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Environmental Conditions During Hot Summer Day in Belgrade – Interaction of Thermal Risk and Noise Pollution

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Abstract: In urban environments, people's exposure to harmful ambient conditions and noise represents a particular challenge in the modern world. Global climate change and increasing population density, along with the increasing number of vehicles in urban areas, are constantly exacerbating this problem. The idea of this study is to assess the effects of temperature risks and noise pollution in two micro-locations. An analysis of the ambient conditions and noise in the urban environment was conducted at two locations in Belgrade, which differed in configuration. Simultaneous measurements of temperature (Ta and Tg), humidity, wind speed, and equivalent noise level were taken during a hot summer day (maximum temperature over 30°C). It was shown that the noise level exceeds the prescribed noise level values for the analyzed acoustic zone. The noise level values differ for the two locations due to the different traffic densities in the environment and different urban characteristics. This study showed that the concept of green space, but also of built-up type in urban planning could has importance impact in regulating thermal and noise conditions and obtained improved urban environments.

Keywords: Belgrade, Micro location, Noise Conditions, Urban Climate, Urban Environment, Thermal Conditions.

1 Introduction

Today cities are under the pressure of intensive urbanization and modified environmental conditions, which are expressed due to climate change, intensification of traffic and constant reduction of green areas. As a consequence of these processes, there is a threat to the urban ecosystem, additional energy consumption, increased thermal risk, as well as threats to the economy and public health. Unfortunately, more land areas and more world population are and will

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be under modified environmental conditions, because in the last decades cities experience very intensive urbanization [1], and this process will continue by increasing urban area from 13% in upper-middle-income countries to 141% in low-income countries until 2070, compared to city land area in 2020 [2].

Cities are characterized by distinct modification of surface comparing to natural surroundings [3], and therefore climate is modified above urban areas [4], particularly thermal conditions, that lead to more intense urban heat island (UHI) effect [5]. This amplification process of thermal conditions in cities is result of predominant impervious surfaces and surface roughness, then different urban forms, construction materials, amount of vegetation, etc. [6, 7]. More intensified thermal amplification, UHI effects and temperature extreme events, in general, could be expected in the coming decades caused by climate change trends. Based on the IPCC report [8] the global surface temperature (air and surface temperature) has increased by 1.09°C from 1850–1900 to the last decade period (2011–2020) and will continue to increase until the end of the century. The SSP5-8.5 (Shared Socio-economic Pathways) scenario, with an assumption of high and very high CO_2 and GHG (greenhouse gas) emissions, projects that global surface temperature will be higher by 3.3 – 5.7°C, in comparison to average temperature from 1850-1900. Even more, projection shows that if temperature changes for 4°C, the frequency of hot extreme events will increase about 35 times, and intensity will rise for about 5.5 C [9]. Therefore, the global climate change impacts force the cities to be more climate-resilient and climate-adaptable and this task should be of paramount importance [10].

Some research has shown that a large number of people are permanently exposed to noise levels that exceed some established limit values. It is believed that over 60% of the population in Europe is exposed to excessive noise levels in rooms where people stay for long periods of time [11]. Today's type of life generates numerous factors that contribute to the worsening of the noise situation, especially in urban areas [12]. The number of devices that generate sound as a side effect is constantly increasing, and there are other factors that modern technology has brought with it, contributing to the deterioration of noise in the environment. However, the most significant in this are two fundamental factors. These are an increase in the concentration of people in a small space and a permanent increase in the density of traffic on the streets. The negative impact of traffic noise can be reflected in disturbing people in performing daily activities, such as sleep. Some studies have shown that noise can have an impact on people's health, primarily on hearing impairments [13]. Also, traffic noise in urban areas can have an impact on the human’s cardio-vascular system [14, 15]. It has been shown in the literature that different urban structures in modern cities can have an impact on the noise level to which people are exposed [16].

Therefore, the main goal of this research is to reveal the urban environmental differences on micro-scale based on following steps: a) perform simultaneously monitoring of climate and noise conditions in diverse urban environments, i.e. in urban parks with different concept of green areas; and b) quantify and present how significant differences of environmental conditions could be occur in urban green areas dependence on density of greenery, ratio of concrete, tree shadows, and urban design types or traffic in immediate surroundings. Also, this study try to present possible problem solutions through discussing on the following scientific questions (SQ): SQ1) how obtained environment datasets (thermal and noise) could contribute to adaptation measures of environmental risks; and SQ2) what kind of monitoring and assessment methods should be performed to get more comprehensive and detailed picture of environmental conditions in cities in order to serve to better adaptation solutions.

2 Materials and Methods

2.1 Research area

Belgrade is located in the Southeastern Europe and represents the capital and the largest city in the Republic of Serbia. The population is about 1.7 million, and agglomeration accounts about 2 million of people, on the urban area of 3,222 km^2. Belgrade is characterized with densely built-up designs, especially in the downtown and its nearby urban surroundings. Towards the suburban areas, there are more detached multi-story buildings and one-story houses with higher ratio of green areas. Belgrade has a Cfa climate [17] according to the Köppen-Geiger climate classification system [18]. During 1991-2020 period mean annual temperature was 13.2°C, mean annual maximum temperature is 18.2°C, mean annual minimum temperature is 9.1°C and the mean annual precipitation is 698.9 mm [19].

2.2 Methodology of measurement and datasets

Measurement campaign was performed on hot summer day, i.e. with maximum daily air temperature higher than 30° C, no precipitation, low cloud cover, low wind speed and intense solar radiation. Therefore, the measurement was conducted on June 21st 2022, from 10 h to 18 h (Central European Summer Time – CEST), at two different locations in urban area of Belgrade. The concept of measurement was to monitor climate differences in various urban designs during the hottest parts of the day and monitor noise differences during the period of the most active traffic and construction activities. For this research we used 10-minute of measurements, even instruments for climate and noise parameters can monitor with higher measure frequencies. Based on previous research [20, 21], the usage of 10-minute values of environmental variables showed to be sufficiently frequent for this kind of analysis. Both sites are in the most urbanized area of the city (Fig. 1), and the main characteristics of measurement locations are: 1) Vukov spomenik – VS is urban park (area of 0.45 km^2) with scattered trees mostly located on the edge of the park, with dominant grass areas and lot of footpaths. This urban park can be identified as lot of sun during the day with minimum tree shadows and very intense motion activities through two main boulevards (Bulevar Kralja Aleksandra – south and Ruzveltova - west); 2) Mali Tašmajdan – MT is urban park (area of 0.64 km^2) with dense trees in combination of grass and footpath areas. This urban park characterised with a lot of tree shadows, and surrounded with small streets with light traffic. Furthermore, this park is surrounded by huge buildings and as a result it is directly protected of intense traffic noise from nearby boulevards (Figs. 2a and 2b). Therefore, the idea is to simultaneously monitor defined environmental parameters in two green areas (urban parks) located in various urbanization surroundings and with different greenery conditions.

(a)

(b)

Fig. 1 – *Measurement locations in the urban area of Belgrade, and measurement sites in both urban parks:* (a) *VS urban park and* (b) *TM urban park.*

(a) (b)

Fig. 2 – *Photos of sensors on both locations.*

The devices Brüel & Kjær 2270 (Mali Tašmajdan – MT) and Norsonic Nor140 (Bulevar Kralja Aleksandra - south and Ruzeveltova – west) were used for noise measurements at two locations. Data on measuring instruments are given in **Table 1** (available at: https://www.bksv.com/en/instruments/handheld/ sound-level-meters/2270-series/type-2270-s, https://web2.norsonic.com/product_ single/ soundanalyser-nor140/).

Table 1

Short specification of sound level meters BK 2270 and Norsonic Nor140. Devices used for noise measurement in Belgrade (Serbia).

	Brüel & Kjær	**Norsonic Nor140**
Class	IEC 61672-1:2002 class 1	IEC 61672-1:2002 class 1
Microphone type and Sensitivity	½″ Microphone 50 mV/Pa	½″ Microphone 50 mV/Pa
Frequency Analysis	1/1 octave filters: 8 – 16000 Hz, class 1 1/3 octave filters: 6.3 – 20000 Hz, class 1	1/1 octave filters: 0.5 – 16000 Hz, class 1 1/3 octave filters: 0.4 – 20000 Hz, class 1
Measurement range	1.1 dB to 140 dB	-10 dB to 137 dB

For the climate monitoring was used the Kestrel 5400 Heat Stress Tracker sensor (Figs. 3b and 3c, **Table 2**), that measure air temperature – T_a, relative humidity – *RH*, wind speed – *v*, and globe temperature – T_g. All climate parameters were measured at 1.1 m from the surface. The T_g is referred as the globe temperature or black globe temperature and resembles the thermal values of surroundings, and that means that T_g simulates the thermal conditions felt by the human body (available at: https://www.designingbuildings.co.uk/wiki/Globe_temperature). The Kestrel Heat Stress Tracker sensors were deployed at least 15 minutes before the start of the measurement in order to allow the sensors to equilibrate to the atmospheric conditions. Furthermore, the equipment is calibrated in accordance with the manufacturer's specifications (available at: https://kestrelinstruments.com/mwdownloads/download/link/id/14/.

Table 2
Accuracy, resolution and range of Kestrel 5400 Heat Stress Tracker sensor used for climate measurement in Belgrade (Serbia).

Sensors	**Accuracy (+/-)**	**Resolution**	**Range**
Air temperature (T_a)	0.5°C	0.1°C	–29.0 to 70.0°C
Relative humidity (*RH*)	±2%RH	0.1%RH	10 to 90% 25°C non-condensing
Wind speed (*v*)	larger of 3% of reading, least significant digit or 20 ft/min	0.1 m/s	0.6 to 40.0 m/s
Globe temperature (T_g)	1.4°C	0.1°C	–29.0 to 60.0°C

3 Results

3.1 Noise measurements

Based on the noise level measurement results shown in Fig. 3a, it can be concluded that both measurement locations have an increased noise level. At the VS location, the noise levels are around 60 dBA, while at the MT location, the levels are slightly lower and vary around 53 dBA. The noise level changes relatively little over time at the VS location. An increase in noise level is visible at the MT location after 4 pm, which is due to the increased number of vehicles after working hours. There is a certain change around 11 am at both locations when there is an increased concentration of vehicles due to traffic congestion.

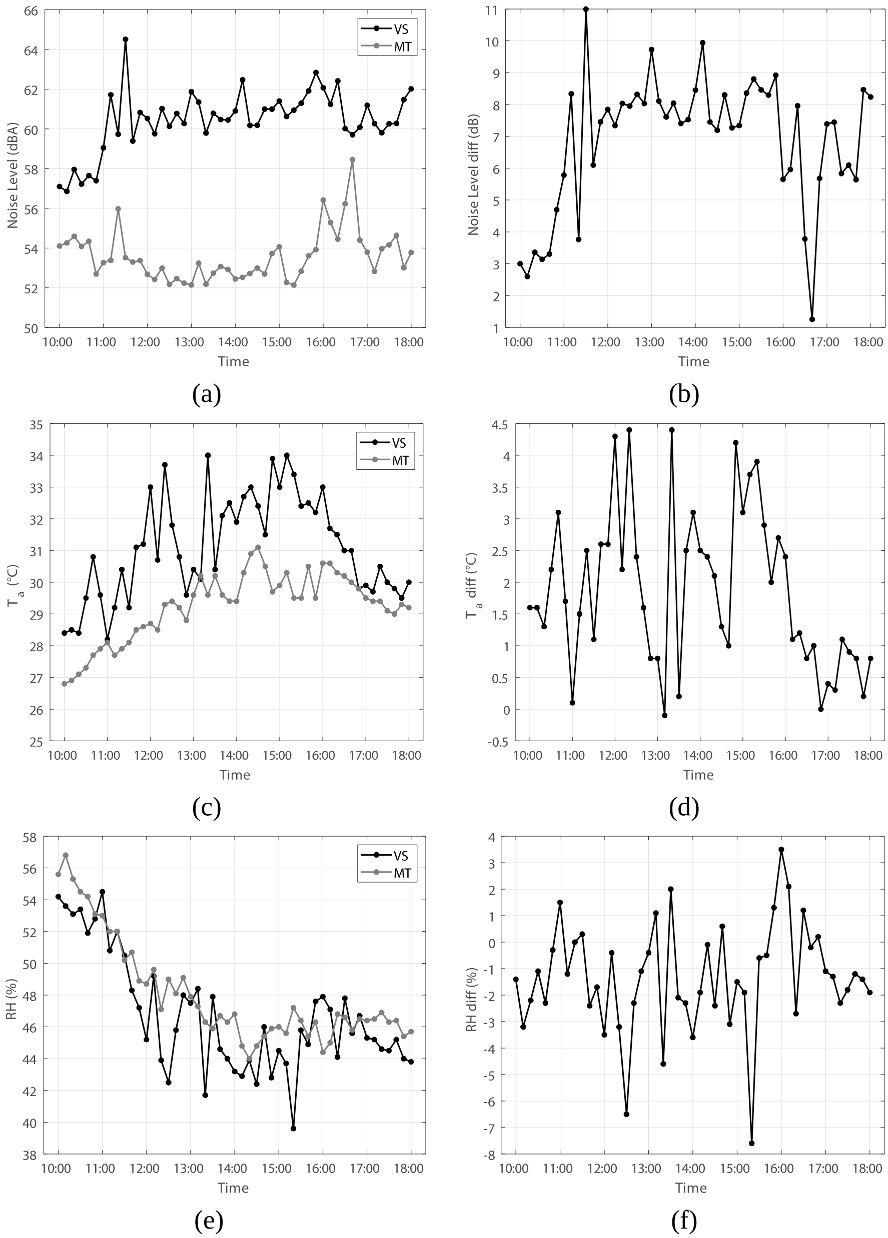

Fig. 3 – *Temporal variation of noise (L_{eq}) and climate (T_a, RH, v, T_g) values in VS (black line) and MT (gray line) sites in Belgrade, recorded at June 21st 2022 (measuring time from 10:00 h to 18:00 h – CEST, 10-minute frequency):*
(a) *L_{eq} values in dB(A);* (b) *L_{eq} differences between measuring sites (in dB);*
(c) *T_a values in °C;* (d) *T_a differences between measuring sites (in°C);*
(e) *RH values in %;* (f) *RH differences between measuring sites (in %);*

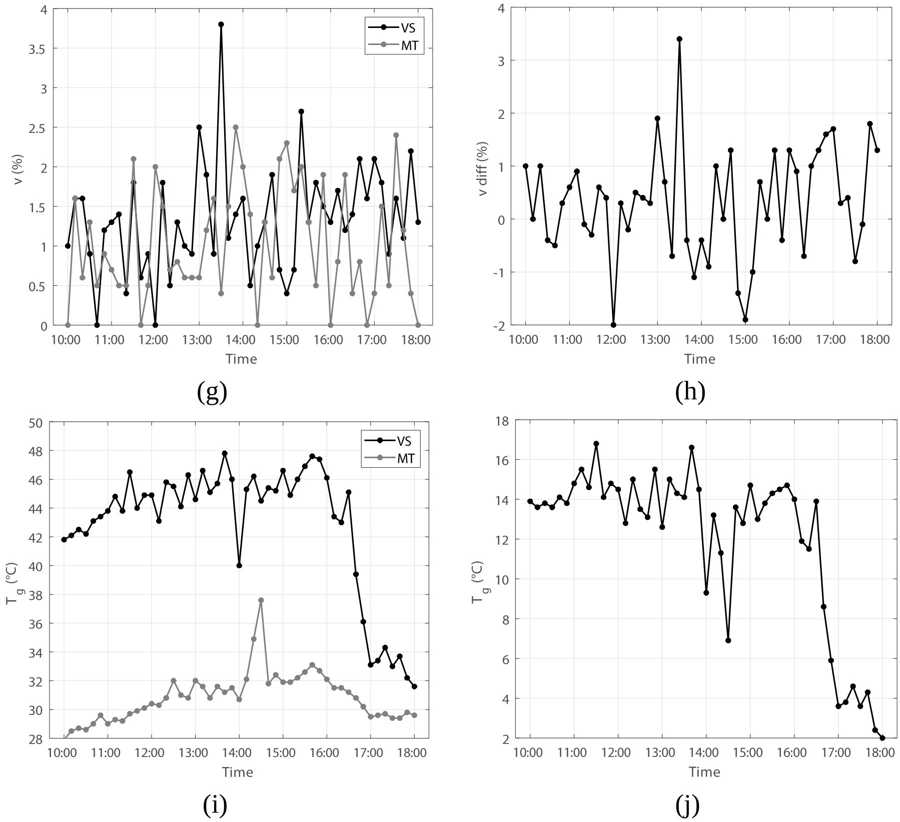

Fig. 2 – *Temporal variation of noise (L_{eq}) and climate (T_a, RH, v, T_g) values in VS (black line) and MT (gray line) sites in Belgrade, recorded at June 21st 2022 (measuring time from 10:00 h to 18:00 h – CEST, 10-minute frequency):*
(g) *v values in m/s;* (h) *v differences between monitoring sites (in m/s);*
(i) *T_g values in °C;* (j) *T_g differences between measuring sites (in °C).*

3.2 Climate measurements

During the measurement time, in all cases were measured same or higher T_a values on VS site, comparing to MT site (Fig. 3c). Of course, oscillations in differences were visible during the whole time, but after 15 h it was noticeable that differences are constantly decreasing (Fig. 3d). Minimum difference is 0°C and maximum is 4.4°C and it is provided at 13:20 h. Furthermore, the maximum temperature in VS is recorded at 15:10 h with value of 34.0°C, and in MT the maximum was 31.1°C measured at 14:30 h.

RH values are mostly higher on MT site and differences are around 2%, but there are situations that *RH* was higher on VS location, too. The most cases when

RH was higher or around 0% on VS site was in afternoon time (between 15:40 h and 18:00 h) (Figs. 3e and 3f). Maximum values on both sites are very similar and recorded in morning hours, i.e., 54.5% in VS at 11:00 h and 56.8% in MT at 10:10 h.

Measured values of wind speed (in m/s) provided more similar tendencies between two locations, comparing to T_a and *RH* (Figs. 3g and 3h). Differences of *v* between VS and MT are mostly around 0 m/s, but it is often that higher values are measured in VS site. Furthermore, the difference tendencies are similar during the whole measurement time. The higher v is measured at 13:30 h with value was 3.8 m/s in VS, and in MT the maximum value was 2.5 m/s at 13:50 h.

The most distinct differences between VS and MT are recorded in T_g values (Figs. 3i and 3j). During the whole monitoring period the T_g values in VS were higher than in MT. Between 10:00 h and 16:40 h differences were between 7°C and 17°C, and in the most cases were around 14°C. After 16:40 h the differences are constantly decreasing with minimum of 2°C at 18:00 h. The maximum recorded T_g in VS site was 47.8°C (at 13:40 h), and the maximum T_g in MT was 37.6°C (at 14:30 h).

4 Discussion

Previous research conducted in various cities around the world has shown that the noise level in urban areas can be very high. Research conducted in Brazil [22] shows that the noise level exceeds 75 dB(A) for most of the day. Research conducted by Khadija Abdur-Rouf shows that in Doha, noise levels exceeded 80 dB(A) [23]. Measurements carried out in major cities in Serbia, such as Niš and Novi Sad, show that noise levels are high, as in other urban areas in the world [24, 25]. In some parts of these cities, the noise level exceeds 70 dB(A).

The level of noise to which people are exposed on the streets varies depending on the time of day and the day of the week [26]. However, there are also locations in urban areas where the noise level on weekdays and weekends is practically the same [27]. Research conducted in Valencia shows the existence of noise levels greater than 70 dB(A) both during the day and at night [28]. In some specific situations, such as during the quarantine due to the COVID-19 pandemic, the noise level in urban areas was somewhat lower [29]. A reduction of only 2 dB indicates high traffic noise pollution and that even in situations where traffic in cities is less, the noise level is still high.

Our research shows that traffic noise levels are high, which is consistent with previously conducted research. The two measuring locations where the measurements were carried out belong to acoustic zones that correspond to zone 1, which includes rest and recreation areas, hospital zones and convalescent centers, cultural and historical sites, and large parks. In this zone, the permitted noise level is 50 dB(A) during the day and 45 dB(A) during the night [30]. At both locations, the noise level exceeded the prescribed limit values of the equivalent noise level during all eight hours of measurement. In some parts of the day, the noise level exceeds 65 dB(A), which is 15 dB higher than the permitted values according to the current regulations in the Republic of Serbia. There were differences in the noise level of about 10 dB at the two measuring locations, which were several hundred meters apart. This indicates that traffic concentration, as well as urban planning in micro-locations, significantly affect the noise level. A more detailed analysis could determine the extent to which urban planning can reduce the impact of traffic noise in cities. Ambient conditions such as temperature and humidity did not affect the change in noise level, so it can be concluded that ambient conditions do not have a significant effect.

According to previous studies that analyzed urban micro-climate conditions in cities from Serbia and Southeast Europe region, in general, green areas (urban parks) have higher cooling potential comparing to densely built-up areas during hot days or heat wave periods. Unger at al. [31] created the first analysis of urban climate in Novi Sad, and they reviled those areas with higher ratio of green areas (urban area of Novi Sad was divided by 500x500 m grids) reducing UHI intensity. Based on NSUNET (Novi Sad Urban Network) system and micro-climate monitoring in urban area of Novi Sad from 2014 to 2021, there are noticed clear distinction in thermal conditions between urban parks and larger green/blue areas, and most built-up zones [32, 20, 7, 33]. Their results show that T_a values in urban park, during the daytime and evening, are by 7-8°C lower comparing the city`s main square as most densely built-up area with 100% of concrete surface. Analysis of different urbanization types, based on LCZ (local climate zone) concept, and their effects on urban climate characteristics, revealed that less built-up types and urban parks provide lower urban thermal conditions, particularly during summer period based on example of Szeged, Novi Sad, Brno and Prague urban areas [34 – 37]. According to monitoring from urban area of Banja Luka (Bosnia and Herzegovina), during heat wave in June 2021, the T_a values were by 5-6°C higher in urban park comparing to downtown urbanized area [21]. Based on measurement campaigns in Belgrade, during summer 2021, general outcomes show that T_a values are by 7°C lower in urban and forest parks comparing to downtown areas [38]. However, datasets from Novi Sad, Belgrade and Banja Luka show that differences in T_g conditions are higher and more intense between green areas and built-up zones, and this T_g distinction reach more than 10°C [21, 33]. Furthermore, urban parks that are close to/or within downtown areas could lower temperature conditions with up to 1°C or more, that is noticed in Ghent, Belgium [39]. Finally, there are more research studies that highlighted the green infrastructures cooling potential in cities by analyzing the impact of trees in Sky View Factor values [40, 41], or pronounced different spatial characteristics of green areas and content of species as elements that driving to cooler thermal conditions in hot periods [42, 43].

Results in our study confirms in general the statements from previous research. Even we monitor and compare locations, both from urban parks, the serious thermal differences are visible, i.e. the T_a reached maximum difference of 4.4°C and the maximum difference in T_g was 17°C. Obviously, the concept of green area (grass domination or tree domination) and selection of species are essential in thermal condition regulation. The location Vukov Spomenik (VS) park the low plants are dominating and most of the park area are under direct sun light. The opposite situation is in Mali Tašmajdan (MT) park, where trees and high buildings in surroundings are dominating. Therefore, the constatation that tree and building shadows are very important in cooling effects and providing better thermal comfort conditions [44, 45] are confirmed in this research, too. Finally, based on our datasets, the rapid decreasing in differences in T_a, but particularly in T_g, between VS and MT started at 16:40 h and later as a result of more cloud conditions from 16:40 h to 17:40 h, and additionally by effect of buildings shade in the VS location from 17:40 h to 18:00 h. Hence, in that one and a half hour of monitoring, T_a differences are between 0°C and 1°C, and T_g difference decreasing to only 2°C.

5 Conclusion

In this study, the monitoring and assessments of thermal and noise conditions in the urban area (different green areas) of Belgrade (Serbia) was presented. One-day monitoring was performed by using the instruments on the field, in two locations with different green concepts and built-up surroundings. Duration of the field monitoring was eight hours, with a 10-minutes of the measurement frequency. Outcomes showed the noise values in the range from 53 dBA in the MT to 60 dBA in the VS, and these values exceeded permitted level of current legislation (50 dBA). Thermal parameters showed differences between two green areas in the range from max 4.5°C of T_a to max 17°C of T_g.

Obviously, the combination of green infrastructure (dense trees) and built-up type (higher buildings in small and calm streets) can contribute to improvement of environmental conditions in cities in case of thermal and noise issues. However, more comprehensive and detailed monitoring and assessments are needed to get clear picture of environmental issues in cities. Some new and innovative approaches of monitoring various climate values are in function already that are based on crowd-sourcing techniques using citizen weather stations, then smart-phone records, web-based tools, or using purpose-designed mobile/portable instruments with specifically-numbered and high-accuracy sensors.

Furthermore, these types of monitoring and assessments could contribute to achieving the sustainable development goals defined by the Agenda 2030 through: (a) contributing to a better implementation of climate-conscious urbanization that can improve the quality of life of the population and adapt cities to climate change and other environmental issues (SDG 11); and (b) contribute to further adaptation to climate change and other environmental hazards (like noise or air quality), especially in urban areas where the microclimate and environment are additionally modified due to the impact of urbanization (SDG 13).

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