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Posted Date: 10 December 2024

doi: 10.20944/preprints202412.0784.v1

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Supporting the Decision of the Road Manager Through Noise Mapping

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Abstract: Noise pollution poses significant challenges for urban infrastructure management, necessitating practical assessment tools such as noise maps. These maps facilitate the visualisation and geo-referencing of noise levels, enabling the identification of areas requiring immediate intervention and long-term strategic responses. Road sections with more than 3 million vehicles per year were selected for measurement. The article presents the results in the form indicated. It obtains an excess of the Long-term Day-Night Average Noise Level (L_{DWN}), affecting approximately 1.899 km² and impacting around 1,200 residents within the exceedance zone. Similarly, the equivalent noise level (L_N) exceeds acceptable limits over 1.220 km², affecting an additional 700 residents. At the same time, there were no exceedances of the key noise impact indicators such as a high annoyance (HA), high sleep disturbance (HSD), and ischaemic heart disease (IHD). For areas that exceed the applicable noise standards, a change in traffic organisation was introduced by banning heavy goods vehicles and introducing local speed limits. The changes made have eliminated the noise problem in the urban area. Further anti-noise measures are planned to involve planting plants in the road lane.

Keywords: noise; noise map; road management

1. Introduction

Studies indicate that around 40% of Europeans are exposed to daytime noise above the World Health Organisation (WHO) recommended threshold of 55 dB [1,2]. The European Environment Agency reported that road noise affects approximately 125 million people and has become a significant social and environmental problem [3,4]. Noise is estimated to contribute to the loss of approximately 1.6 million disability-adjusted life years (DALYs) per year in Europe alone [5,6]. The ever-increasing urbanisation and increased demand for transport services, with the simultaneous increase in the number of motor vehicles, significantly impact the magnitude of the adverse effects of noise on people and the environment [7]. According to the Polish Central Statistical Office, car transport in the context of freight transport accounted for over 80% of all freight transport carried out in Poland [8], which compounds the problem of noise emissions. Car transport is a major contributor to urban noise pollution, accounting for about 80% of the overall noise levels in many cities [9,10]. The relationship between traffic congestion and noise levels is the subject of several research papers, which at the same time point to the co-occurrence of public health problems as a result of increased noise impacts [3,8,11,12]. The main organ exposed to excessive noise impact is hearing, while indirect effects related to increased stress levels and reduced quality of life caused by increased dB values are indicated [13,14].

The World Health Organisation (WHO) has established guidelines indicating that noise levels above 55 dBA can lead to significant annoyance and health disorders. In comparison, levels above 70 dBA can cause permanent hearing loss and increased mortality from cardiovascular causes [15]. Studies also indicate that noise can lead to physiological stress responses, manifest as elevated blood pressure, heart disease and other cardiovascular conditions [16,17]. A meta-analysis by Badisch

 doi:10.20944/preprints202412.0784.v1

highlights that road noise is a risk factor for coronary heart disease and potentially influences increased stroke risk [18]. Similarly, studies have shown that people living near roads with heavy traffic experience more sleep disturbances and other health issues. Estimates point to the indirect impact of road noise as a cause of 2,000 premature deaths per year in Japan alone [19]. The effect of noise on sleep disturbance is associated with a potential increased risk of cognitive impairment and mental health [16,20–24]. The relationship between noise exposure and annoyance is also significant, with studies showing that even at similar decibel levels, different types of noise (e.g. road vs aeroplane) can induce various degrees of annoyance and health impacts [25,26]. This suggests that noise characteristics, including frequency and duration, are key in determining health effects [25]. Researchers indicate that prolonged exposure to high noise levels can result in increased irritability, anxiety and depression [13,27].

In addition to direct health impacts, noise from motorised transport has wider implications for urban planning and community well-being. Metropolitan areas with high traffic noise often experience reduced physical activity among residents, as noise discomfort can discourage outdoor activity [28,29]. Reduced physical activity can contribute to several health problems, including obesity and related chronic diseases [30,31]. In addition, green spaces have been shown to mitigate some of the adverse effects of noise pollution by promoting physical activity and mental well-being [32].

The accumulation of noise pollution in urban areas can reduce the quality of life, disrupt local ecosystems [33,34] and contribute to biodiversity loss [35,36]. Animals exposed to high levels of anthropogenic noise may alter their behaviour, leading to habitat fragmentation and reduced reproductive success [35,36]. Noise pollution can disrupt wildlife habitats and change their behaviour, leading to broader ecological impacts [9]. As urban areas continue to develop, the need for effective noise management strategies becomes more critical.

Effective noise mapping and mitigation strategies are essential for identifying high-exposure areas and implementing measures to reduce noise pollution, thereby protecting public health and improving environmental quality [37–42]. This article presents an example of carrying out road noise impact measurements by developing maps that indicate the area exposed to negative impacts.

2. Materials and Methods

Urban development requires effective noise management strategies [43–45]. While the implementation of noise regulations is a key element of a comprehensive noise management approach [3,14], there is currently insufficient control [46].

The simplest solution applied to multi-lane roads is the introduction of noise barriers [47,48], while for single-lane roads, the application of the indicated solution is economically and visually irrational. Therefore, research and application of road noise mitigation pavements is essential [49,50]. Transport development is also related to the use of quieter engines and the implementation of tyres that reduce noise emissions from motor vehicles [14,51]. The electrification of transport is also an essential aspect of combating noise emissions [52–54]. as electric motors operate much quieter than traditional internal combustion engines [14,51].

An interesting conclusion of the study is that traffic control should be considered to reduce road noise emissions. Traffic reduction measures like priority for public transport, development of cycling infrastructure [55], the concept of the 15-minute city and promotion of walking [53,56] are key. Educating residents about the health impacts of noise and encouraging community involvement in local planning decisions can foster a collective approach to noise reduction [55]. In addition, policies that promote public transport and non-motorised modes can help shift social norms towards quieter, more sustainable transport options [14,55]. Awareness campaigns can also educate communities about the health impacts of noise pollution and encourage them to engage in noise reduction initiatives [57].

Measuring and mapping road transport noise is essential to establish areas of harmful exposure and is key to verifying noise standards [7,58]. One of the primary methods for mapping road noise involves using statistical models that correlate noise levels with various urban parameters such as

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traffic volume, road geometry and environmental conditions. For example, Hanigan et al. [59]. A statistical approach was used to generate high-resolution health risk maps related to road noise. In contrast, Adza et al. [60] used Geographic Information System (GIS) techniques to investigate the combined effects of road noise and air quality according to the UK Road Noise Calculation Method (CRTN). This research highlights the importance of integrating statistical analysis with spatial data to improve the accuracy of noise mapping. Suyunov emphasises the importance of using noise data to update noise maps and produce mapping work that reflects the changing urban landscape [61]. The systematic collection of noise data is essential to accurately represent noise exposure in urban environments based on actual measurement data [62,63].

By the regulations in force, the assessment was carried out for one-hour indicators. The basis of the evaluation is the Regulation of the Minister of Environment of 14 June 2007 on permissible noise levels in the environment and the requirements contained therein [64].

According to the Environmental Protection Law, the basis for categorising areas subject to noise protection are the provisions of local spatial development plans. Article 114 (1) of the Act states that when drawing up a local spatial development plan, when differentiating between areas with different functions or development principles, it shall be indicated which of them belong to the particular types of areas referred to in Article 113 (2) para. 1 (i.e. the areas specified in the Decree of 14 June 2007 [64]). The applicable values of permissible sound levels in the environment are presented in Tables 1 and 2.

Table 1. Permissible levels of environmental noise caused by specific groups of noise sources, excluding noise caused by aircraft take-offs, landings and overflights, and power lines expressed in terms of LAeqD and LAeq N [65].

No.	Type of terrain	The permissible noise level in [dB]			
		roads or railway lines		other facilities and noise-generating activities	
		LAeq D time reference interval equal to 16 hours	LAeq N 8-hour post-elevation time interval	LAeq D reference time interval equal to the 8 least favourable hours of the day consecutively	LAeq N time reference interval equal to 1 least favourable hour of the night
1	a) Spa protection zone ‘A’ b) Hospital areas outside the city	50	45	45	40
2	a) Areas of single-family residential development b) Areas of buildings connected with permanent or long-term residence of children and young people c) Social housing areas d) Hospital areas in cities	61	56	50	40
3	a) Areas of multi-family residential development and collective housing b) Areas of homestead development c) Recreation and leisure areas d) Residential and service areas	65	56	55	45
4	Areas in the inner city zone of cities with more than 100,000 inhabitants	68	60	55	45

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Table 2. Permissible environmental noise levels caused by specific groups of noise sources, excluding noise caused by aircraft take-offs, landings and overflights, and power lines, expressed in terms of L_{DWN} and L N [65].

No.	Type of terrain	Permissible noise level in [dB]			
		roads or railway lines		other facilities and noise-generating activities	
		L_{DWN} reference time interval equal to all days of the year	L N reference time interval equal to all times of the night	L_{DWN} reference time interval equal to all days of the year	L N reference time interval equal to all times of the night
1	a) Spa protection zone 'A' b) Hospital areas outside the city	50	45	45	40
2	a) Areas of single-family residential development b) Areas of buildings connected with permanent or long-term residence of children and young people c) Social housing areas d) Hospital areas in cities	64	59	50	40
3	a) Areas of multi-family residential development and collective housing b) Areas of homestead development c) Recreation and leisure areas d) Residential and service areas	68	59	55	45
4	Areas in the inner city zone of cities with more than 100,000 inhabitants	70	65	55	45

Methods and data used to perform acoustic calculations

Measurements and development of the noise map were performed by the requirements of the Minister of Climate and Environment Regulation of 1 July 2021 on the detailed scope of data included in strategic noise maps, the manner of their presentation and the form of their transmission [66]. For the calculations, CadnaA software was used with the CNOSSOS-EU methodology implemented as required by law in accordance with the provisions of Directive 2002/49/EC of the European Parliament [67].

The reference methodology for the measurement of road noise levels discharged into the environment is set out in the Decree of the Minister of the Environment of 16 June 2011 on the requirements for conducting measurements of the levels of substances or energy in the environment by the manager of a road, railway line, tramway line, airport, port [68]. The method of determining the long-term L_{DWN} indicator is set out in the Regulation of the Minister of the Environment of 10 November 2010 on the process of determining the value of the L_{DWN} noise indicator [69], according to which the value of the indicator is determined according to the following relation:

$$L_{DWN} = 10\lg\left[\frac{12}{24} * 10^{0,1L_D} + \frac{4}{24} * 10^{0,1(L_W+5)} + \frac{8}{24} * 10^{0,1(L_W+10)}\right] \quad (1)$$

where:

L_D - long term average A sound level expressed in dB, determined during all daytime periods of the year, including the time of day (understood as the interval from 06:00 to 18:00 hours),

L_W - long-term average sound level A expressed in dB, determined over all the evening periods of a year, including the daytime (defined as the interval from 06:00 to 22:00),

L_N - long-term average sound level A expressed in dB, determined during all the night periods of the year (understood as the time interval from 22:00 to 06:00).

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Description of the methodology used to calculate the number of dwellings in residential buildings and the population attributed to residential buildings

Central to the strategic noise mapping is the analysis related to determining the potential number of inhabitants exposed to noise and the related harmful effects. These analyses, according to point 2.8 of Annex II of Directive 2002/49/EC, concern the calculation of noise emissions at the façade of residential buildings [67]. Then, based on the estimation of the number of dwellings, the number of inhabitants is estimated for the area; for this purpose, data published by the Central Statistical Office [70] for the municipality where the measurements were carried out was used.

Testing ground

Central to noise mapping is the accurate characterisation of the area being assessed. It is essential to identify potential noise sources regarding the impact on the regulatory adopted characteristic regions. In the methodology adopted, communication routes (roads) are treated as linear noise sources in the computational model, the generated noise level of which depends on many factors such as:

- geometrical parameters of the noise source (road): type and technical condition of the road surface, cross-section of the road (width of the carriageway, number of lanes, width of the separation lane), location of the road about the ground level (on an embankment, in a trench, at ground level), location of engineering structures limiting noise emissions (acoustic screens),
- traffic parameters: traffic volume and structure (number of light and heavy vehicles), average traffic speed, type of traffic (smooth, interrupted, accelerated, decelerating),
- independent parameters: topography and land cover between the noise source and the reception point, meteorological conditions.

Basic information about the testbed under consideration is presented in Tables 3 and 4.

Table 3. Geographical coordinates of the analysed sections.

Road number	Street name	vehicles / year	Length [m]	GPS coordinates in the 1992 system	
				Start of road section X / Y	End of road section X / Y
1503	Grodzisk Mazowiecki - Siestrzeń Ojrzanów	3.901.120	8060	472176,28 / 611955,16	467138,46 / 617626,89
1505	Grodzisk Mazowiecki - Józefina	4.113.915	2870	472031,80 / 611317,31	469229,06 / 611540,84
1511	Milanówek - Falęcin - Kotowice	5.114.380	620	474633,94 / 613882,26	474284,26 / 614061,16
1526	Grodzisk Mazowiecki- Milanówek	3.935.795	1200	472789,29 / 611620,36	473320,31 / 612598,64

Table 4. Characteristics of the central district roads.

Road	Road class	Width of road lane	Surface width	Width of roadway	number of roadways	number of lanes	type of surface
Droga 1503W Grodzisk Maz. - Siestrzeń – Ojrzanów, ul. Nadarzyńska	Main road (G)	do 25m	6-7 m	8-9 m	1	2 (1 in each direction)	Bituminous mass
Droga 1505W Grodzisk Maz. - Józefina	Collective (Z)	20	6,5-7,5 m	8-9 m	1	2 (1 in each direction)	Bituminous mass
Droga 1526W Grodzisk Mazowiecki ul. 3-go Maja, Milanówek ul. Dębowa	Collective (Z)	20m	6,7-7,2 m	8-9 m	1	2 (1 in each direction)	Bituminous mass
Droga 1511W Milanówek – Falęcin – Kotowice, ul. Kazimierzowska, ul. Nowowiejska, ul. Piłsudskiego, ul. Dębowa, ul. Smoleńskiego, ul. Kościelna, ul. Kościuszki	Collective (Z)	20m	5,9-6,2 m	6,5-7,5 m	1	2 (1 in each direction)	Bituminous mass

The following assumptions were made for the measurements:

- Traffic intensity. The traffic volume values on the individual road sections included in the scope of this study were assumed based on the traffic volume measurements carried out on the separate sections of the analysed roads. The 24-hour average traffic volumes used in the calculations, broken down into daily and annual numbers of vehicles, are shown in the table below.
- Traffic speed. For the purpose of the calculations, the average speed of vehicle traffic was assumed to be equal to the permissible speed of vehicles at a given time of day. The permissible traffic speeds were determined according to the list of vertical signs provided by the Contracting Authority.
- Type and condition of the road surface. The type and condition of the pavement in the calculation model were adopted in accordance with the actual condition found based on the site visit during the conducted noise level field measurements.
- Landforms, Screening Objects. For this study, a Numerical Terrain Model (NMT) layer and a Topographic Database (BDOT) were obtained from the resources of the Central Land Surveying and Cartographic Documentation Centre. The data received made it possible to appropriately model the nullification of individual road sections about neighbouring areas, the landform in the immediate vicinity, and objects of a reflective and screening nature.

3. Results

For the verification and calibration of the computational model, measurements were carried out using the sampling method by point G of the reference methodology, recording the value of the equivalent sound level A at representative noise emission intervals. The number of measurements in each representative measurement interval tk of not less than three and with a duration of at least 10 minutes depended on the gap between the extreme results of these measurements. If the difference between the results of the individual measurements is greater than 7 dB, the duration of a single measurement is increased to a minimum of 15 minutes. The value of the acoustic background level was determined as far as possible when the source noise was not emitted, and if this was not possible, using the L95 index.

Description of the calculation model calibration methodology

Calibration of the computational model was carried out concerning the results of noise measurements and vehicle traffic recorded during the study. The calibration process sought to minimise the error resulting from the difference between the measured sound level value and the value derived from the calculation model. During the calibration process, corrections were made to parameters determined with the most significant uncertainty, e.g. parameters relating to the type of road surface and ground absorption coefficient G.

The calibration started once the complete data had been entered into the computer model, viz:

- complete geometry of the individual road sections,
- traffic volume and vehicle speeds observed during the noise measurements,
- type of pavement - based on visual inspection,
- geometry of shielding, attenuating and reflecting objects,
- elevation model of the area.

Irrespective of the measured sound level, either a single measurement result, *Lzm*, or a set of n values is available for comparison with the calculation results. In the second case, the average value used in the validation procedure is determined from the formula (2):

$$L_{zm} = 10\lg\left[\frac{1}{n}\sum_{i=1}^{n} 10^{\frac{L_{zm,i}}{10}}\right] \quad (2)$$

Validation is a process that aims to determine the degree of agreement between the model predictions and the actual value. More specifically, validation will be understood as the methodology for assessing the accuracy of the calculation method, with the measure of accuracy being the error (difference) between the calculated and measured sound level. The result of the validation procedure will be the determination of a so-called calibration correction to the computational model (a value-added or subtracted to the result of the calculation or to the emission level of the noise source, depending on the software used), introduced to increase its accuracy. If the calibration correction is within the allowed range (meets the criterion), then the model and its predictions can be considered valid, The smallest possible value of the calibration correction is determined in a procedure referred to as calibration or adjustment of the acoustic model parameters in order to obtain the best agreement with the measurement result.

Comparison of measurement and calculation results

Table 5 compares the measured results with the results obtained by calculation.

Table 5. Summary of results of calibration of the computational model.

Street	Measured value [dB]		Calculated value [dB]		Difference [dB]	
	LAeq D	LAeq N	LAeq D	LAeq N	LAeq D	LAeq N
ul. Nadarzyńska	67,2	61,4	66,9	60,9	0,3	0,5
3 Maja	67,4	61,1	66,2	60,3	1,2	0,8
ul. Smoleńskiego	65,1	60,2	64,8	59,6	0,3	0,6

Based on the calculations performed, it is concluded that the prerequisite for calibration has been met.

Results of the Strategic Noise Map Development

Description and location of areas where permissible noise levels expressed by the L_{DWN} indicator are exceeded.

The permissible value of the L_{DWN} indicator = 50 dB applies to development areas:

- protective zone 'A' of the spa,
- hospital areas outside the city.

The permissible L_{DWN} = 64 dB applies to the development areas:

- areas of single-family residential development,

- areas of buildings connected with permanent or temporary residence of children and young people
- Areas of social housing
- Urban hospital areas.

The limit value of L_{DWN} = 68 dB applies to the areas of:

- areas of multi-family residential development and collective residence,
- areas of farm buildings,
- recreation and leisure areas,
- residential and service areas.

Description and location of areas where permissible noise levels expressed by the L_N indicator are exceeded.

The permissible value of the indicator L_N = 45 dB applies to the development areas:

- protective zone 'A' of the spa,
- areas of hospitals outside the city.

The permissible value of indicator L_N = 59 dB applies to development areas:

- areas of single-family housing development,
- areas of buildings connected with permanent or long-term residence of children and young people
- Areas of social housing
- urban hospital areas,
- areas of multi-family residential development and collective residence,
- areas of farm buildings,
- recreation and leisure areas,
- residential and service areas.

Population figures exposed to noise.

The following subsections summarise statistics on the estimated number of dwellings, residents, facilities for the permanent or temporary residence of children and young people, hospitals and social care homes exposed to road noise expressed by L_{DWN} and L_N indicators.

The data relating to the number of residents and dwellings exposed to noise expressed by L_{DWN} and L_N indicators in accordance with the guidelines contained in Appendix No. 2 of the Regulation of the Minister of Climate and Environment of 01.07.2021 on the detailed scope of data included in strategic noise maps, the manner of their presentation and the form of their transmission [66] were rounded to the nearest 100, i.e. according to the explanations in Annex VI of the Directive 2002/49/EC of the European Parliament and of the Council on standard methods of noise assessment 'the numbers are rounded to the nearest hundred (i.e. 5 200 = between 5 150 and 5 249; 100 = between 50 and 149; 0 = less than 50).

Statistics on the occurrence of acceptable noise levels are shown in Tables 7 and 8.

Table 7. Statistics on the occurrence of exceedances of noise limits for district roads.

Grodzisk District	L_{DWN}				L_N			
	1–5 dB	**5,1–10 dB**	**10,1–15 dB**	**> 15 dB**	**1–5 dB**	**5,1–10 dB**	**10,1–15 dB**	**> 15 dB**
area [km²]	0,114	0,012	0,000	0,000	0,022	0,000	0,000	0,000
number of residential units	0	0	0	0	0	0	0	0
number of residents	0	0	0	0	0	0	0	0
facilities for the permanent or temporary stay of children and young persons	0	0	0	0	0	0	0	0
healthcare facilities	0	0	0	0	0	0	0	0
social welfare facilities	0	0	0	0	0	0	0	0

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Table 8. Noise exposure statistics for district roads.

Grodzisk District	L_{DWN}						L_N					
	55-59 dB	**60-64 dB**	**65-69 dB**	**70-74 dB**	**75-79 dB**	**+ 80 dB**	**50-54 dB**	**55-59 dB**	**60-64 dB**	**65-69 dB**	**70-74 dB**	**+ 75 dB**
area [km²]	0,836	0,527	0,367	0,169	0,000	0,000	0,572	0,410	0,230	0,008	0,000	0,000
number of residential units	372	301	232	0	0	0	252	312	11	0	0	0
number of residents	600	500	100	0	0	0	500	200	0	0	0	0
facilities for the permanent or temporary stay of children and young persons	1	3	4	0	0	0	0	0	0	0	0	0
healthcare facilities	0	0	0	0	0	0	0	0	0	0	0	0
social welfare facilities	0	0	0	0	0	0	0	0	0	0	0	0

Harmful effects of noise

Based on the data obtained, values were calculated for indicators to assess the harmful effects of environmental noise:

- significant annoyance (HA, from high annoyance),
- high sleep disturbance (HSD),
- ischaemic heart disease (IHD).

The results of the analyses are presented in table 9.

Table 9. Analysis of the number of residents affected by the harmful effects of noise.

District	The number of people affected by the harmful effects of noise, as expressed by the indicator		
	HA	**HSD**	**IHD**
grodziski	0	0	0

Strategic noise map for district roads

Noise maps have been produced for all road routes, as indicated in Table 3. Three sections are presented below for visualisation:

- Noise immission map showing noise expressed by L_{DWN} (Figures 1–3).
- Immission map showing noise expressed as L_N (Figures 4–6).
- Map of acoustically protected areas with permissible noise levels expressed in L_{DWN} and L_N indicators (Figures 7–9).
- Map of noise-prone areas where the permissible noise levels expressed in L_{DWN} are exceeded (Figures 10–12).

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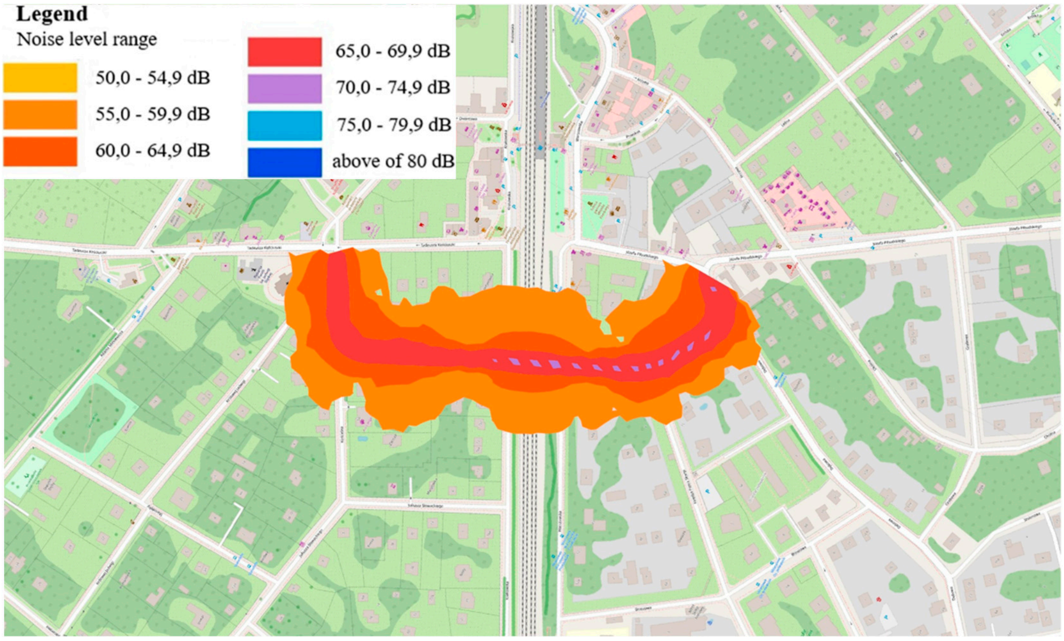

Figure 1. Noise immission map showing noise expressed by L_{DWN}.

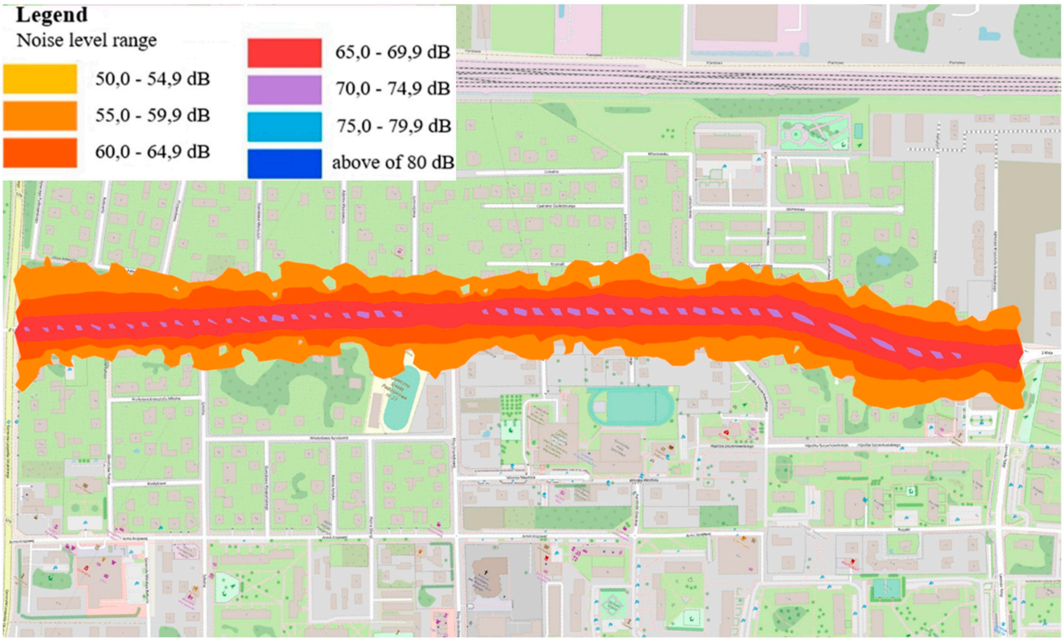

Figure 2. Noise immission map showing noise expressed by L_{DWN}.

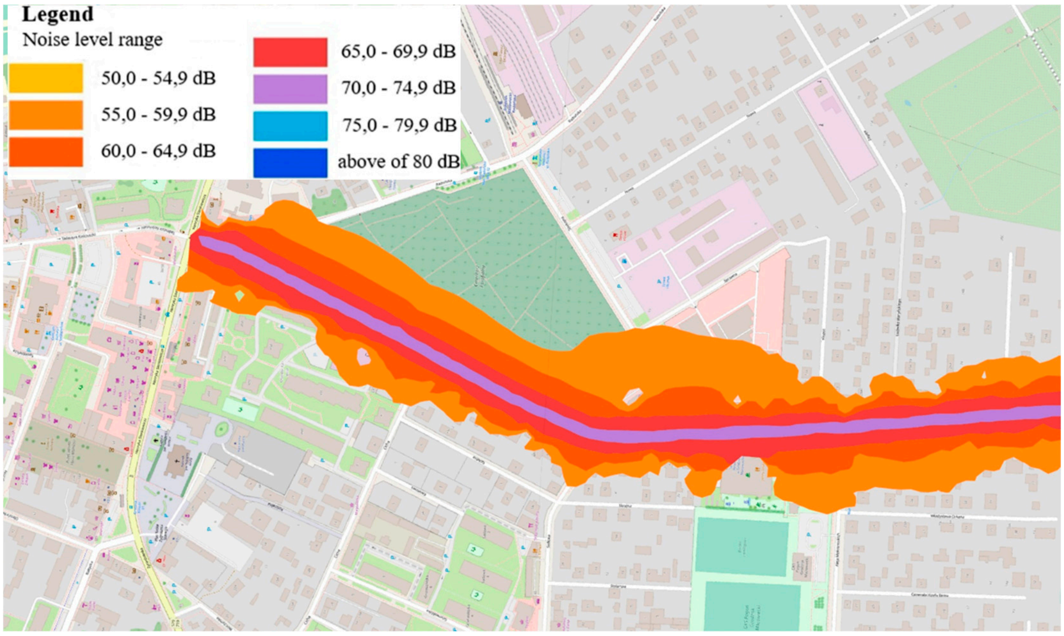

Figure 3. Noise immission map showing noise expressed by L_{DWN}.

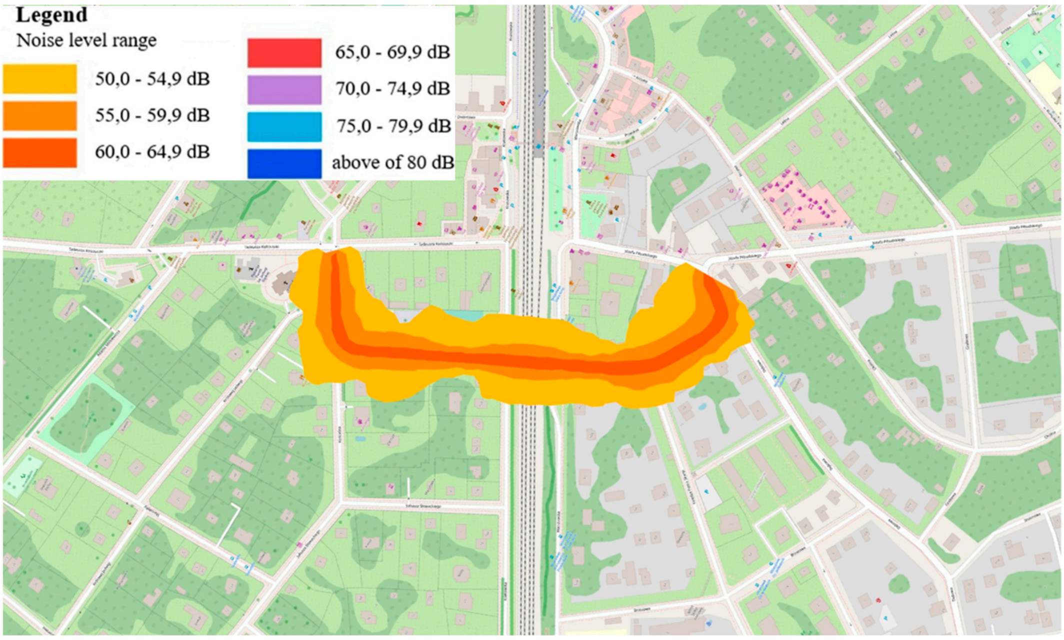

Figure 4. Immission map showing noise expressed as LN.

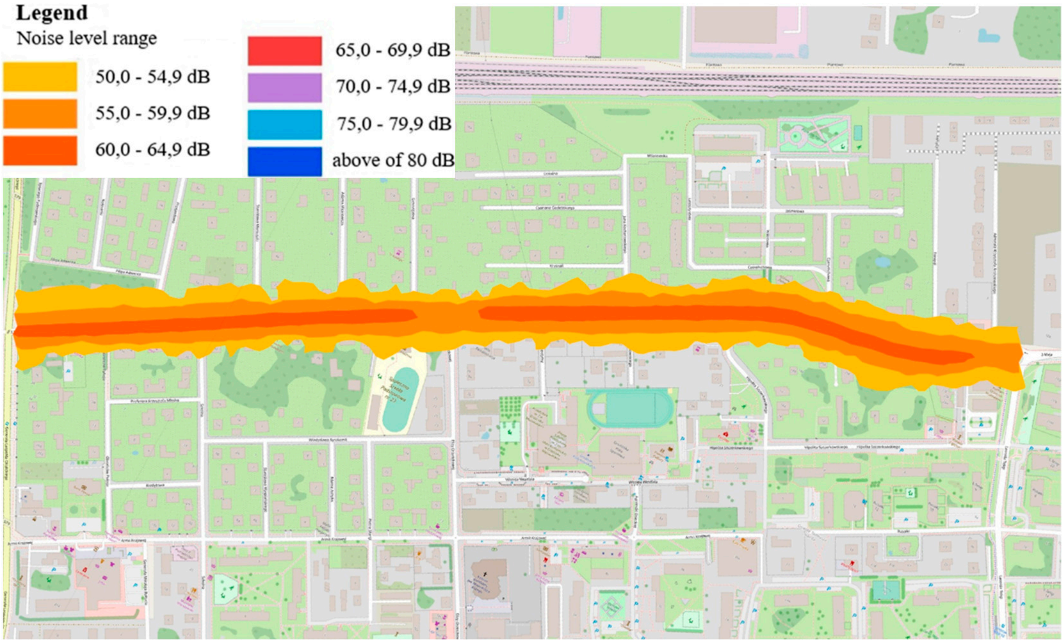

Figure 5. Immission map showing noise expressed as LN

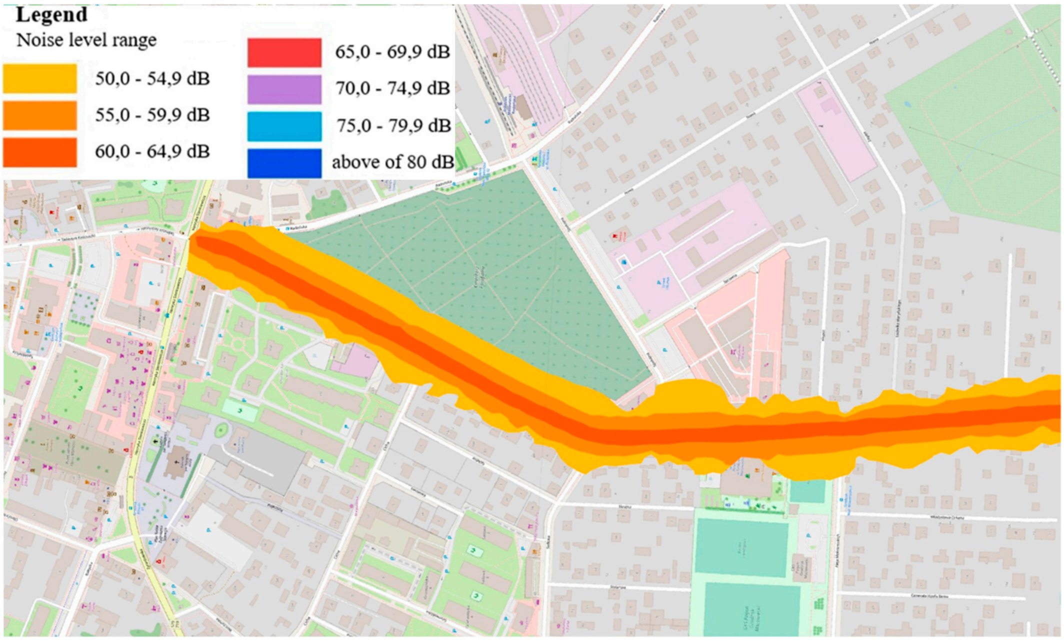

Figure 6. Immission map showing noise expressed as LN.

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Figure 7. Map of acoustically protected areas with permissible noise levels expressed in L_{DWN} and LN indicators.

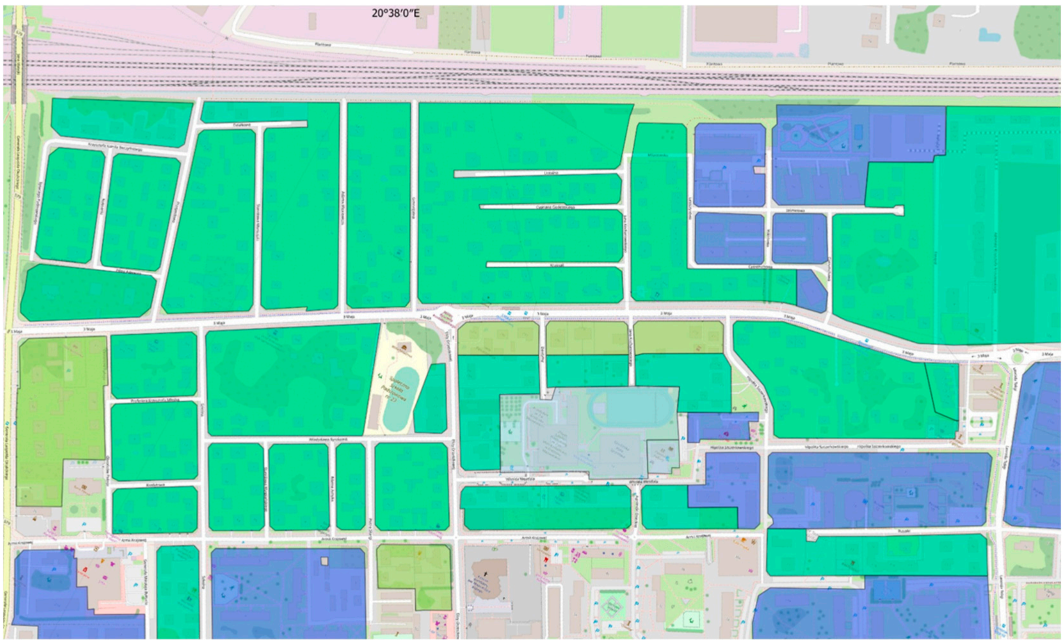

Figure 8. Map of acoustically protected areas with permissible noise levels expressed in L_{DWN} and LN indicators.

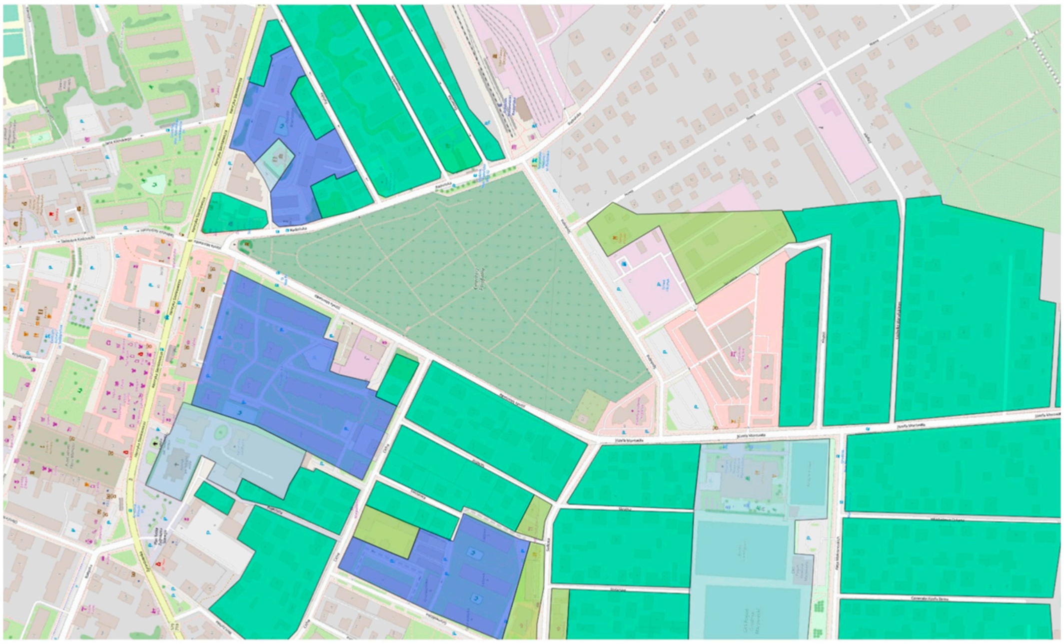

Figure 9. Map of acoustically protected areas with permissible noise levels expressed in LDWN and LN indicators.

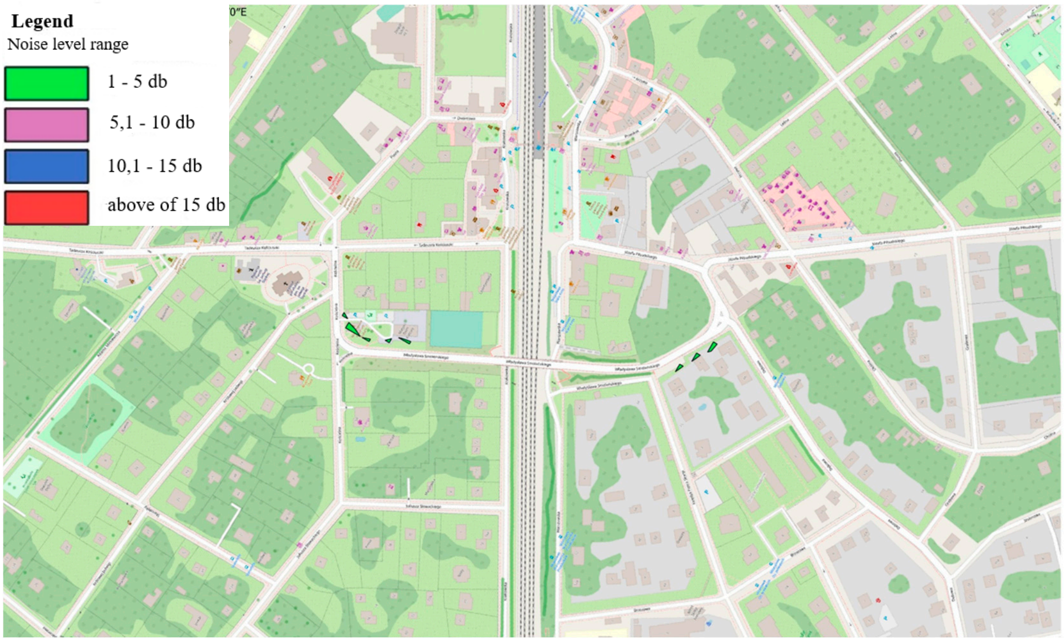

Figure 10. Map of noise-prone areas in which the permissible noise levels expressed in LDWN are exceeded.

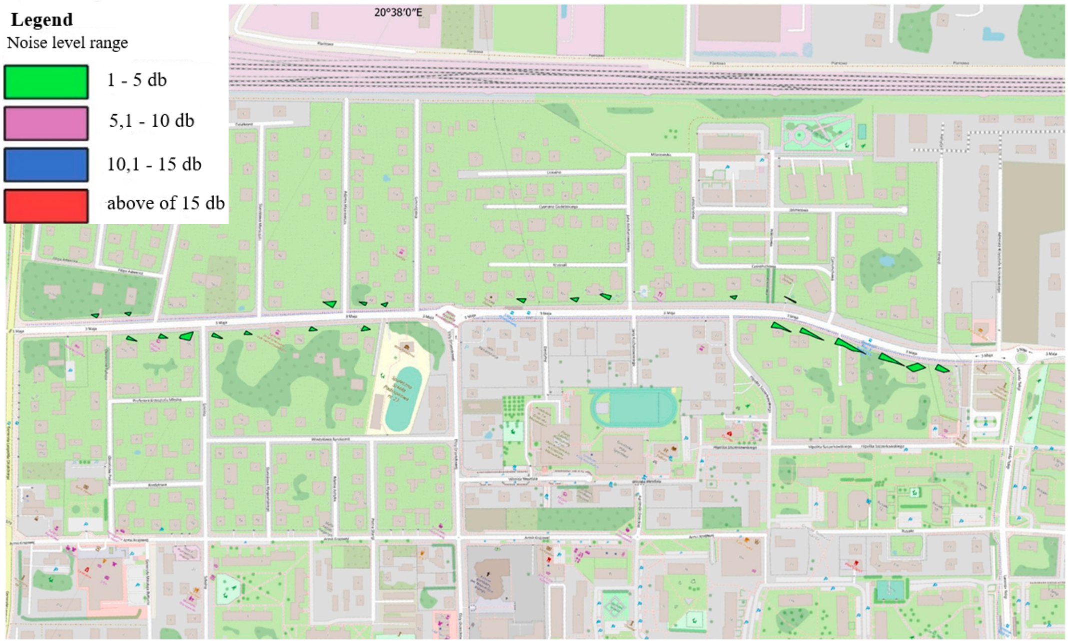

Figure 11. Map of noise-prone areas in which the permissible noise levels expressed in L_{DWN} are exceeded.

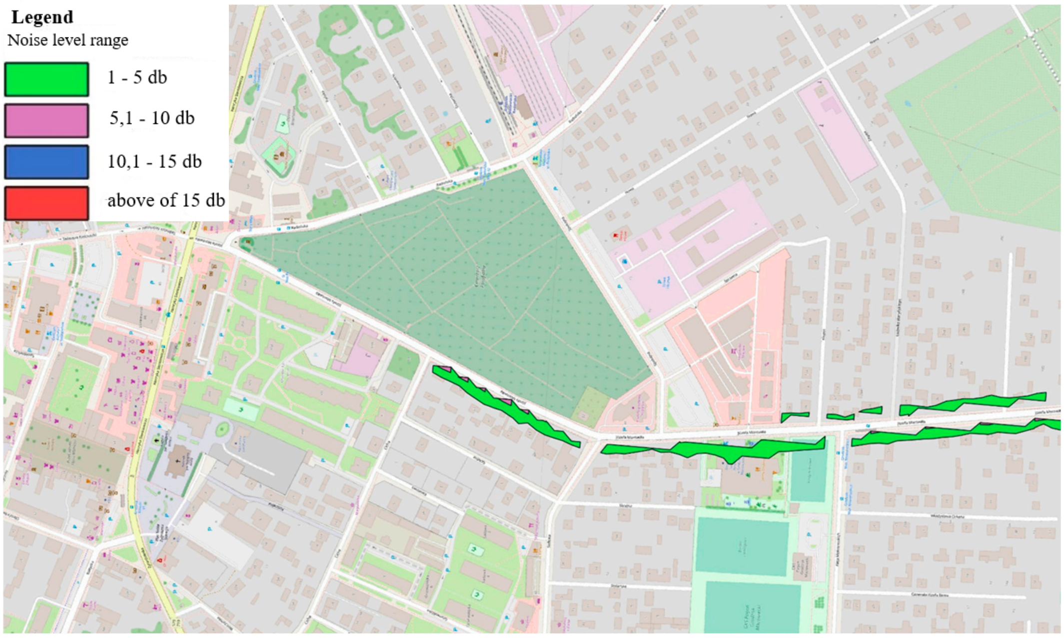

Figure 12. Map of noise-prone areas in which the permissible noise levels expressed in L_{DWN} are exceeded.

4. Discussion

Noise maps are one tool to assess the scale of the noise problem for infrastructure managers [71–73]. The visualisation of noise levels on a map, together with the geo-referencing of data, makes it possible to clearly identify sites which require intervention or which will require a response in the long term. The issue of noise pollution in the context of building approvals should be included in the local spatial development plan. According to the measurements carried out, noise impact according to L_{DWN} was found on 1.899 km^2. This translates into an impact on approximately 1,200 residents living in the exceedance zone of the indicated indicator. In the case of L_N, the exceedance occurs over an area of 1.220 km^2 and affects around 700 residents. It should be noted, however, that none of the key indicators were referenced for the study area, i.e. LN: significant annoyance (HA, from high annoyance), high sleep disturbance (HSD) and ischaemic heart disease (IHD).

One of the most common solutions to reduce traffic noise is the use of noise barriers [74–76]. However, this measure is often ineffective due to difficult urban conditions and lack of space for their installation [77]. Minor noise exceedances can be reduced by using greenery in the road lane [78–80]. The main elements in the fight against traffic noise in cities are the use of noise protection measures consisting of proper traffic organisation [81,82] or the introduction of new solutions such as noise-reducing pavements[49].

As part of the results, the infrastructure manager decided to reduce noise levels by applying speed limits and increasing enforcement of existing speed limits [15,83]. For the short section of road with the highest exceedances, it was decided to ban heavy goods vehicle traffic [84,85]. In the next stages, it is planned to plant greenery in the road lane. Applying the indicated solutions has made it possible to reduce noise levels and eliminate the problem for the surveyed road sections.

Author Contributions: Conceptualization, P.J. , M.K., J.M. and A.K.; methodology, P.J. and M.K.; software, P.J. and M.K..; validation, J.M. and A.K.; formal analysis, P.J. , M.K., J.M. and A.K.; investigation, P.J. , M.K., J.M. and A.K.; resources, P.J. , M.K., J.M. and A.K.; data curation, P.J. and M.K.; writing—original draft preparation, P.J. , M.K., J.M. and A.K.; writing—review and editing, P.J. , M.K., J.M. and A.K.; visualization, P.J. and M.K.; supervision, X.X.; project administration, P.J. and M.K.; funding acquisition, P.J.. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

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