Article

Soundscape Assessment of Green and Blue Infrastructures

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Abstract: Green and blue infrastructures provide economic, environmental, and social benefits to urban life. Various areas that are passing through such infrastructures have implications for those benefits. For instance, urban, rural, agricultural, and industrial zones extend the services and disservices of green and blue infrastructures. Such extensions also have various implications on the environment and public health. Sound is one of those under-examined aspects of aggregated effects of green and blue infrastructures. This study aims to contribute to whether soundscape is affected by three pillars of urban, industrial, and rural areas among green and blue infrastructures. The study result shows no significant difference among those zones; however, urbanized areas include the highest sound levels. Industrial and rural zones show similar patterns. The study also identified that green infrastructure has more effects on the soundscape paradigm. The results also imply that green and blue infrastructures should be designated in harmony to produce a more sound-friendly environment considering the current major uses of the areas.

Keywords: green infrastructure; sound; urbanization

1. Introduction

The changing trend of the world significantly expands to a critical urbanization level on a global scale. Given this, while one-third of the world's population lived in cities in the 1950s, this rate is expected to increase to two-thirds by 2050 [1,2]. However, the increase in the rate of people living in cities not only shows a pattern from rural to urban areas, but also the number of people living in urban areas increases, natural areas and wildlife habitats are destroyed for urban development, and the urban fabric invades the rural fabric along with natural areas [2,3]. In addition, since the urban sprawl increases as a result of the human population increase, the road, energy, and infrastructure also need to increase, and such transformation causes the diminishment of remaining natural areas into urban areas. This transactive association of urbanization and infrastructure also results in much human-induced noise in cities [2,4].

In addition to these, natural ecosystems deteriorating with urbanization also degrade the green infrastructure systems in cities. Urban green infrastructure (UGI) provides vital ecosystem services for cities and their users [5]. Ecosystem services underpin human well-being by revealing the complexity and diversity of interactions between society and natural systems, including health, economic and social activities [5]. Even if almost all cities are formed and managed by humans, many different urban ecosystems can be described as natural, such as street afforestation, parks, urban forests, agricultural areas, wetlands, lakes/sea, and streams [6]. At the same time, the recreational potential of the areas designed within the scope of green infrastructure activities will also provide another ecosystem service to increase the quality of life of the people living in that region [6]. With all these benefits, urban green infrastructure working together with blue infrastructure has been associated with improvements in anxiety, stress, and emotional well-being and

a lower risk of depression [7,8]. Blue and green infrastructure can constitute substantial and significant biodiversity reserves as they provide habitats for a wide variety of species, from birds, terrestrial insects, mammals, reptiles, and amphibians to aquatic insects, fish, algae, and aquatic plants [9]. Green and blue infrastructures also provide essential services to modern cities, such as improving aesthetics and air quality, regulating microclimates and air humidity, lowering air temperature, and balancing the sound environment [10].

Regarding the sound environment, green and blue infrastructures have different impacts based on the regions where those infrastructures are located: urban, rural, agricultural, industrial, etc. Considering the aggregated effects of transportation features, advanced developments, changing agricultural practices with new technology, and industrial zones of factories and heavy machines result in higher sound pressure levels. As such, this study aims to understand sound patterns of green and blue infrastructures that include the aforementioned urban characteristics. The study aims to contribute different daily life zones in a case study that includes green and blue infrastructure characteristics in the core of a densely populated city, as previous studies did not concentrate on a case study that intersects green and blue infrastructures attributes. To do this, the study explores a study area that includes urbanization, rural and agricultural, and industry attributes to address the fundamental research questions: what are the associations between green and blue infrastructures and soundscapes? How do urban, rural, agricultural, and industrial areas affect soundscapes?

1.1. Sound Concerns in the Urban Environment

Sounds have accompanied human civilizations with the interaction of nature, helping them make sense of the world and shape their cultures. Meanwhile, city densification, often seen as sustainable city growth and will make more sound sources and more people be closely related packed together, further increasing their noise exposure [11,12]. Consequently, living in rapidly urbanized areas does not constitute a consensus regarding sound implications. On the one side, such environments result in more negative health outcomes [13,14] and a further decrease in the quality of life of citizens [15]. Therefore, the emerged environmental noise issue in urban environments has become a significant threat. Traffic noise is the second most important cause of diseases' environmental burden in Western Europe, behind only air pollution by fine particulate matter [16].

On the other hand, living in the green and blue infrastructures introduce and provide more diverse sounds to urban life, particularly nature-related ones. For instance, some soundscapes can also positively mitigate noise problems [17–19]. Besides this benefit, the soundscapes also have other ecological and social values [20]. Natural soundscapes positively affect human health, and cultural soundscapes could be considered part of the cultural heritage [21]. Therefore, soundscape preservation should be considered in order to improve the urban sound environment. Some other projects were performed in specific small blocks, such as the national parks [22] or other nature reserves [23–25], historic city centers [26], and small villages [27].

However, the urban soundscapes in cities have their characteristics and internal relationship, additional studies on soundscape preservation from the perspective of city-level also need to be conducted to create more dynamic and vigorous cities.

1.2. Sounds and Green Infrastructure

The sound characteristics of urban parks and other green areas, which are the elements of the green infrastructure system in cities, are essential in the sound landscape quality of an urban environment. These areas, which have restorative effects on the physical and mental health of the urban residents, also improve the sound of the urban environment by preventing noise pollution in the environment depending on their scale and functions [28]. Especially the soil and vegetation texture, green roofs, and vertical gardens in the city absorb and reduce the noise [28]. Researchers who have examined the place and effects of sound in the landscape in recent years have determined that bird sounds are perceived as

relaxing, some natural sounds such as the sounds of tree leaves are expressed as calming and pleasing, and all these sounds evoke more positive feelings on people than anthropogenic sounds [8,20,29]. Understanding how sustainable and livable cities can be accomplished crucial to monitor how biodiversity responds to different urban green infrastructures. Greater efforts are allocated for monitoring the biodiversity and ecosystems supported by urban green infrastructure [30] so that a solid evidence base can inform urban planning decisions. The use of acoustic ecology as a method of quantifying ecological communities and their habitats has received increasing attention [31–34].

Various studies reported that acoustic indices have tended to focus on less disturbed environments than cities, where a positive relationship was reported between avian diversity and acoustic indices values along an urban-rural gradient. A range of sounds has been identified to affect acoustic indices, including road traffic, human speech, rain, and wind [34–36].

The soundscape is increasingly popular in landscape architecture, urban planning, environmental planning, and green management. Sound increasingly frequently contributes to positive or negative knowledge of various areas, and cohesiveness between sound and urban environments leads to a better assessment of green areas [28]. As such, the study aims to understand how different areas in the urban environment may affect the soundscapes of green and blue infrastructures.

2. Materials and Methods

2.1. Study Area

The study was conducted in a region that includes the cases of urbanized, rural and agricultural, and industrial zones to better understand the soundscapes of green and blue infrastructures along with one of the river mainstreams of Bursa city, Turkey. The selected part of the river is about 10 miles in length (Figure 1). Ayvalı Creek, one of the important branches of the Nilufer Stream in the urban context, is a stream of the Nilufer district. The creek collects the water of Cali and Kayapa Creek and, after passing the Ozluce canal, takes the name Ayvali Creek in the north of Ozluce village. Afterward, it passes through Cayirkoy Plain and pours into Nilufer Stream.
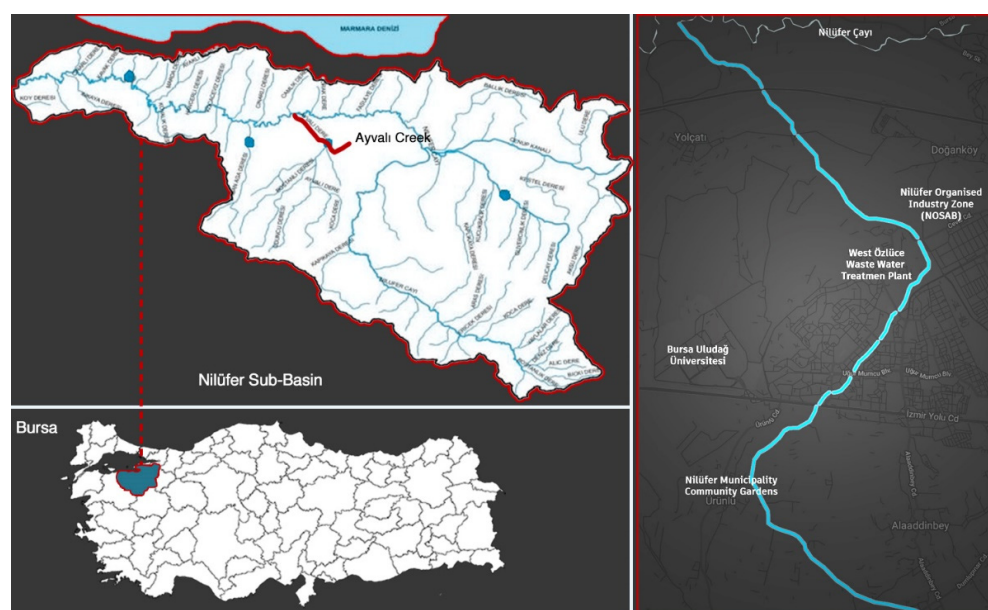

Figure 1. The study area.

2.2. Data Collection and Procedure

A total of 19 soundscape sampling and observation points were identified, and the reason for selecting those points was to establish the standardization of road intersections.

Three different criteria were taken into consideration for choosing these points; road and stream intersections, bridges (pedestrian/vehicle), and changing land use contexts. While the former was gathered from google earth, the latter was collected from the city data to define which areas are included in rural/agricultural, urban, and industrial.

Sound measurements were collected in those sampling points both weekdays and weekends at three different time intervals; morning, noon, and afternoon to capture the different sound patterns during days. Following ISO 1996-1: 2016 guidelines [37], the sound measurement procedure was performed using a PBX LXTI type I professional sound level meter. Sound levels were measured in decibels with dB(A) parameter by having 15 min (L_{eq}-15 min) on each point. Eventually, six key parameters were collected during sound sampling; LA_{eq} (A-weighted equivalent continuous sound level), LA_{min} (instantaneous minimum sound level), and LA_{max} (instantaneous maximum sound level) as well as percentiles of 10, 50, and 90 (LA_{10}, LA_{50}, LA_{90}).

For those 19 soundscape sampling points, nine were categorized as urbanized/developed areas, three were for industrial areas, and finally, seven of them were for rural/agricultural areas (Figure 2). Key characteristics of those locations for urbanized/developed areas include mainly high-rise apartments and recreational green and blue infrastructures. Looking at the industrial zones, various factories and related pollutants contribute to gray water for the blue infrastructure. Finally, rural/agricultural areas show different vegetable farms and gardening patterns adjacent to the green and blue infrastructures.
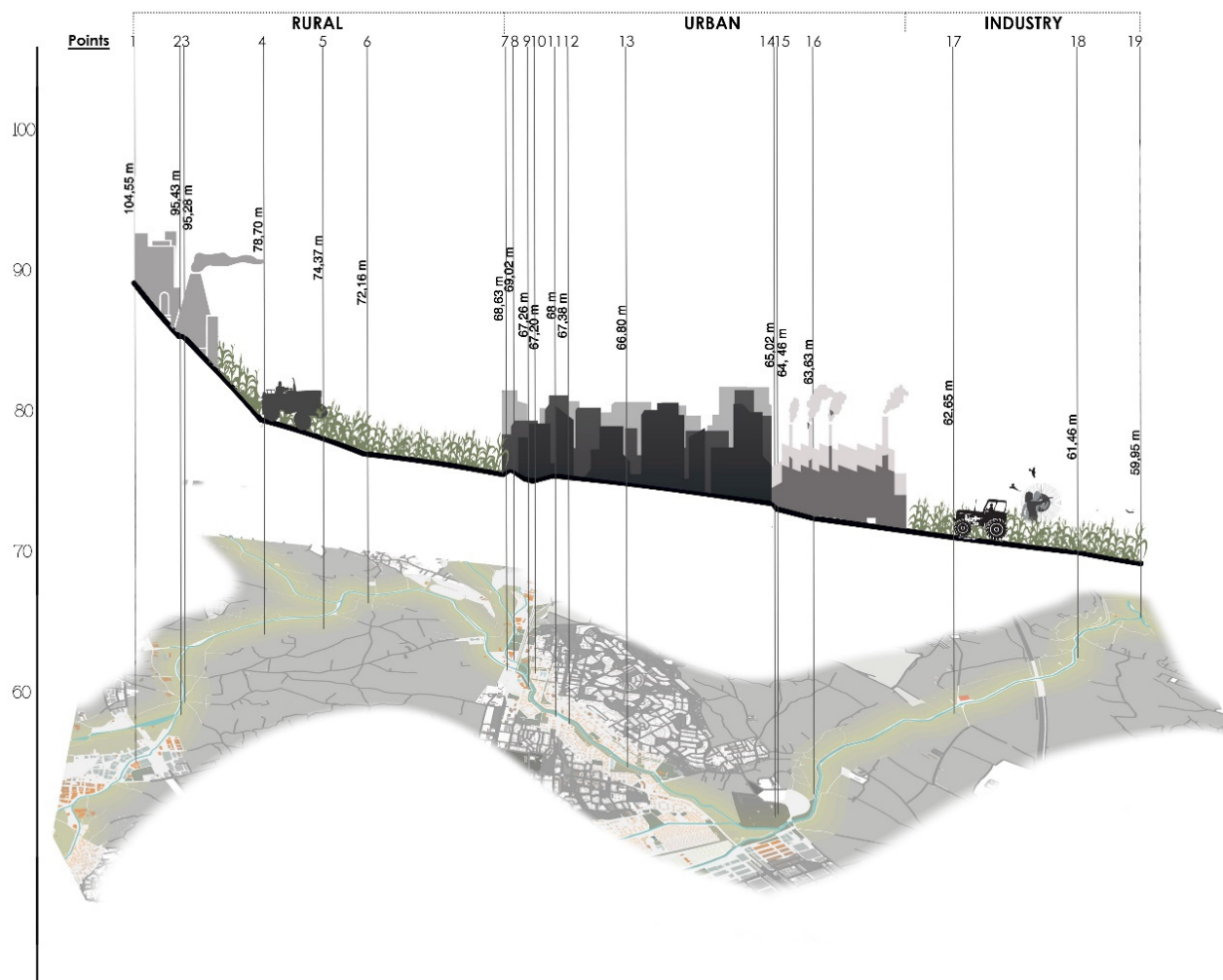
Figure 2. Three zones along with the green and blue infrastructure.

To examine the associations between time intervals, urbanized/industrial/rural areas, and sound, *t*-test and ANOVA (Analysis of Variance) tests were performed using the SPSS V.25.0 software. Descriptive statistics and statistical test results are discussed in the following sections.

3. Results

The study performed various quantitative analyses, and Table 1 provides descriptive statistics for sound measurements of each zone with various parameters, including STD (standard deviation), minimum, maximum, average values of LA_{min}, LA_{max}, LA_{eq}, LA_{10}, LA_{50}, and LA_{90}. Since the urbanized area includes nine sampling points, a total of 36 measurements (N = 36) were conducted both weekdays and weekends in the mornings and afternoons. It is followed by seven sampling points, a total of 28 sound samplings (N = 28), and four sampling points of a total of 12 measurements (N = 12) for the industrial zone.

Table 1. Descriptive statistics of sound measurements.

Zone	Measured Points	Lmin				LAeq				Lmax				L10				L50				L90			
		M	SD	Mn	Mx	M	SD	Mn	Mx	M	SD	Mn	Mx	M	SD	Mn	Mx	M	SD	Mn	Mx	M	SD	Mn	Mx
Rural (N:28)	P1–P7	45.1	6.87	31.2	58.0	58.6	4.39	45.3	65.0	71.3	3.80	61.9	78.8	60.2	4.11	48.7	66.4	55.3	4.51	44.1	63.9	50.8	5.57	36.0	61.3
Urban (N:36)	P8–P16	45.8	4.25	35.2	56.5	60.9	5.67	45.8	70.1	76.3	7.71	59.2	92.4	64.3	5.84	48.4	73.4	56.5	5.39	41.6	65.7	51.7	6.14	39.3	62.9
Industry (N:12)	P17–P19	44.4	5.89	35.7	53.1	59.8	3.78	53.6	63.7	75.3	5.73	66.9	81.0	61.9	3.78	56.6	67.0	56.4	4.14	49.5	61.2	50.4	4.62	41.9	56.3

Based on this, the urbanized zone includes the highest LA_{eq} sound levels with almost 61.0 dBA, and it is followed by industry and rural zones with 59.8 and 58.6 dBA, respectively. Notably, the sampling points adjacent to transportation features, i.e., wide lanes, intersections, etc., indicate higher sound levels. On the contrary, the lowest sound samplings occurred in rural zones, particularly near vegetable gardens with 52.7 dBA.

In addition, the sound range shows a different pattern, where urbanized areas show the greatest range with roughly 25 dBA (minimum is 45.8, and the maximum is 70.1), and it is followed by the rural zone that includes almost 20 dBA (the minimum is 45.3 and maximum is 65.0,) and the industrial zone has a 10 dBA range (the minimum is 53.6 and the maximum is 63.7). More specifically, as Figure 3 shows, the sound sampling points of urbanized areas include more sound levels variance than the other zones.
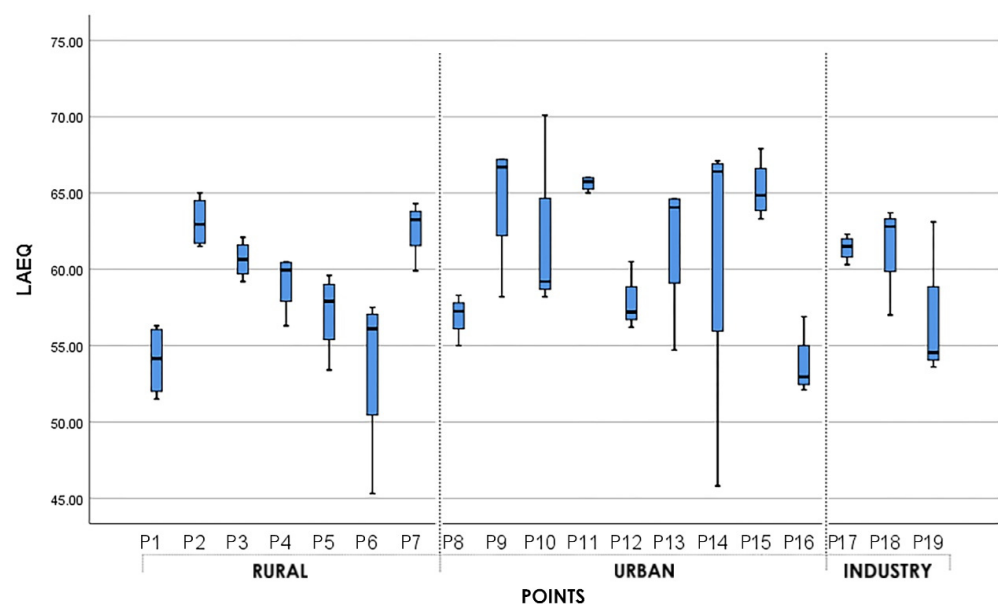
Figure 3. Sound range distribution of three zones.

Looking at the time intervals of the sounds, afternoon measurements are higher than morning ones in all sound parameters at about 0.7 to 2.5 dB(A) differences; however, there is no significant difference between morning and afternoon measurements. Moreover, time intervals in three zones show different patterns. Accordingly, afternoon measurements of the rural zone for the LA_{eq} parameter have the lowest sound levels at 58.1 dB(A), and it is followed by the morning measurements of the same zone at 59.1 dB(A). The highest measurements were recorded in the urbanized area for morning and afternoon measurements at 60.5 and 61.4 dB(A), respectively, while there is no significant difference. All other parameters show similar patterns, except LA_{10} and LA_{max} parameters, as they show significant differences at $p = 0.035$ and $p = 0.048$, respectively.

Beyond descriptive statistics, to determine whether there is a difference between urbanized, rural, and industrial zones, a one-way analysis of variance (ANOVA) with Tukey post hoc test was performed. The test results show no significant difference in mean LA_{min} sound levels $F(57,18) = 1.398$, $p = 0.219$ between within three zones. Additionally, there is no significant difference in mean LA_{10} sound levels $F(58,17) = 1.402$, $p = 0.223$, and LA_{90} sound levels $F(58,17) = 0.970$, $p = 0.559$. However, there is a significant difference in mean LA_{eq} sound levels $F(63,12) = 3.030$, $p = 0.019$ between the three zones. Similarly, there is a significant difference in mean LA_{max} sound levels $F(65,10) = 4.677$, $p = 0.006$. Additionally, there is a significant difference in mean LA_{50} sound levels $F(54,21) = 3.248$, $p = 0.002$. This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

4. Discussion

Sound measurements showed that overall there is a pattern among time intervals. This is in the same line with many other studies reported that there are more people and transportation activities that dominate the sound environment in afternoons compared to mornings [38–41].

Considering the sound sampling points, urbanized areas include the highest sound levels. Given this, some fauna and flora, whether they are in the protected status, are threatened by noise concerns. Urbanized areas are expected to include various anthropogenic factors to contribute such threats. From another point of view, there is also a lack of regulations and technical infrastructures. For instance, while the creek hosts various important bird and amphibian species, none of the noise monitoring or controlling infrastructures exist in any urbanized, rural, and industrial zones. On top of that, there is no sound or noise-related policy or regulation approach to protect fauna and flora and guidance for residents of urbanized areas, workers and farmers of the rural zone, and workers and laborers of the industrial zone. These are the shreds of evidence that sound-related zoning ordinances are imperative for susceptible areas to regulate both anthropogenic and natural sounds. To do this, as the study recognized, urbanized and industrial zones should be mainly considered as these areas may include species richness [39]. As suggested regulations based on other countries, plant design with dense trees and bushes help reduce excessive sound levels [42–44]. Considering the thick body of tree species, i.e., poplar and maple, strategic urban infrastructure design might be implemented accordingly. Furthermore, some buffer zones may offer 8–10 dB(A) noise reduction, and it might be considered in locations adjacent to potential noisy areas, i.e., highways and factories. On the other hand, introducing green infrastructures that host various animal species, particularly birds, may attract people to prefer recreating and using such environments by desirable sounds. Additionally, such areas may offer some "quiet" environments that people prefer to be in [45,46].

While there are spatial and temporal effects as well as different zones along the green and blue infrastructure, the sound levels are not at the levels that threaten the residents, fauna, and flora of the surrounding area. Therefore, green and blue infrastructure somehow keeps the sound levels at 70 dB(A) and mainly around 60 dB(A). Therefore, green and

blue infrastructure also contribute to creating sound-friendly environments besides their environmental and economic benefits. Beyond some other studies that already reported that residents in urban areas are annoyed more than rural areas [47], this study also confirms that urban areas include the highest sound levels from in situ sound sampling. On the other hand, as a limitation of the study, an audio-visual-based engagement of residents could better understand the restorative context of the acoustic environments.

5. Summary and Conclusions

This study assessed the sounds of three key zones—urbanized, rural, and industrial—along with green and blue infrastructures. Temporal and spatial examinations of sound levels are recorded to be essentially affected by those attributes. Afternoons are more noisy, and urbanized areas include higher sound levels. However, there are small changes in the zones, as sound is a part of daily life no matter what urban areas are examined [23].

While green and blue infrastructure absorbs the higher sound levels, there are still various strategies to protect residence, fauna, and flora from noise implications. First and foremost, sound-related strategies should be adopted based on the different areas by considering the attributes and risks within such zones. In addition, any anthropogenic impact, including transportation, urbanization process, etc., should also include the noise and sound effects, particularly along with the green and blue infrastructure. Furthermore, green and blue infrastructures may contribute more pleasant soundscapes with urban design and planning approaches. As such, the route and depth of blue infrastructure may create a soundscape "oasis" by masking noise and creating a pleasant acoustic environment within dense urban areas. This approach might be supported by the green infrastructure components in certain locations. Therefore, it is also vital to categorize and implement appropriate green and blue infrastructures based on their sound implications. For instance, regulatory aspects of different green infrastructures, i.e., river zones, green corridors, should be prioritized holistically. By doing this does not only create a pleasant sound environment for residents, but also preserve fauna and flora species from noise pressures. Last but not least, this approach may establish a well-designated platform between residents, local officials, city managers, and designers.

The study is subject to some limitations. The study method included only quantitative techniques, and such a method might involve calibration and technical concerns of the sound level meter even though particular calibration was conducted. Furthermore, the study may suffer from generalizability concerns as various built and natural environment attributes affect sound levels at different stakes. Nonetheless, the study aimed to contribute the sound and environmental aspects of green and blue infrastructures that eminently engage with sounds. Studies may attempt to identify the key variables to understand how they affect sound levels as a future direction. Furthermore, since soundscape is also about people's attitude, having residents' and visitors' preferences of sounds on green and blue infrastructure.

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