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Assessment of Annoyance of Traffic Noise Based on Residents' Subjective Evaluations and Actual Noise Measurements in Environment

Abstract: The aim of the article is to assess the traffic noise on one of the main streets in the city of Poznań. The authors chose to discuss the topic of evaluating the impact of the sound phenomena that is generated by vehicles in urbanized areas. This decision resulted from the fact that approximately 20% of the EU population live in places where permissible noise levels are exceeded – both during the day and at night. The selected street for the study is precisely such a location; it is characterized by a very high volume of vehicle traffic throughout the day (a road that leads out of the city toward Warsaw) and residential buildings close to it. The research involved residents' subjective assessments of noise as well as actual noise measurements. The survey addressed issues that were mainly related to residents' perceptions of the sound phenomena on the street, while the second stage of the research focused on actual noise measurements. A 24-hour measurement of noise and traffic intensity was conducted on the selected street. The results that were obtained in this way allowed for an assessment of the acoustic climate considering applicable regulations and the residents' experiences. The experimental studies showed that, on Warszawska Street, the equivalent sound levels exceed 71 dB during the day and 68 dB at night. In the survey, 33% of the respondents indicated that living on this street was bothersome due to the noise, with it being most disruptive during the night hours (10:00 p.m.–6:00 a.m.) according to 26% of the responses, and between 12:00 noon and 6:00 p.m. according to 31% of the responses.

Keywords: traffic noise, survey research, traffic intensity, noise measurements

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1. Introduction

Traffic noise is considered to be one of the main factors that negatively impact the environment. It is estimated that, in the European Union, approximately 20% of the population live in areas where permissible levels of traffic noise are exceeded – both during the day and at night. Analyses of strategic noise maps that were conducted in 28 European Union countries in 2017 showed that the number of people who were exposed to sound levels that exceeded 55 dB in terms of L_{DEN} were as follows: for road transport – 113 million people; for rail transport – 22 million people; and for air transport – 4 million people [1, 2].

Taking the L_N indicator into account (50 dB), the number of people that were at risk were as follows: for road transport – 78 million; for rail transport – 17 million; and for air transport – 1.5 million [1, 2]. Most of the people that were exposed to high levels of noise lived in urban areas. Among the individual sources of traffic noise in the environment, road transport can be considered to be the most widespread and dominant one, followed by railway and aircraft noise. According to the provisions of the European Union Directive on the Assessment and Management of Environmental Noise [3], aircraft noise is defined as the noise that is caused by aircraft landings and take-offs in areas around airports. This affects a smaller part of the population than road and railway noise does, but it is considered to be more annoying than the noise from land-based transportation [1].

The noise levels that are generated by individual means of transport are generally too low to cause hearing damage; however, prolonged exposure to sounds that are above a certain level can lead to so-called non-auditory health effects, such as irritation and sleep disturbances [4–8], negative impacts on the cardiovascular and metabolic systems [9], and impaired cognitive functions in children [1, 10]. Studies on the subjective assessment of the sound phenomena that are related to traffic noise (road, rail, and air) have been conducted in many countries worldwide, including Switzerland [4, 9], France [11], Germany [5, 6], Canada [8], and China [12, 13], among others. These studies were based on linking research that was conducted directly on people who were exposed to noise in laboratories; e.g., by measuring their blood pressure levels and, heart rates, conducting sleep-disturbance studies (polysomnography), or conducting listening tests with analyses of actual sound measurements that were obtained in the environment based on various sound parameters such as the following: equivalent continuous sound pressure levels (L_{Aeq}); day-evening-night noise indicators (L_{DEN}); night-time noise indicators (L_N); spectral analyses; and psychoacoustic parameters (loudness, roughness, fluctuations, and sharpness). The complexity of conducting such interdisciplinary studies makes developing models of human annoyance to traffic noise a complex scientific problem that has yet to be fully solved. The studies that have been conducted so far have shown that aircraft noise is the most disturbing factor in the environment, followed by road and railway noise.

In addition to the studies on the subjective impact of traffic noise on people, noise-monitoring studies that are related to assessing transportation's impact on the environment have also been conducted. Their objective has been to evaluate the acoustic climate that is prevalent in each area [14–17], to prepare acoustic maps of large cities and major transportation routes [18–20], or to model transportation noise [21, 22]. In the context of modeling road traffic noise in cities, several models can be identified that can indicate residents' exposures to noise based on measured instantaneous sound levels [23] or spatio-temporal noise distribution [24]. Additionally, a regression model for road traffic noise has been developed, that allows for noise prediction without the need of field measurements [25]. There is also a system that is based on deep learning that enables a correlation of road traffic noise with traffic volume [26], as well as the creation of new online software that includes integrated data-management and generates a three-dimensional noise prediction model for a more accurate and realistic analysis of traffic noise's impact on the environment [27]. Another aspect of the negative impact of road traffic noise on the environment is the issue that is related to the decreases in the values of residential properties that are located in those areas with high traffic volumes. By using hedonic regression in Vienna, Austria, it was confirmed that noise that exceeded 65 dB could lead to reductions in property prices [28].

The aim of this article was to assess the acoustic climate on one of the main streets of the city of Poznań (Warszawska Street) based on survey research that was conducted among the people who lived on the discussed street as well as actual 24-hour noise and traffic-intensity measurements. The objective of the conducted studies was to compare the residents' subjective perceptions with the actual noise measurements. While bringing undeniable economic benefits, the rapid developments of cities, industry, transportation networks, and airports have also introduced several negative phenomena; one of these is increases in the emissions and spread of traffic and industrial noise in urban areas. Noise emissions in urban areas have now reached such high levels that the suitability of these areas for their intended purposes has significantly diminished.

An example of this is Warszawska Street in Poznań. On the one hand, this is a location where residential buildings that are, inhabited by people, are situated close to the roadway. On the other hand, it is one of the city's main traffic routes, with approximately 3,000 vehicles passing per hour during the day (6:00 a.m.–10:00 p.m.) and about 800 vehicles per hour during the night (10:00 p.m.–6:00 a.m.), with a speed limit of 70 km/h [29].

2. Method

The subject of the noise study was Warszawska Street in Poznań; it is a two-way street with two lanes of traffic in each direction that are separated by a dedicated tram track that runs through the middle of the street and then alongside the street. This street is one of the main arterial roads of the city of Poznań, serving as an alternative route to the A2 motorway toward Września and Warsaw (National Road No. 92) and classified as GP (a main road with accelerated traffic). The speed limit on this street is 70 km/h; its length from Środka Roundabout to Bałtycka Street (Antoninek Bridge) is approximately 5 km. Residential buildings are located along a stretch of about 3 km between Środka Roundabout and Mogileńska Street; these consist of 3-, 4-, and 11-story blocks of flats, detached houses, allotment gardens, and recreational areas. Figure 1 shows a map of the location of Warszawska Street in Poznań, with the noise measurement point marked. Additionally, an ellipse highlights the area where most of the residential buildings on this street are located.

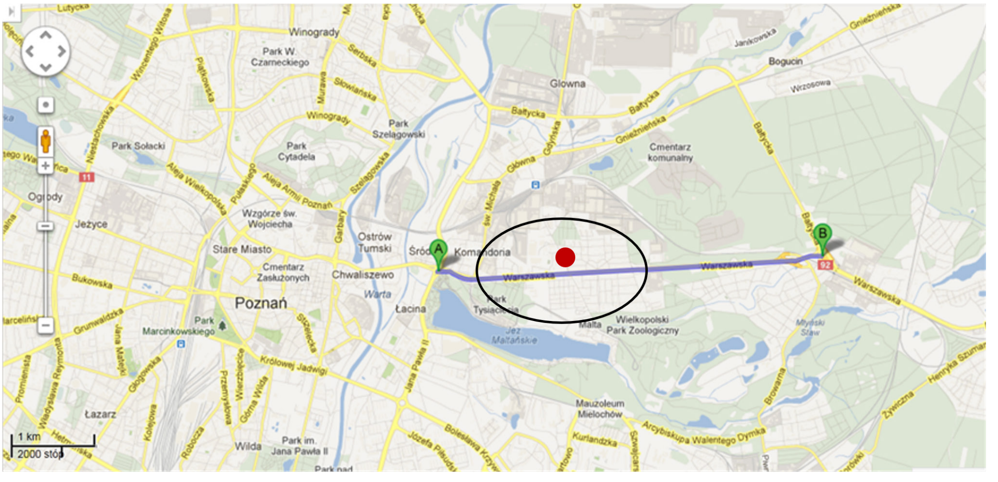

Fig. 1. Location of Warszawska Street in Poznań and noise measurement Points A–B (section of Warszawska Street from Środka Roundabout to Antoninek Bridge [Bałtycka Street])

Source: [30]

The nearest buildings are about 11-m-away from the edge of the road. Additionally, an extra lane of the road was designated to allow the residents of the single-family houses to access their properties (this lane is about 1,000 m long, and the speed limit is 40 km/h). Between Mogileńska Street and Antoninek Bridge, there are also a Poznań Public Transport bus depot, Municipal Cemetery Miłostowo, and Volkswagen Poznań facility buildings. Warszawska Street is served by two tram lines as well as four daytime bus lines and two nighttime bus lines. The entire stretch of this street where the residential buildings are present (approximately 3 km) is classified as an area that is at-risk regarding traffic noise, with levels that exceed the permissible noise limits as expressed by the L_{DEN} and L_N indicators (above 5 dB over allowable levels). Due to the high traffic volume, the street is subject to regular noise monitoring; this is connected to the calibration of the adopted calculation model for the development of Strategic Noise Maps for the city of Poznań. The 24-hour measurements that were conducted for the acoustic maps in 2022, 2017, and 2012 showed that the L_{AeqD} (equivalent continuous sound pressure levels day) indicator values were 73 dB during the day, and the L_{AeqN} (equivalent continuous sound pressure levels night) values were 68 dB at night [20, 31].

The study of the acoustic climate on Warszawska Street consisted of two stages: in the first stage, the residents evaluated the noise that was present in their living environments, while the second stage focused on noise measurements.

Fig. 2. View of section of Warszawska Street in Poznań
Source: [29]

The noise measurements were conducted at one of the several detached houses that were located on the discussed street. The measurement point was chosen in order to assess the impact of the traffic noise that was generated by the vehicles that moved along Warszawska Street. The measurements were taken outside the residential building, with the measurement point that was located on the balcony (0.5 m from the building facade in the window of the exposed floor), at a height of approximately 5.7 m above ground level, a distance of about 11 m from the edge of the road, and about 42 m from the tram track. Figure 2 presents a view of the section of the street where the measurements were made, and Figure 3 shows the location of the measurement point with the distances between the individual sections of the street and the measurement point marked.

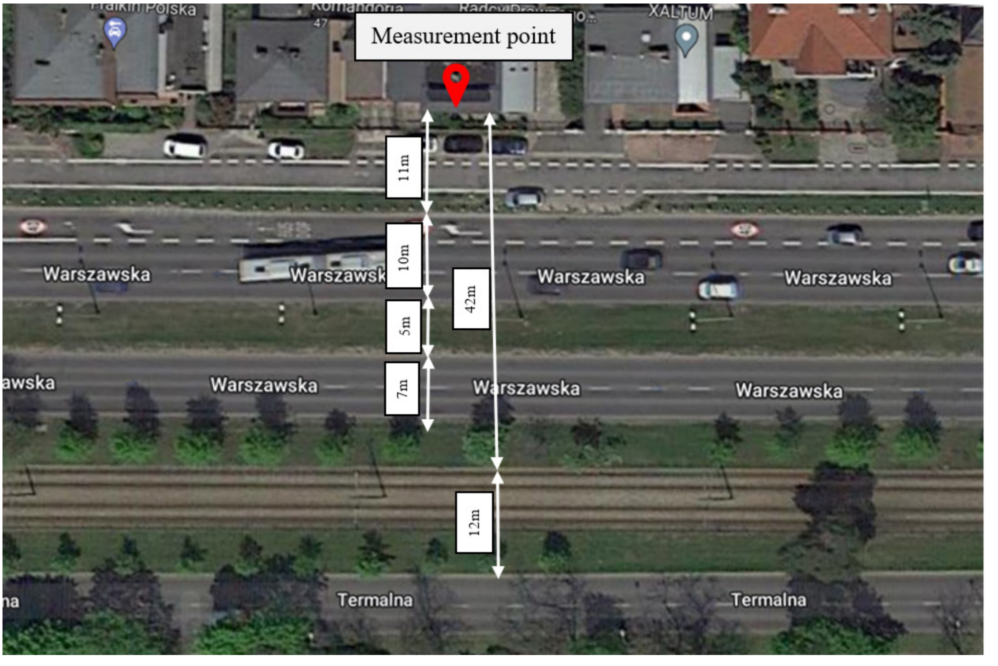

Fig. 3. View of noise-measurement point, with distances between individual sections of street and measurement point marked

Source: [29]

For the purposes of the research, a custom methodology was developed based on the Regulation of the Minister of the Environment (dated June 16, 2011), concerning the requirements for measuring the levels of substances or energy in the environment by the entity that manages a road, railway line, tram line, airport, or port. This methodology involved recording equivalent sound levels over a 24-hour period. During each hour of the day, 10-minute measurement sessions were conducted; these involved measuring the noise outside the building as well as the traffic intensity. The measurements were taken on two days: Tuesday, and Friday, and they allowed for assessing the noise from Warszawska Street in Poznań during the periods of 16 hours of the day and 8 hours through the night. The noise measurements were accompanied by recordings of the traffic intensity, including passenger cars, semi-trailer trucks, buses, motorcycles, and trams [29, 32]. The permissible noise level for external building exposure was adopted as L_{AeqD} = 65 dB for daytime and L_{AeqN} = 56 dB for nighttime [33]. The noise measurements were conducted using a Type-2250 single-channel sound-level analyzer, that was manufactured by Brüel & Kjær. Before and after the measurements, the analyzer was calibrated using a Type-4228 Brüel & Kjær calibrator with a calibration signal of 250 Hz and a level of 124 dB (Lin). Figure 4 presents a view of the measurement equipment that was used to conduct the noise measurements on Warszawska Street.

Fig. 4. Brüel & Kjær 2250 sound-level analyzer
Source: [29]

During each 10-minute measurement session, the equivalent L_{Aeq} sound level was recorded.

3. Findings

The conducted studies were carried out during the spring of 2023 and were divided into two stages: subjective, and actual noise research. The first stage involved a survey that was conducted among the residents of Warszawska Street. The survey consisted of 12 choice questions: 11 were single-choice questions, and 1 was a multiple-choice question. In the first three questions, the respondents were asked about their genders, ages, and how long they had been living on Warszawska Street. The remaining questions were divided into two groups: the first being related to the perception of the sound phenomena by the respondents, and the second concerning the measures that had been taken to reduce the traffic noise in the respondents' living areas. The survey was conducted online (Google Forms), with the use of social media, and the answers were collected from April through June 2023 among 92 residents of Warszawska Street; of these, 74% (68 individuals) were women, and 26% (24 individuals) were men. The distribution of the respondents' ages was as follows: the largest group consisted of those who were aged 25 through 40 (42 individuals – accounting for 45%), followed by those who were aged 41 through 60 (31 individuals – accounting for 34%). The two smallest groups were those below the age of 25 (11 individuals – accounting for 12%), and those who were 61 and above (8 individuals – accounting for 9%). Most of the respondents had been living on

Warszawska Street for more than ten years; this accounted for 51% (47 individuals); 15% of the respondents indicated that they had been living there for up to 10 years, while 34% of respondents indicated that they had been living on Warszawska Street for up to 5 years. Figure 5 presents the responses to the following question 'Is living on Warszawska Street bothersome for you in terms of the traffic noise?'. Among the participants of the survey, 51% stated that the traffic on Warszawska Street was bothersome for them, with 33% finding the noise very bothersome and 18% finding it moderately bothersome. For 27% of the respondents, the noise was not an issue that bothered them, while 22% stated that the noise from Warszawska Street was not bothersome at all.

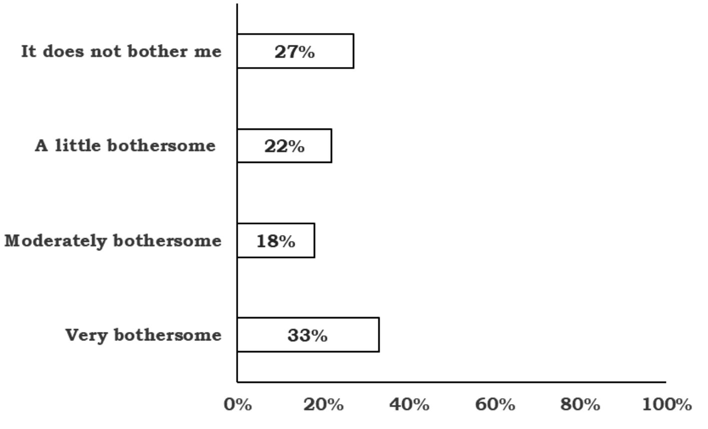

Fig. 5. Responses to question
'Is living on Warszawska Street bothersome for you in terms of traffic noise?'

The next question of the survey pertained to which means of transportation were the most audible. Figure 6 presents the results of the obtained responses (in this question, the respondents could select multiple answers). The largest number of respondents indicated motorcycles as being the most audible means of transportation (with 64% of the responses). A similarly high number of votes were assigned to trams, which were identified as the most audible by 59% of the respondents. Fewer votes (but equally significant) were assigned to trucks (chosen by 53% of the respondents) and passenger cars (44%). Among the selectable options, there was also an answer that indicated airplanes as the most bothersome; this was, chosen by 17% of the respondents. A small group of respondents (3%) indicated that it was difficult for them to determine which means of transport were the most bothersome. In addition to the options that were listed in the questionnaire, the respondents added their own answers; these accounted for 7% of the responses. Buses, cars driving in the car park at night, trams (but only late in the evening and at night), and train horn signals were identified by individual respondents as the most bothersome means of transport regarding the noise that they produced.

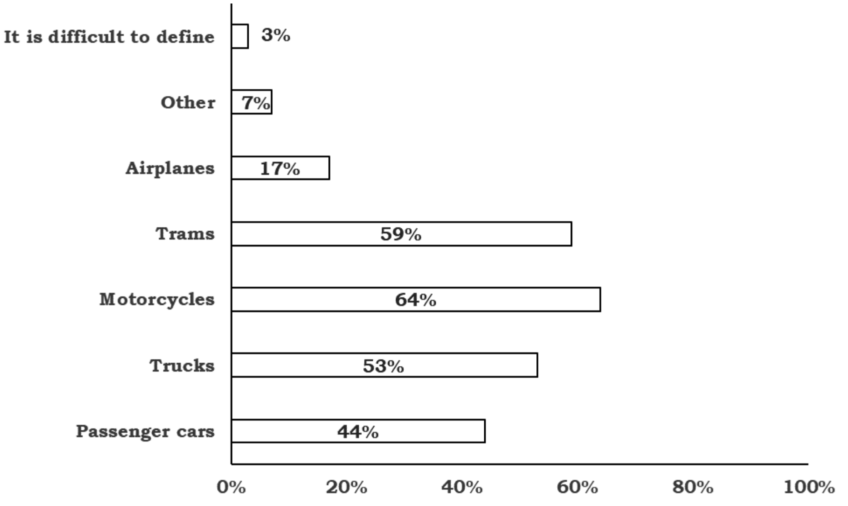

Fig. 6. Responses to question 'Which means of transport are the most audible?'

Figure 7 presents the responses to the following question 'During which hours of the day is the traffic noise in your home most bothersome?'.

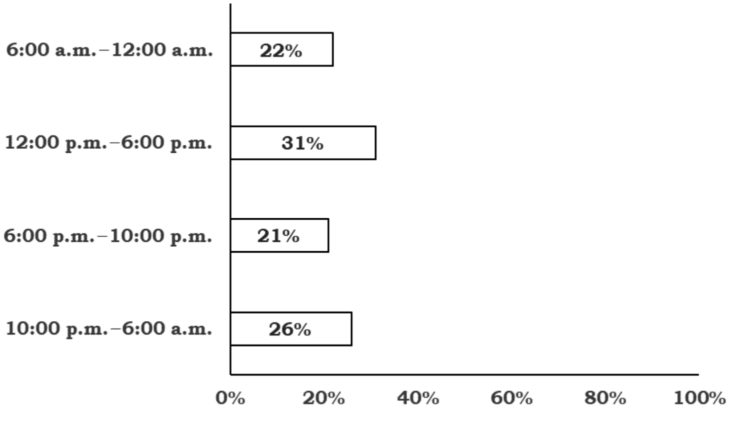

Fig. 7. Responses to question
'During which hours of the day is the traffic noise in your home the most bothersome?'

The distribution of the responses to this question was very similar across different hours of the day (each comprising approximately 30% of the responses). The largest number of responses (31%) were assigned to the time interval between 12:00 noon and 6:00 p.m., while the nighttime hours from 10:00 p.m. through 6:00 a.m. received 26% of the responses. Meanwhile, the hours of 6:00 a.m. through 12:00 noon and 6:00 p.m. through 10:00 p.m. were the options with the smallest numbers of responses (both with 22%).

Figure 8 presents the results of the responses to the following question 'During which season is the traffic noise at your place of residence most bothersome?'.

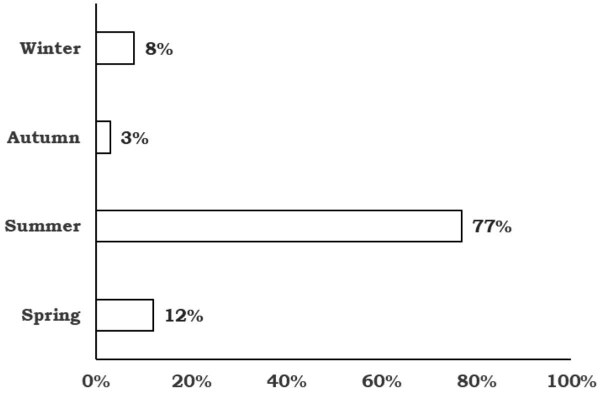

Fig. 8. Responses to question
'During which season is the traffic noise in your place of residence the most bothersome?'

The vast majority of the respondents indicated summer as the season during which the traffic noise was most bothersome, with 77% of the respondents choosing this option. Only 12% of the respondents selected spring, 8% selected winter, and 3% selected autumn.

The last four questions of the survey pertained to issues that were related to the subjective perceptions of the noise and the noise-reduction measures. A compilation of the responses is presented in Figure 9.

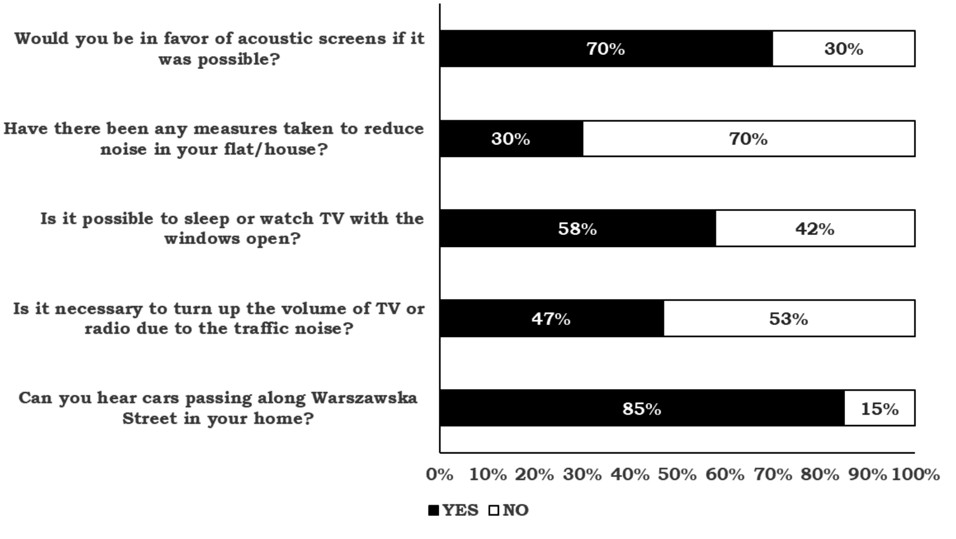

Fig. 9. Responses to questions related to respondents' subjective perceptions of noise phenomena and issue of noise reduction

The first set of questions pertained to issues that were related to the subjective perception of noise in the respondents' flats and houses. The vast majority of the survey participants (85%) responded that they could hear passing vehicles in their places of residence. More than half of the survey participants (53%) stated that they did not need to increase the volume while watching TV or listening to the radio, whereas 47% stated the opposite opinion. Similarly, most of the respondents (58%) were able to watch TV or sleep with open windows, while 42% responded negatively. Regarding noise-reduction measures, 70% of the respondents did not undertake any actions to reduce the noise in their homes. Likewise, 70% of the survey participants were in favor of installing screens at their places of residence.

The second stage of the study involved conducting noise and traffic-intensity measurements on Warszawska Street. The measurements were carried out over a 24-hour period, on two days of the week: Tuesday, and Friday. Each measurement session lasted for 10 minutes; during this time, the noise levels were recorded, along with the traffic intensity (which was categorized into passenger cars and heavy vehicles; i.e., trucks, buses, motorcycles, and trams). According to the Regulation of the Minister of the Environment, the permissible noise levels for the selected area were 65 dB for the daytime and 56 dB for nighttime hours [33]. Figure 10 presents the results of the noise measurements from 6:00 a.m. through 10:00 p.m.

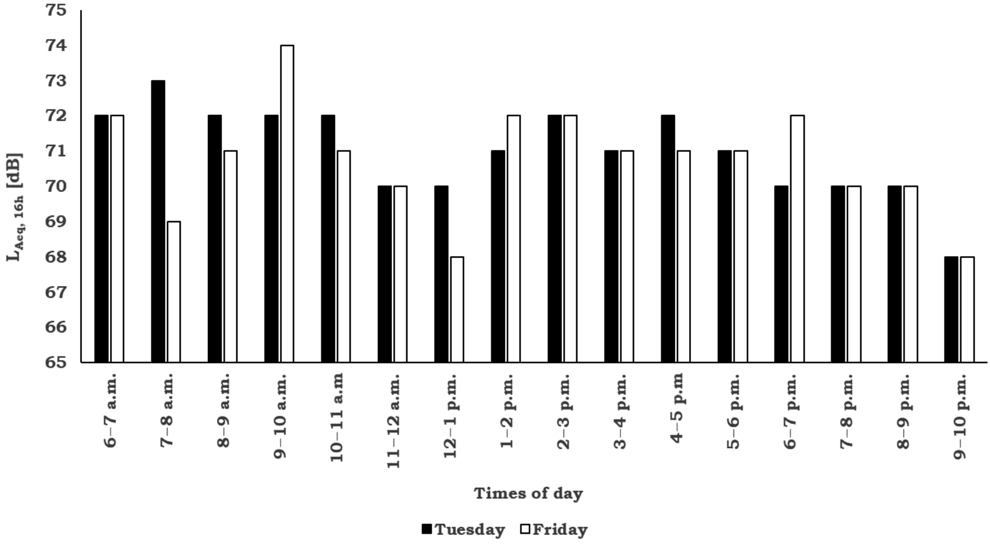

Fig. 10. Distribution of equivalent sound levels on Warszawska Street from 6.00 a.m. through 10.00 p.m.

On Warszawska Street throughout the entire daytime period (6:00 a.m.–10:00 p.m.), the registered equivalent sound levels ranged from 68 to 74 dB. These levels were constant, and it was not possible to identify specific hours or days when they were significantly low or high. Over the entire daytime period (16 hours), the average equivalent sound level on this street was 71 dB (which was 6 dB higher than the permissible level). Figure 11 illustrates the distribution of the equivalent sound levels during the nighttime hours from 10:00 p.m. through 6:00 a.m.

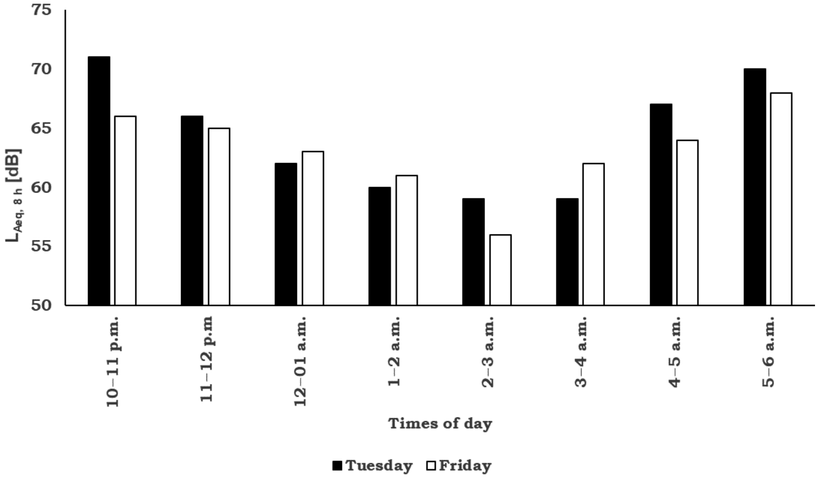

Fig. 11. Distribution of equivalent sound levels on Warszawska Street from 10:00 p.m. through 6:00 a.m.

During the nighttime period, the recorded sound levels also exceeded the permissible level that was designated for these areas (by 10 dB). The registered equivalent sound levels during the nighttime period on Tuesday ranged from 59 to 71 dB, and on Friday from 56 to 68 dB. The highest sound levels of 70 dB were measured on Tuesday between 10:00 p.m. and 11:00 p.m. and between 5:00 a.m. and 6:00 a.m. The lowest equivalent sound levels occurred between 2:00 a.m. and 3:00 a.m., measuring 59 dB on Tuesday and 56 dB on Friday. Figure 12 presents a comparison of the average hourly traffic intensity that was recorded during the noise measurements at the measurement site (Warszawska Street).

During the noise registration (Tuesday and Friday), the average traffic intensity between 6:00 a.m. and 10:00 p.m. (the black bars in Figure 8) was approximately 2,200 vehicles per hour, with heavy vehicles (trucks, buses, trams, and motorcycles) accounting for 5% of the total. The highest intensity was recorded during the morning hours from 6:00 a.m. through 9:00 a.m. and in the afternoon from 1:00 p.m. through 6:00 p.m. During the nighttime measurements from 10:00 p.m. through 6:00 a.m. (the white bars in Figure 8), the average traffic intensity was around 500 vehicles per hour, with heavy vehicles comprising 15% of the traffic. The lowest traffic intensity during the nighttime period occurred between 12:00 noon and 4:00 a.m., with approximately 150 vehicles per hour (although heavy vehicles accounted for 15% of the traffic during these hours) [29].

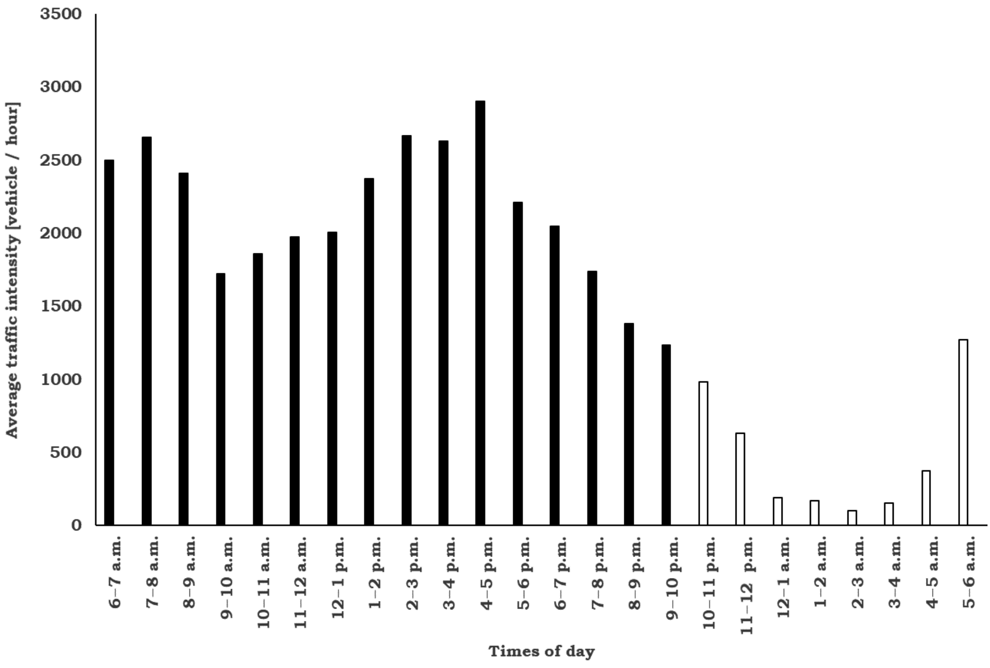

Fig. 12. Average hourly traffic intensity on Warszawska Street

4. Conclusions

The following conclusions can be drawn from the conducted survey:

- Around half of the respondents who answered the survey questions (51%) were individuals who had been living on Warszawska Street for more than 10 years. The respondents also confirmed that they could hear passing vehicles in their places of residence; mainly motorcycles, trams, and semi-trailer trucks.
- Living on this street was very bothersome for 33% of the respondents. Despite this fact, the respondents did not need to increase the volume while watching TV or listening to the radio, and it was possible to sleep or watch TV with the windows open.
- The noise from Warszawska Street was most bothersome for the respondents during the nighttime hours (from 10:00 p.m. through 6:00 a.m.) and from 12:00 noon through 6:00 p.m. Additionally, the respondents indicated that the traffic noise was most bothersome for them during the summer season.
- The respondents also indicated that no actions were taken in their houses/flats to reduce noise, and that, they would like to have sound barriers installed at their places of residence if possible.

Experimental noise studies on Warszawska Street showed that, during the day (6:00 a.m.–10:00 p.m.), the average equivalent sound level was 71 dB (which was 6 dB higher than the permissible level). During daytime, there were no specific hours when the registered equivalent sound level decreased below 68 dB. During the nighttime hours, the permissible level was also exceeded by 10 dB, with the recorded equivalent sound level being 66 dB. However, the measured sound levels did not exceed 60 dB between 2:00 a.m. and 3:00 a.m. An analysis of the vehicle traffic intensity showed that, on average, about 2,200 vehicles per hour passed through Warszawska Street during the day (6:00 a.m.–10:00 p.m.), and about 500 vehicles per hour passed during the night (10:00 p.m.–6:00 a.m.). The share of heavy vehicles was 5% during the day and 15% during the nighttime hours.

The experimental studies confirmed the residents' opinions regarding the nuisance and the hours when the noise had the greatest impact. The measurements showed that high sound levels were recorded on Warszawska Street both during the day and at night. These levels remained consistent with those that were recorded for the Strategic Noise Maps from 2012 through 2022.

Due to the fact that Warszawska Street Poznań is one of Poznań's main streets, it is not possible to implement noise-reduction measures in order to achieve the recommended permissible levels that were set by the Regulation of the Minister of Climate and Environment. The strategic noise map for the city of Poznań from 2017 outlined the necessary actions for restoring acceptable noise levels for this street [31]:

– Replacing the asphalt surface with a quieter one (minimal implementation in 2010–2011, with an optimal scenario planned for 2008).
– Reducing the speed limit to 70 km/h using speed cameras (minimal implementation in 2008).
– Modernizing the tram tracks from Rondo Środka to the Miłostowo loop (2,700 m) (minimal implementation in 2008–2009).

Other more general measures that could result in noise reduction include the following:

– Upgrading bus and tram fleets to newer and more environmentally friendly vehicles.
– The periodic cleaning of all quiet surfaces (at least twice a year) (implementation from 2008–2013).
– The grinding of the rails with the tamping of the tram tracks.
– Adjusting the profile of the trams' wheel rims.
– Monitoring and addressing flat spots and buildup on the trams' wheels.

According to the recommendations in the Strategic Noise Map of the city of Poznań that were made in 2022, actions that were aimed at reducing the negative impact of the traffic noise on Warszawska Street mainly involved maintenance and repair activities that were related to tram traffic; these included maintaining the tram tracks in good technical conditions, periodic rail grinding at least once a year, and rail reprofiling every three years. In the area of road transport, measures were taken to limit vehicle speeds to values that were consistent with the traffic code – particularly during the nighttime hours. This street is still considered to be an area that is at risk of road noise, where permissible noise levels are exceeded both during the day and at night [20].

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CRediT Author Contribution

P. Ł.: preparation of a survey sheet and noise survey methodology, carry out a survey and noise surveys, elaboration of survey results.

M. O.: substantive consultation on survey and noise studies, the article concept, literature review, preparation, drafting and editing of the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All of the research and analysis results that are included in the article have been published in the body of the article.

Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were employed in the preparation of this manuscript.

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