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Assessment of acoustic climate and traffic noise pollution: A case study

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ABSTRACT

Lublin, like many large cities, faces the problem of environmental pollution caused by noise and a steadily deteriorating acoustic climate. This study aimed to assess the acoustic climate and environmental pollution caused by traffic noise in Lublin in four selected locations near universities: the John Paul II Catholic University of Lublin (KUL), Maria Curie-Skłodowska University (UMCS), University of Life Sciences (UP), and Lublin University of Technology (PL). The study measured an indicator of environmental noise pollution – the equivalent sound level (L_{Aeq}) – used to evaluate the acoustic climate. The acoustic conditions identified during the study were unfavourable, with moderate noise hazards, and noise was found to be moderately or highly disruptive. Excessive daytime noise was identified in location 2 (UMCS), location 3 (UP), and location 4 (PL). Given the high pedestrian traffic in location 3 (UP), actions to improve acoustic comfort should be considered in this area. Meanwhile, the highest noise levels were identified in location 4 (PL), which also requires protection from traffic noise.

Keywords: traffic noise pollution, acoustic climate, Lublin.

INTRODUCTION

The development of civilization and progressive urbanization have resulted in increasing environmental noise. Initially, this type of pollution was not controlled to the same extent as other environmental pollutants (Murphy & King, 2022). However, as more literature linking environmental noise to adverse health effects emerged, this problem began to gain attention. Once referred to as the "forgotten pollutant", environmental noise is now recognized as a public health issue that must be addressed in modern society (King, 2022). Noise is considered one of the most disruptive environmental factors, affecting people's quality of life and their health. Its impact is now more pervasive and significant than ever before, and it is expected to grow in scale and severity due to population growth, urban development, and the increasing use of robust, diverse, and mobile noise sources. Noise leads to direct and cumulative adverse effects, impairing health and degrading the environment in which people live, work, and socialize, causing both economic and intangible losses (Jariwala et al., 2017). Noise is defined as any sound that, under certain conditions, is undesirable, disruptive, or harmful. The nuisance caused by noise depends on its intensity, frequency, duration, and inaudible components, as well as human factors such as health status, age, psychological condition, and individual sensitivity to sound (Wieszała & Gajdzik, 2011).

In Poland, the primary legal act governing environmental protection, including the acoustic climate, is The Act of Environmental Protection Law of April 27, 2001 (Dz.U. 2001.62.627). It defines noise as sounds with frequencies from 16 Hz to 16,000 Hz, the range audible to the human ear, regardless of the source or duration. According to the European Parliament's Framework Directive on the Assessment and Management of Environmental Noise from 2002 (2002/49/EC), noise is unwanted or harmful sounds generated by human activity outdoors, including noise from road, rail, and air traffic, as well as industrial sources. Other definitions of noise emphasize its nuisance (Magiera, 2021), disruptiveness and harmfulness (Augustyńska et al., 2000; Leśnikowska-Matusiak & Wnuk, 2014).

Economic development, urbanization, and the growth of motorized transport are among the main factors causing environmental noise hazards (Héroux et al., 2015). Alongside $PM_{2.5}$, lead, and benzene, noise is one of the most significant environmental stressors generated by transportation, leading to health burdens and public health risks (Tainio, 2015). Road transport is the most important cause of environmental noise and air pollution (Safaee & Nematipour, 2021). The primary noise sources from vehicles include engine work, the operation of powertrains, the interaction of tires with the road surface, and aerodynamic noise (Merkisz et al., 2005). In urban environments, noise is omnipresent, and the availability of areas providing acoustic comfort is steadily decreasing (Basner et al., 2014). According to the World Health Organization (2011), road traffic noise is Europe's second most harmful environmental factor after air pollution, significantly reducing quality of life and public health. Traffic noise is characterized by the time-dependent variability of its influencing factors, such as weather conditions, the structure and speed of moving vehicles, traffic flow parameters, and the propagation conditions of sound in adjacent areas (Benocci et al., 2020; Margaritis et al., 2018). Most monitoring and modelling studies focus on road traffic noise (Alam et al., 2020).

Public awareness of the risks of noise pollution is low, primarily due to a lack of knowledge about the health effects of excessive, prolonged noise exposure (Leśnikowska-Matusiak & Wnuk, 2014). Noise's harmfulness stems mainly from the stress response it induces in the human body, which can also occur during sleep. Noise can cause irritation, impair cognitive functions, disrupt sleep (Dzhambov & Dimitrova, 2014), and lead to hypertension, cardiovascular diseases, and even premature death (Babisch et al., 2005; Öhrström, 2004). In large urban areas, the impact of noise has become particularly disruptive due to growing urbanization. Road traffic noise, one of the most pervasive noise categories, significantly shapes the acoustic climate of the environment (Paszkowski, 2015). Noise levels on roads often range from 55 to 65 dB, and prolonged exposure to noise of this intensity harms human health, triggering stress responses (Okokon et al., 2015). Chronic exposure to 65–80 dB noise levels can lead to hearing impairment (Stansfeld et al., 2000).

The acoustic climate is closely related to the functional use of an area, which is shaped by human activity (Han et al., 2018). A study of noise levels in educational buildings at the Białystok University of Technology and the Warsaw University of Life Sciences found that acoustic comfort requirements were met, and external noise levels did not affect indoor noise levels. However, both universities are located in green areas, far from sources of urban noise (Wiater & Gładyszewska-Fiedoruk, 2024). The dynamic growth of transport, especially road transport, has a dominant influence on the acoustic climate. In today's urbanized environment, where noise is pervasive, acoustic design is essential in spatial planning and urban development (Bernat, 2015).

Like many large cities, Lublin struggles with environmental noise pollution and a steadily worsening acoustic climate (Khomenko et al., 2022; Rymarz et al., 2012). This applies primarily to areas near roads with high traffic volume, areas around railway lines, and industrial zones. Spatial and temporal variations in acoustic phenomena have been observed throughout the city (Zubala & Sadurska, 2016).

An analysis of Lublin's strategic noise maps [https://geoportal.lublin.eu] indicates that road traffic is the city's most significant source of noise, both day and night. Noise imission maps depict the noise intensity reaching recipients. Depending on the chosen method, results are modelled rather than measured (Joachimowicz & Nieścioruk, 2018).

The aim of this study was to assess the acoustic climate and environmental noise pollution caused by traffic in four selected locations near public universities in Lublin: the John Paul II Catholic University of Lublin (KUL), Maria Curie-Skłodowska University (UMCS), University of Life Sciences (UP), and Lublin University of Technology (PL). The study focused on pedestrian pathways used by students moving between buildings or public transport stops, which are also important urban communication routes. Vehicle and pedestrian traffic intensity was also examined to correlate noise emission with traffic intensity and identify the number of people potentially exposed to elevated environmental noise levels (students, university staff, and nearby residents).

METHODOLOGY

Study area characteristics

Lublin is the largest city in eastern Poland and one of the largest in the country. It serves as the regional capital and a university hub with significant academic potential. Approximately 60,000 students attend its five public and four non-public higher education institutions. The city's population is 339,700 (https://student.lublin.eu). Four locations near public universities in the central part of Lublin were chosen for the study due to their exposure to road traffic noise. The measurement points were as follows:

- location 1 – KUL: The intersection of Aleje Racławickie and Hieronima Łopacińskiego Street, near the John Paul II Catholic University of Lublin;
- location 2 – UMCS: The intersection of Józefa Sowińskiego and Idziego Radziszewskiego Streets, near Maria Curie-Skłodowska University;
- location 3 – UP: The intersection of Głęboka and Rektora Henryka Raabego Streets, near the University of Life Sciences;
- location 4 – PL: Nadbystrzycka Street, near the Faculty of Mechanical Engineering at the Lublin University of Technology.

Measurement of equivalent sound level

In the selected locations, the equivalent sound level (L_{Aeq}) was measured to assess the state of environmental noise pollution. L_{Aeq} evaluates the acoustic climate over a 24-hour period and is not tied to long-term policy goals. It is the primary numerical parameter used to describe acoustic conditions, representing noise exposure levels. The direct measurement method was employed as it accurately reflects the acoustic climate, assuming that sound propagation is unaffected by disturbances such as terrain changes or building structures. Measurements were conducted using direct sampling methods, with one hour's reference period (T). Short-term traffic noise measurements were taken during the daytime (D) and nighttime (N) for weekdays and weekends. A microphone was placed 7.5 metres from the road axis, at a height of 1.2 metres, perpendicular to the axis of passing vehicles. Weather conditions included temperatures above 5°C, wind speeds below 5 $m \cdot s^{-1}$, and no precipitation, ensuring dry road surfaces. The noise measurements were conducted using a Class 1 sound level meter (SVAN 958, Svantek, Poland). The equipment included a microphone cable (10 m), preamplifier, 1/2-inch measurement microphone, windscreen, tripod, calibrator (1,000 Hz, 114 dB), and measuring tape. This device is designed to perform, among others, acoustic measurements and monitor noise in the environment. The settings were: signal measurement time – 15 minutes, A-weighted frequency correction, FAST time weighting, measurement range: 110 dB, integration time: 1 second.

The measurement results were averaged over one hour using the following formula:

$$L_{Aeq(mean)} = 10\log\left(\frac{1}{n}\sum_{i=1}^{n} 10^{0.1L_{Aeq\,T}}\right) \quad (1)$$

where: $L_{Aeq\ (mean)}$ – average equivalent sound level for the data set, n – number of samples (data points) used in the calculation, $L_{Aeq}\ T$ – equivalent sound level for a given sample.

The standard deviation was calculated using the following formula (Perzyński et al., 2019):

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(L_{AeqT} - L_{AeqT(mean)}\right)^2} \quad (2)$$

Measurement of vehicle and pedestrian traffic intensity

During noise level measurements, vehicle and pedestrian traffic intensity was also recorded. Vehicle counts included all vehicles passing through the road section, regardless of direction. Similarly, the number of pedestrians was counted on both sides of the road during the measurement period.

RESULT AND DISCUSSION

Vehicle and pedestrian traffic intensity results

The traffic intensity of vehicles and pedestrians was also measured during the noise intensity measurements. The results are presented in Tables 1 and 2. Traffic intensity is a crucial factor influencing noise levels (AlyAldin et al., 2024; Lu et al., 2019). Daytime traffic exceeded 1,000 vehicles per hour in all surveyed locations during weekdays and weekends. Nighttime traffic was significantly lower, averaging about 200 vehicles per hour.Pedestrian traffic does not directly

Table 1. Hourly vehicle traffic intensity in the analyzed locations

Location	Hourly vehicle traffic intensity [vehicles per hour]			
	Weekdays		Weekends	
	Daytime	Nighttime	Daytime	Nighttime
1 - KUL	1354	234	1084	200
2 - UMCS	1512	252	1180	164
3 - UP	1414	228	1276	124
4 - PL	1268	232	1106	148

Table 2. Hourly pedestrian traffic intensity in the analyzed locations

Location	Hourly pedestrian traffic intensity [people per hour]			
	Weekdays		Weekends	
	Daytime	Nighttime	Daytime	Nighttime
1 - KUL	538	132	260	114
2 - UMCS	320	181	64	108
3 - UP	411	48	32	20
4 - PL	226	80	76	45

contribute to increased road noise but helps estimate the number of individuals exposed to excessive noise levels. The highest pedestrian traffic during daytime was observed at location 1 – KUL, likely due to two nearby bus stops servicing approximately 120 buses and trolleybuses per hour. Other streets experienced three times fewer buses and significantly less pedestrian traffic. Daytime exposure to excessive traffic noise on weekdays affected approximately 200–400 individuals, with the highest number at UP (location 3). The heaviest pedestrian traffic was observed at location 1 - KUL; however, the noise level was not excessive by the applicable regulations.

Noise immission results

Results of the equivalent noise level measurements for the studied locations are presented in Table 3. Variations in acoustic climate were observed based on the time and the weekdays/weekends. Weekdays' highest daytime noise levels were recorded at location 3 – UP and location 4 – PL. This could be attributed to topographical factors. For example, near UP, Rektora Henryka Raabego Street slopes upward from Głęboka Street. Vehicles turning onto this street often maintain high engine revolutions in low gear to drive uphill, which increases traffic noise levels in this area. In the vicinity of location 4 – PL, urban infrastructure – characterized by densely packed buildings near the roadway and a shortage of open spaces – can negatively impact recorded noise levels. The lowest daytime noise levels were observed at location 2 – UMCS, which features a small park and three pedestrian crossings near the intersection. These elements help to reduce vehicle speeds.

Table 3. Results of equivalent noise level measurements in the studied locations

Location	Equivalent sound level L_{Aeq} [dB]							
	Weekdays				Weekends			
	Daytime	σ	Nighttime	σ	Daytime	σ	Nighttime	σ
1 - KUL	63.6	1.4	57.7	1.0	60.7	1.3	55.9	0.9
2 - UMCS	62.0	1.6	56.0	0.8	59.3	1.5	54.4	0.6
3 - UP	66.6	1.4	56.4	0.9	64.4	1.2	53.4	0.5
4 - PL	67.1	1.7	59.1	1.1	64.6	1.6	55.7	1.0

Most of the studied locations are designated for the permanent or temporary presence of children and young people, subject to acoustic protection. Only location 1 – KUL is in a city centre area (for cities with populations over 100,000). Different permissible noise levels apply to these areas depending on their function. Obtained research results of traffic noise levels were compared with the permissible levels defined in Polish regulations (Dz.U. 2014.112) for daytime (16-hour period – L_{AeqD}) and nighttime (8-hour period – L_{AeqN}). L_{AeqD} and L_{AeqN} are short-term indicators referring to 24 hours. For areas designated for the presence of children and young people, the permissible daytime noise level is 61 dB, while the nighttime level is 56 dB. However, since these areas are not used for their intended purpose at night, nighttime limits do not apply. For city centre areas with populations over 100,000, the permissible noise levels are 68 dB during the day and 60 dB at night. In most studied locations, daytime noise levels (weekdays and weekends) exceeded the permissible values. No exceedances were observed at location 1 – KUL, where the higher permissible levels for city centre areas applied. Moreover, no noise levels exceeding permissible levels were recorded at night.

However, in comparison with the threshold noise levels in the environment (Dz.U. 2002.8.81), the noise level should not exceed, respectively, for the day and night: 65 dB and 60 dB in development areas associated with the permanent or long-term stay of children and adolescents and 75 dB and 67 dB in residential development areas. This criterion is used to assess noise in the environment and was exceeded in location 3 – UP and location 4 – PL during the day (on a working day by 1–2 dB), which indicates that these areas may be at risk of excessive noise. It should also be remembered that the values provided for in legal acts (Dz.U. 2014.112; Dz.U. 2002.8.81) refer to the entire day (16 hours of day and 8 hours of night), and the obtained results of the tests of the equivalent environmental noise level are a sample, for a reference time of 1 hour. Nevertheless, comparing these values allows us to indicate areas potentially at risk of excessive noise. In the remaining regions studied, the level of traffic noise was at an acceptable level. Nevertheless, the L_{Aeq} indicator was only a few decibels lower than the limit value of the permissible noise level in the environment during the day (0.5–2 dB) and at night (4–5 dB). There are also opinions that the requirements contained in Polish legal acts do not provide adequate protection of the environment from noise and do not correspond to EU regulations on the assessment and management of noise levels in the environment. They are too mild, which may expose people to noise that harms their health (Poniatowski, 2022).

While nighttime noise levels did not exceed permissible limits, the measured values – particularly on weekdays – are concerning. Similar issues have been observed in other cities, such as Bielsko-Biała, where nighttime noise levels have risen (Vaverková et al., 2021). According to WHO guidelines (Hurtley, 2009), nighttime noise levels above 55 dB are considered hazardous to public health, leading to adverse health effects, significant irritation, and sleep disturbances for many of the population. Evidence also links road traffic noise above 65 dB with an increased risk of cardiovascular diseases (Kupcikova et al., 2021).

Under Directive 2002/49/EC, EU member states must monitor environmental noise and take preventive measures to minimize its adverse effects. Strategic noise maps (SMA) are developed for urban areas with populations over 100,000. Based on long-term indicators, these maps provide an overview of noise exposure throughout the year. They are recommended by WHO and play a key role in assessing the health impact of noise. Therefore, these maps were included in the discussion to provide a complete picture of the threats. Selected study locations in Lublin were analyzed against the 2022 strategic noise map for the daytime-evening-night period (L_{DEN}). The map (Fig 1.) revealed 1–5 dB exceedances in location 4 (PL), which also recorded the highest equivalent noise levels during field measurements. The L_{DEN} values presented in Figure 1. referred to the recommendations included in the position of the European Commission on the impact of transport noise on irritation (European Commission, 2002) indicate that the highest percentage of people annoyed (A) or highly annoyed (HA) by road noise occurs in location 1 – KUL and location 4 – PL, it is 36% (A) and 16% (HA) respectively, where the noise level is 65-69.9 dB. Therefore, the noise irritation descriptor is over 50%. In the vicinity of UMCS, this percentage is the lowest, 18% (A) and 6% (HA) and concerns a lower noise level in the range of 55–59.9 dB. In assessing the acoustic condition of the environment, an auxiliary scale is used in relation to the criteria resulting from legal regulations relating to acoustic comfort (Table 4).

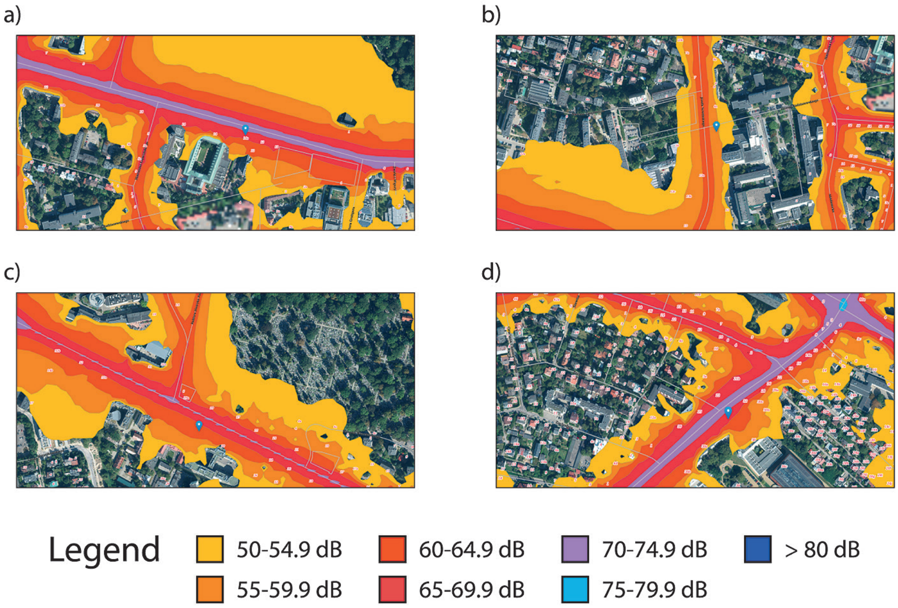

Figure 1. Locations selected for research against the Strategic acoustic map of road noise emissions for the day-evening-night time LDEN in 2022: (a) location 1 – KUL; (b) location 2 – UMCS; (c) location 3 – UP; (d) location 4 – PL; (https://geoportal.lublin.eu)

The classification of noise nuisance is based on surveys and was developed by the National Institute of Hygiene (NIH) based on research.

Across almost all studied locations, daytime acoustic conditions indicated a moderate noise hazard (60–70 dB) and nighttime conditions indicated a moderate hazard (50–60 dB). This suggests unfavourable acoustic conditions. Even if moderate, prolonged exposure to elevated noise levels is as harmful as short-term exposure to high-intensity noise. Considering subjective sensitivity to noise and the acoustic comfort scale, the noise nuisance across all studied locations was rated as significant. Subjective sensitivity to noise significantly influences the relationship between individuals and acoustic conditions (Table 5). A change in sound by 3 dB corresponds to a doubling of the sound pressure at which a person begins to experience differences in the noise they hear (Leśnikowska-Matusiak and Wnuk, 2014).

In summary, the acoustic conditions in the studied locations were unfavourable, with a moderate noise hazard and noise levels rated as significant or significant nuisances. The World Health Organization recommends that environmental noise levels not exceed 55 dB during the day and 40 dB at night (WHO, 2018). Exceeding these limits can lead to health problems such as sleep disturbances, stress, and, over time, cardiovascular diseases. Approximately 40% of the EU population is exposed to daytime noise levels above 55 dB, while 20% is exposed to noise levels exceeding 65 dB (Hänninen et al., 2014, https://europa.eu/european-union/about-eu/agencies/eea_pl).

Numerous studies confirm not only the link between exposure to noise from various sources and its health effects on humans (Basner et al., 2014; Münzel et al., 2021) but also a decrease in cognitive function. A comparative analysis of individuals living in noisy city areas (L_{Aeq} > 70 dB)

Table 4. Acoustic comfort and noise hazard levels (Szyszlak-Bargłowicz et al., 2012; Pietrzak et al., 2018, based on NIH data)

Acoustic conditions	Noise level [dB]	
	Daytime	Nighttime
Full acoustic comfort	<50	<40
Average acoustic conditions	50–60	40–50
Moderate noise hazard	60–70	50–60
High noise hazard	>70	>60

Table 5. Traffic noise nuisance assessments scale* (Koszarny & Szata, 1987) and noise pollution assessment scale for urban areas** (Lopatin, 2020)

Noise nuisance level	L_{Aeq} [dB]*	L_{Aeq} [dB]**
Low	< 52	35–50
Moderate	52–62	51–60
High	63–70	61–70
Very high	> 70	> 70

and those residing in areas with moderate noise levels (L_{Aeq} < 57 dB) revealed significant differences in health and well-being. High-intensity traffic noise causes a sense of specific psychological pressure induced by noise, discomfort, and annoyance, as well as a more frequent need for painkillers and sleep aids (Koszarny, 2001). Cognitive abilities influence not only academic achievement but also mental health and overall well-being (Thompson et al., 2022). Moreover, the perception of noise burden is subjective and constitutes an individual assessment of sound characteristics (Buckers et al., 2012; Park & Siebein, 2012). Therefore, there is a need to include subjective assessments of acoustic comfort and traffic noise annoyance in appropriate methodologies for future studies. However, noise annoyance is not explicitly defined; it is considered an indicator of environmental well-being or a symptom of future health effects caused by noise (Ouis, 2001). Noise annoyance is a subjective reaction to exposure and is not entirely explained by environmental acoustics (Waye & Öhrström, 2002). Chiarini et al. (2020) examined discrepancies between subjectively perceived noise exposure and objective pollution and concluded that an individual's sensitivity and awareness of environmental issues related to the threshold of subjective acceptance are crucial. Institutional features, environmental regulations, and cultural and psychological aspects influence this acceptance.

Actions aimed at reducing noise should consider location-specific factors influencing annoyance, as this can increase public support for such initiatives and, consequently, enhance success rates (Okokon et al., 2015). Vegetation near roads, open spaces, and proper spatial arrangements of buildings can mitigate the negative perception of road noise and support sustainable urban development (Yuan et al., 2019). Among the many methods of reducing environmental noise, those that do not impair landscape values, such as quiet pavements, speed limits, and weight restrictions, enjoy the greatest public acceptance. Although it is not always possible to reduce noise levels to threshold values, any reduction in road noise generation that is perceptible to people improves the acoustic climate. A measurable decrease in road noise improves the subjective opinion on changes in acoustic impact caused by traffic and enhances living comfort. An average noise reduction of approximately 3 dB is sufficient to notice an improvement in the acoustic climate (Wrótny et al., 2022).

CONCLUSIONS

One of the European Commission's goals is to reduce the number of people chronically disturbed by road noise by 30% by 2030 compared to 2017. However, according to the European Environment Agency (EEA), achieving this goal is unlikely (https://www.eea.europa.eu, https://www.teraz-srodowisko.pl). The European Parliament has repeatedly emphasized the need to lower threshold values further for environmental noise levels and improve measurement procedures. It also approved the gradual introduction of new, lower noise emission limits for passenger cars.

Road noise is the strongest factor shaping the acoustic climate of the environment and one of the most bothersome types of noise. The acoustic condition of the environment can be improved through spatial planning instruments (permits) and environmental protection instruments (noise protection programs, acoustic barriers). These should always be considered individually, and ecological effectiveness, which does not require achieving absolute effects leading to permissible sound levels, should be applied.

The study's results shed light on locations in Lublin that require prioritization and direction of actions to reduce excessive noise levels and minimize its annoyance. The acoustic conditions found in the study were unfavourable, the noise hazard was average, and the noise was moderate to highly annoying. Daytime noise levels above standards were observed near Maria Curie-Skłodowska University, University of Life Sciences and Lublin University of Technology. Considering the high pedestrian traffic in the vicinity of the University of Life Sciences, it is worth implementing measures to improve acoustic comfort in this area. The highest noise level was observed near the Lublin University of Technology, which also requires protection from traffic noise. The results indicate a need for further in-depth studies in this area. To expand knowledge in this area, it would be helpful to consider describing the soundscape using competing sound indicators to counteract the potential adverse effects of noise on health and quality of life. It is necessary to consider not only the noise level but also its frequency characteristics, tone, continuity, duration, and source of origin.

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