 Conclusions

This paper introduces the heat wave risk assessment in the Novi Sad urban area during the summer of 2015. The methodology is based on UHI intensity as a hazard index and the average daily number of deaths in the population in each LCZ as the impact index. The final results of the risk assessment and map noted that extreme temperatures during heat waves have significant impacts on population health. The presented results suggest that city districts with the most densely built-up features (LCZs 2 and 5) have negative impacts on

urban populations and the environment. Because urban areas with the most severe heat stresses are recognized, these outcomes could be useful for local and regional representatives in charge of population health strategies and urban planning and to these representatives to address the adverse effects of urban climate and expected climate change in urban areas. Furthermore, the obtained risk assessment maps will provide useful information for local authorities (emergency service, police, fire service), medical institutions (i.e., Institute of Public Care of Vojvodina in Novi Sad), urban planners, building companies and ancillary services who are in charge of acting during various hazards at a local level. However, developing a risk assessment methodology that is scientifically sounds for a variety of hazard types and for various elements at risk is a very challenging task (Papathoma-Köhle et al. 2016b).

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