

Analysis of the impact of road noise on urban green spaces: a case study of the dendrological garden in Poznań, Poland

Abstract

Green parks and gardens in urban areas are an essential part of ecosystem services for inhabitants, especially in cities where people are affected by road noise. These problems have been the subject of many studies worldwide. Such works have been carried out at many levels—both in the contexts of spatial planning and ecological analyses. In relation to this, the design of noise maps and related spatial modelling is significant. The paper presents the results of a survey of the acoustic environment in the Dendrological Garden in Poznań—the fifth largest city in Poland—which is a vital part of the city's green zone. The analysis of the noise distribution across the park's zones was carried out at frequent intervals using sound-level surveys during 2014 and 2020. Moreover, acoustic maps developed for Poznań in 2012 and 2017 were compared with these recent studies. The changes (gain or loss) in those areas with a particular noise level are based on the area variability index.

Keywords

Green area • traffic noise • dendrological garden

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Introduction

Traffic noise nuisance is a very real problem in the European Union. According to Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002, which relates to the assessment and management of environmental noise, 'environmental noise shall mean all unwanted or harmful sounds caused by human activities in the open air'. Based on the source of the environmental noise, there are two basic categories: traffic noise and industrial noise. Traffic noise is divided into road, airplane, and railroad noise, with these groups of noises affecting the acoustic environment, including urban areas (Kucharski 2002; Podawca & Staniszewski 2019). The biggest threat to the acoustic environment is traffic noise, which is the dominant type of noise in the environment. The main communication routes (roads, railroads, airways) produce high noise levels and significantly degrade surrounding areas. Due to its widespread occurrence, perceived road noise is the most annoying component in this category. This component is mainly characterized by having a large number of sources: these can be transport vehicles and, in some areas, trams or trolleybuses. Of the mentioned group of vehicles, the loudest are trucks, emitting sounds exceeding 90 dB (Kolaska 2002). Several different quantifiable variables and indicators are commonly used to assess environmental acoustic conditions.

Appropriate values are utilized to prepare acoustic maps, which is required by law, to ensure the uniformity of the map's form and content, and the comparability of results (Kucharski 2011). The amended Environmental Protection Law introduced two

primary indicators for assessing environmental noise (Legal Act from 27 April 2001). These consist of short-term indicators used to determine and control the conditions of use of the environment during a single day: (1) LAeqD, equivalent sound level A for the daytime (understood as the period from 6.00 a.m. to 10.00 p.m.) and (2) LAeqN, equivalent sound level A for the night (from 10 p.m. to 6 a.m.) (Podawca & Karpiński 2021).

Stress and the pace of life forces people to seek rest in urban areas which are surrounded by plants and which offer ecosystem services. In most cities there are many parks, promenades, and botanical and dendrological gardens which provide this opportunity. Parks and other urban green spaces offer recreational environments which positively influence human health (Wilson et al. 2016). Often, these zones occupy small areas of land that are adequate for visual separation but do not always provide the expected acoustic conditions. Many authors have investigated the impact of urban noise on parks and other green areas, and the possible limiting of this impact through the use of vegetation barriers, the use of low-noise, thin asphalt layers (TALs), and a reduction in the permissible vehicle speed on adjacent roads (Rey Gozalo et al. 2020; Grangeiro et al. 2021; Petrovici et al. 2016). Good quality soundscapes in parks can only be achieved through a thorough understanding of the complex relationship between noise sources and the environment (Tse et al. 2012). Noise pollution is a challenging environmental issue in densely-built urban areas (Tashakor et al. 2023).

As urban parks are located in city centres and surrounded by roads with heavy traffic and intensive commercial activity, noise

levels often exceed acceptable values (Ozdemir et al. 2014; Zannin et al. 2006). They have therefore been the subject of numerous studies (Margaritis et al. 2018; Yalili Kilic & Abus 2020). Urban parks can act as a buffer against noise pollution (Tashakkor et al. 2020), significantly reducing this negative impact (Cohen et al., 2014). Noise levels vary throughout the year within park areas, with significant differences occurring between leaf fall and foliage periods (Tashakkor & Chamani 2021). The density and number of trees strongly correlates with the amount of noise being blocked. Factors such as the shape and size of the planted areas, and terrain conditions (slope and cover) influence noise distribution across park zones (Oliveira et al. 2022). In addition, there has been indications that there is a relationship between different plant species and a reduction in noise pollution levels (Yofianti & Usman 2021). The fences effectively reduce pollutants, and sound is noticeable in its shadow. At the same time, dense conifers can trap pollutants along park borders and lower concentrations in interiors, but are less efficient at reducing noise (Xing & Brimblecombe 2020). In many countries around the world, such parks very popular, some of which have a long history and contain a large number of plant and animal species (Bednorz & Urbaniak 2005; Celewicz-Goldyn & Boryca 2012; Filimon et al. 2021; da Silva Santos et al. 2023). Another interesting issue is how to increase the rate of green space per capita in cities and how extensive this rate should be to achieve sustainable development goals (Mitincu et al. 2023).

In Poznań—one of the largest cities in Poland—the green space area covers over 500 ha, which includes 45 parks, 119 green spaces, and 42 sites with minimal human intervention (Środowski 2024). These areas shelter inhabitants from noise and heat, and the garden under study is one such place. The studied green area is a dendrological garden situated in a busy part of the city where heavy traffic has been present since the 1990s. The area was planted with flora which constituted both an acoustic and visual barrier. The beginnings of the Dendrological Garden date back to the year 1922, when the living laboratory for students of the Faculty of Wood Science was opened (Dendrological Garden of the Poznań, University of Life Sciences 2024). The first collection included 190 species and covered an area of 0.86 ha. In 1927, the collection grew to 452 species and varieties, and in 1939 this figure nearly doubled; however, the garden was almost destroyed because of the Second World War. In the 1960s, the garden was reconstructed with an area of 4.3 ha, and currently occupies about 20 ha. There are numerous species of forest trees, including those which are deciduous: *Acer campestre* L., *Acer pseudoplatanus* L., *Acer platanoides* L., *Alnus incana* (L.) Moench, *Alnus glutinosa* (L.) Gaertn., *Betula pendula* Roth, *Carpinus betulus* L., *Fagus sylvatica* L., *Fraxinus excelsior* L., *Populus alba* L., *Populus tremula* L., *Quercus petraea* (Matt.) Liebl, *Quercus robur* L., *Quercus rubra* L., *Salix alba* L., *Salix caprea* L., *Sorbus aucuparia* L., *Tilia cordata* Mill., *Tilia platyphyllos* Scop., *Ulmus glabra* Huds., and *Ulmus laevis* Pall. It also contains coniferous trees: *Abies alba* Mill., *Larix decidua* Mill., *Picea abies* (L.) H. Karst., and *Pinus sylvestris* L.

This study aimed to determine the road noise distribution within the Dendrological Garden and its spatial variability. To achieve this, noise measurements were taken at 20 points within the Dendrological Garden and three points directly next to the road. In addition, available acoustic maps were used in the analysis for further comparisons.

The study area

The Dendrological Garden is a park belonging to the University of Life Sciences in Poznań, and is located in the western part of the city between a busy road and the east-northwest railway line (Fig. 1). In addition to the presence of many

trees and shrubs, a small body of water in the centre enhances the attractiveness of the area, and there are bee hives located in the northern part. The park's western side is set back from the road and is perceived by visitors as being a quiet resting place. In fact, the park is densely and almost uniformly wooded along the side of the road.

The area selected for study measured 5.07 ha. The maximum difference in altitude is 11.6 m, and the highest part of the park is located in the northern part of the study area. The slope of the land is from north to south and from northwest to southeast. The slopes are generally uniform and concave. The primary noise source is the main neighbouring street, which consists of six lanes and has a total width of 28 m. In 2006, the average traffic volume was 70,000 vehicles per day (Administration of Municipal Roads 2024). The studies for this paper were conducted in 2014 and 2020 and were carried out only in the case of the absence of vehicle and pedestrian traffic (south and west sides) and the lack of railway and aircraft traffic (Poznań-Lawica Airport route).

Methods

Data collection

Field surveys were carried out during the pre-holiday period in May and early June of 2014 and 2020. Measurements were made at a height of 1.5 m above the ground surface, a regulation intended for undeveloped areas (Regulation of the Council of Ministers 2023, Regulation of the Minister of Climate 2021), using a Center 320 sound level meter (Center, product information 2024). The single microphone was mounted on each of the 20 test stands (1–20) so that the axis of its maximum sensitivity was directed towards the street which was being investigated for noise impact on the park. In addition, three test stands (A, B, C) were placed near the street to determine the noise emitted by vehicles. The three points were located at altitudes of 75.45, 74.02, and 72.98 m asl, respectively. The locations of the test sites are shown in Figure 1. The test stands located within the Dendrological Park were at altitudes of between 70.86 and 79.37 m asl, with point 19 being located at the highest altitude and point 4 at the lowest. The results of calculations based on field measurements are presented in Tables 2 and 3, and Figures 5 and 6.

The first series of measurements were performed in the year 2014:

- 25 May 2014 (Sunday); 12:20 p.m. and 1:50 p.m.; air temperature +27 °C; pressure 1013 hPa; cloud cover 0%; wind speed 13 km/h, westerly direction; regular traffic; vehicle flow - without obstacles.
- 27 May 2014 (Tuesday), 10:00–11:30 a.m.; air temperature +22 °C; pressure 1007 hPa; cloud cover 5%; wind speed 19 km/h, westerly direction; vehicle flow - traffic jam.

The second series was performed in the year 2020:

- 16 May 2020 (Saturday), 10:00–12:00 a.m.; air temperature +12 °C; pressure 1010 hPa; cloud cover 100%; wind speed 18 km/h, westerly direction; vehicle flow - due to COVID-19 restrictions there was limited traffic volume, but most vehicles were traveling at high speed (from 4 May home improvement tool and supply markets were open on weekends, and hotels and art galleries were open).
- 9 June 2020 (Tuesday), 12:00–2:00 p.m.; air temperature +15 °C; pressure 1006 hPa; cloud cover 100%; wind speed 10 km/h, westerly direction; vehicle flow - traffic jam.

The measurement time at each site was 2 min. During the studies, correction curve A was used for sound level measurements, taking into consideration the properties of human hearing. At each site, LAeq (A-weighted equivalent continuous sound level) was determined based on formula (1), from all

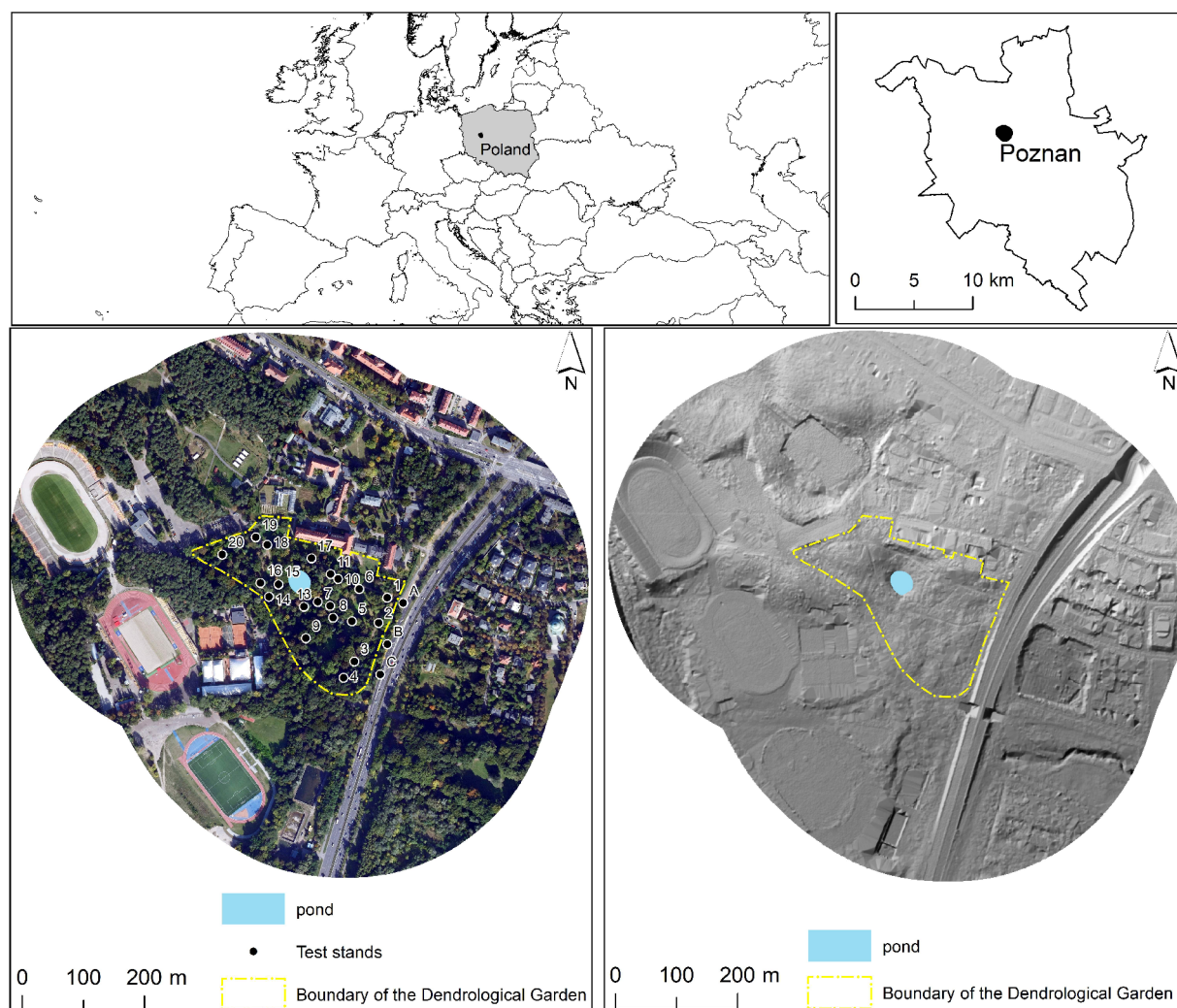


Figure 1. Study site location with satellite and LIDAR-derived images
Source: own elaboration based on Geoportal

recorded momentary values for the examined time interval (Kucharski et al., 1996):

- low annoyance, $LA_{eq} < 52$ dB;
- moderate annoyance, $52 \leq LA_{eq} \leq 62$ dB;
- high annoyance, $62 < LA_{eq} \leq 70$ dB;
- very high annoyance, $LA_{eq} > 70$ dB.

$$L_{eq} = 10 \log \frac{1}{n} \sum_{k=1}^n 10^{0.1 L_k} \quad (1)$$

where:

- L_{eq} is the equivalent sound level,
- n is the number of elementary measurements,
- L_k is the result of elementary measurement in dB.

Based on the results of the noise studies, acoustic maps were developed to illustrate the degree to which noise from road vehicles penetrated into the park. In the evaluation of the acoustic environment of the studied area, a scale of subjective annoyance for external traffic noises was used; this was developed by the State Hygiene Institute based on questionnaire studies (Kolaska 2002):

To analyse the noise under comparable conditions, the results for holidays in 2014 and 2020 and weekdays in 2014 and 2020 were compiled separately. It was assumed that the road traffic intensity would be lower on Saturdays and Sundays than on Monday to Friday, and that recreational use of the park would be higher on holidays than on working days. In 2020, the park was closed to visitors due to pandemic restrictions connected with COVID-19. It should also be noted that the research was carried out during analogous vegetation periods so that the plants in the park were at the same stage of development. The study's results were compared with Poznan's acoustic maps for 2012 to 2017.

Acoustic characteristics in the planning context

The basis for analysing changes in the acoustic environment from a planning point of view is the Decree of the Minister of the

Environment of 1 October 2012, which amended the regulation on permissible noise levels in the environment (Regulation of the Minister of Environment 2012). It shows that recreational and rest areas, which include parks, are classified as noise-sensitive areas. Concerning the long-term policy of sustainable spatial administration, including the designation of new recreation areas, indicators for long-term average sound level A in dB, determined for all days of the year were used: L_{DWN} for *day-evening-night* and L_N for *night periods*. The acoustic maps of road noise for Poznań prepared by the AkustiX and LEMITOR environmental protection offices (The Municipality Office of the City of Poznań 2017) were the data sources utilised for comparing the years 2012 and 2017.

Acoustic maps

The surface area and percentage change in the area of zones which were exposed to different sound levels were determined in order to characterise changes in the acoustic environment; also determined was the course of the noise contours (contour lines of equal sound volume), for example, 68 dB for L_{DWN} and 59 dB for L_N . These characteristics were obtained using ArcGIS software by applying the following steps:

- generated raster acoustic maps for road noise for the years 2012 and 2017, L_{DWN} and L_N indicators;
- georeferenced the raster according to the PUWG_92 mapped coordinate system (Borkowska & Pokonieczny 2022);
- vectorization (routing) by changing the raster graphics to vector graphics;
- determined the areas of surface change at individual boundary intervals using spatial analysis, superimposition, and transformation tools.

Using a data management tool, changes in the course of particular noise contours between 2012 and 2017 were presented as:

$$W_{CA} = \left[\frac{A_{LDWN(LN)2017} - A_{LDWN(LN)2012}}{A_a} \right] (-) \quad (2)$$

where:

- $A_{LDWNx(LN)2017}$ is the area covered by consecutive noise intervals according to the L_{DWN} or L_N indicators for the year 2017 [m^2];
- $A_{LDWNx(LN)2012}$ is the area covered by consecutive noise intervals according to L_{DWN} or L_N for the year 2012 [m^2];
- A_a is the area of the analysed site [m^2].

A negative W_{CA} value indicates a decrease in area and a positive value indicates an increase.

Geostatistical assessment of the acoustic situation of the studied area was carried out using ArcGIS software in the following stages:

- entered the measurement points on the base topographic map according to the coordinates in the PUWG92 system (1992 State Geodetic Coordinate System);
- exported the table with data to a *.shp file;
- created a graphical image of noise contours using interpolation with the 'topo to raster' tool in a spatial analysis based on digital terrain models (Naji et al. 2019);
- raster reclassification carried out according to the assumed values of individual noise contours;
- vector image created of individual acoustic areas utilizing conversion raster to polygon together with their geometry;
- showed changes in the course of individual noise contours for 2014 and 2020 using a data management tool, with an

assumed noise level using the area variability index in the form of

$$W_{CAR} = \left[\frac{A_{X-X(2020)} - A_{X-X(2014)}}{A_a} \right] (-) \quad (3)$$

where:

- $A_{X-X(2020)}$ is the area covered by noise level ranges measured in 2020 [m^2],
- $A_{X-X(2014)}$ is the area covered by noise level ranges measured in 2014 [m^2],
- A_a is the area of the studied park [m^2].

Data analysis

As a result of the analysis of the acoustic maps (Portal of the Spatial Information System of the City of Poznań 2024), an improvement in the acoustic environment can be observed within the study area between 2012 and 2017. Analyses of the road noise maps according to the L_{DWN} index showed that most zones exposed to each noise range had lower noise levels in 2017. The index was within 15% of the 60–70 dB noise level for the total area, and over 3% for the 70–75 dB range's area. Notably, in 2017, there appeared a zone exposed to a noise range of 50–55 dB, which was not present in 2012. The most significant difference occurred in the 55–60 dB range, the area of which had increased by over 33% since 2012 (Table 1, Figure 2).

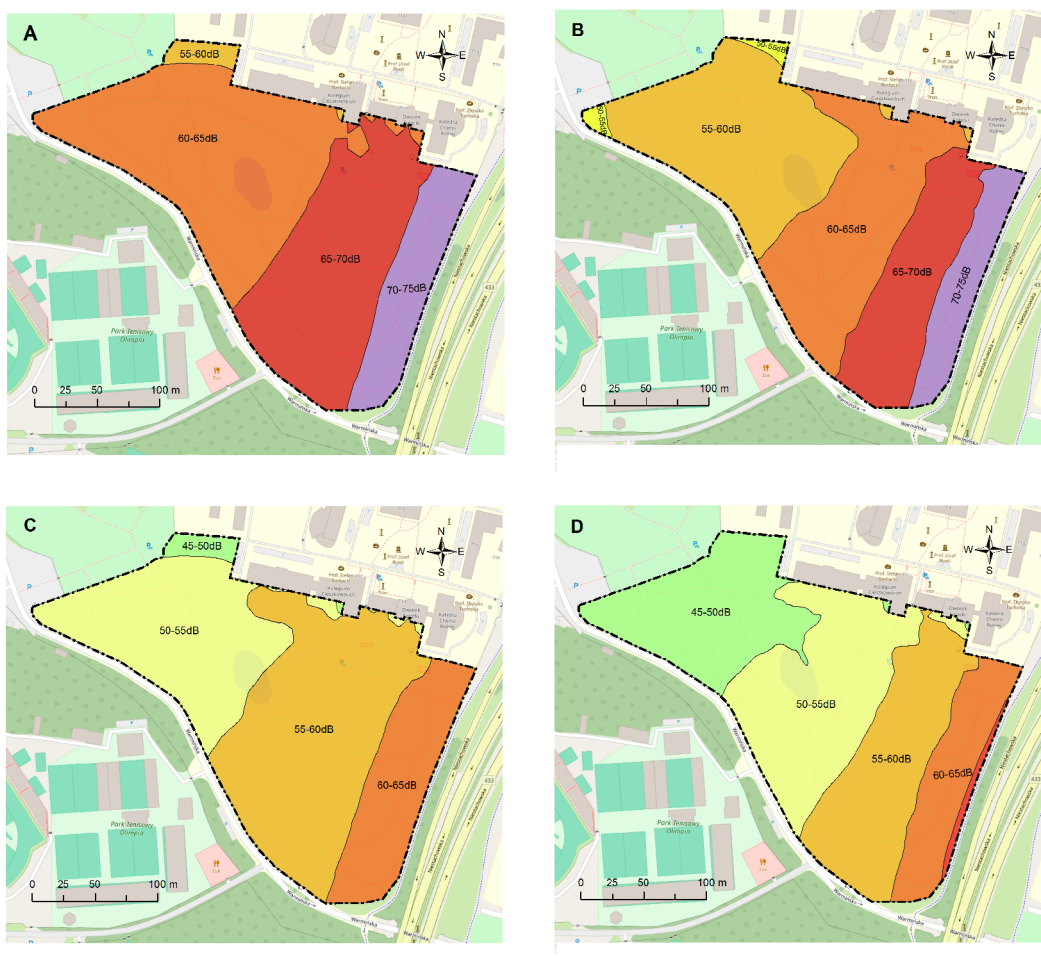
In addition to the significant changes in the areas of the noise range zones, it is noteworthy that the higher noise levels in 2017 were adjacent to the road. The width of the difference between 2012 and 2017 for the 70 dB noise contour, near Niestachowska Street, was 13 m at its widest point, the width of the 65 dB noise contour was 72 m, and the width of the 60 dB noise contour was 170 m. Overall, the park's acoustic environment improved significantly between 2012 and 2017 so that the course of the 55 dB noise contour for 2017 was similar to that of the 60 dB noise contour for 2012 (Figure 3). Considering only the ratio between 2012 and 2017 of the risk area regarding abnormal noise levels, one can discover that the acoustic environment had also improved. In 2012, 28.1% of the analysed area was within the 68 dB noise contour (the maximum limit for recreational areas), while in 2017, this area was only 18.8%. Similarly, the night noise level at 59 dB was 27.8% in 2012 but 20.9% in 2017. Due to the nature of the use of recreational areas, it is not necessary to consider the night-time requirements.

A similar situation occurred when analysing the L_N index. Most of the zones exposed to particular sound ranges decreased in area. For the 55–60 dB noise zone, it was almost 20% of the total study area and for the 60–65 dB zone, 4.5%. The area of the 50–55 dB zone remained almost unchanged. The most significant difference occurred with the enlargement in area of the quietest zone (45–50 dB) by about 23% in relation to the area of the surveyed section (Table 1, Figure 4). In addition to significant changes in area, it should be noted that in 2017, the road noise disappeared at a much closer distance from the road to the garden terrain. The course of the 60 dB noise contour, at its widest point, was closer to the street by about 13 m, while the 55 dB zone was closer by about 60–65 m and the northern strip by as much as 106 m. The 50 dB noise contour was at a distance of 100 m from the street in the year 2012. In general, the acoustic environment of the park improved significantly between the years 2012 and 2017, leading to a situation where the 2017 course of the L_{DWN} 55 dB noise contour was close to that of the 60 dB noise contour in 2012, while at night the L_N 50 dB noise contour moved significantly closer to the 2012 55 dB noise contour (Figure 3). The obtained results for L_{Aeq} , based on the field analyses,

Table 1. Changes in areas exposed to road noise described by L_N and L_{DWN} for the years 2012 and 2017

No.	Features	Range [dB]	Code	Area [m ²]		Index W_{CAR} [-]
				2012	2017	
	Area exposed to road noise in accordance with L_N	45–50	$A_{LN45-50}$	1,018	12,804	0.232
		50–55	$A_{LN50-55}$	16,461	16,380	-0.002
		55–60	$A_{LN55-60}$	23,634	13,613	-0.198
		60–65	$A_{LN60-65}$	9,596	7,293	-0.045
		65–70	$A_{LN65-70}$	0	619	0.012
	Area exposed to excessive noise, L_N	>59	$A_{>59LN}$	27.8%	20.9%	
	Area exposed to road noise in accordance with L_{DWN}	50–55	$A_{LDWN50-55}$	0	750	0.015
		55–60	$A_{LDWN55-60}$	1,086	17,918	0.332
		60–65	$A_{LDWN60-65}$	23,903	15,974	-0.157
		65–70	$A_{LDWN65-70}$	18,616	10,704	-0.156
		70–75	$A_{LDWN70-75}$	7,104	5,387	-0.034
	Area exposed to excessive noise, L_{DWN}	>68	$A_{>68LDWN}$	28.1%	18.8%	

Source: own elaboration

Figure 2. Changes in noise ranges for the L_{DWN} and L_N indicators for 2012 and 2017A - L_{DWN} 2012, B - L_{DWN} 2017, C - L_N 2012, D - L_N 2017

Source: own compilation based on acoustic maps of Poznań

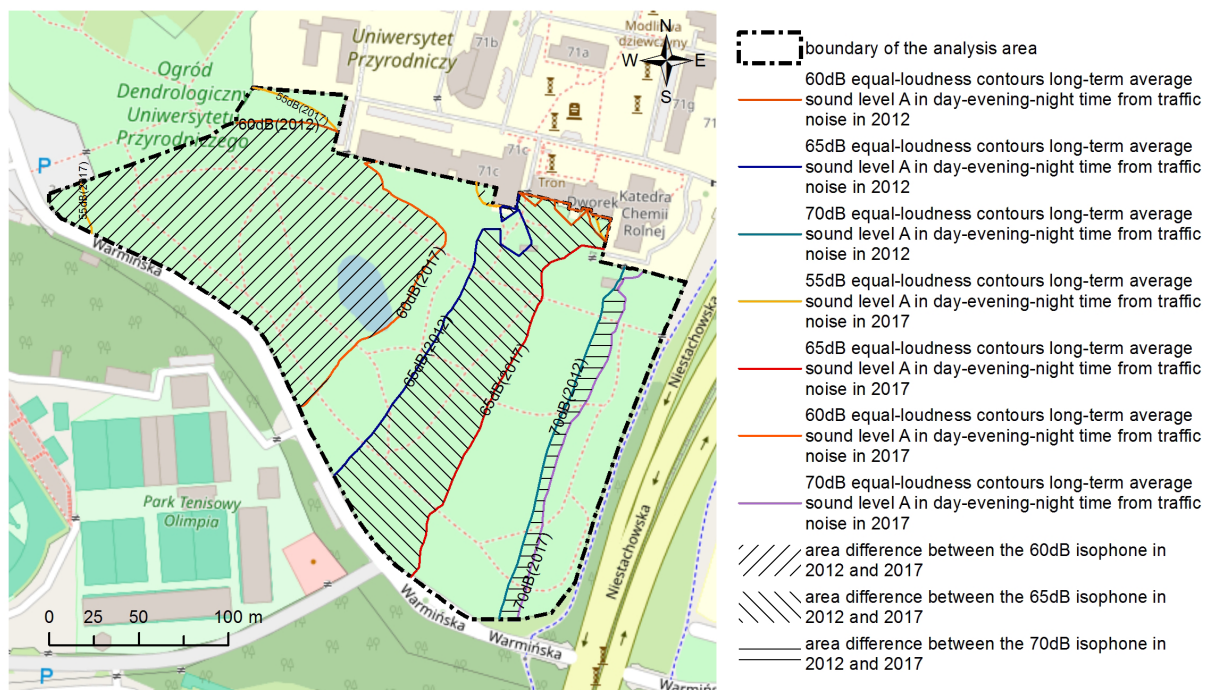


Figure 3. Changes in the course of L_{DWN} noise contours for 2012 and 2017
Source: own elaboration

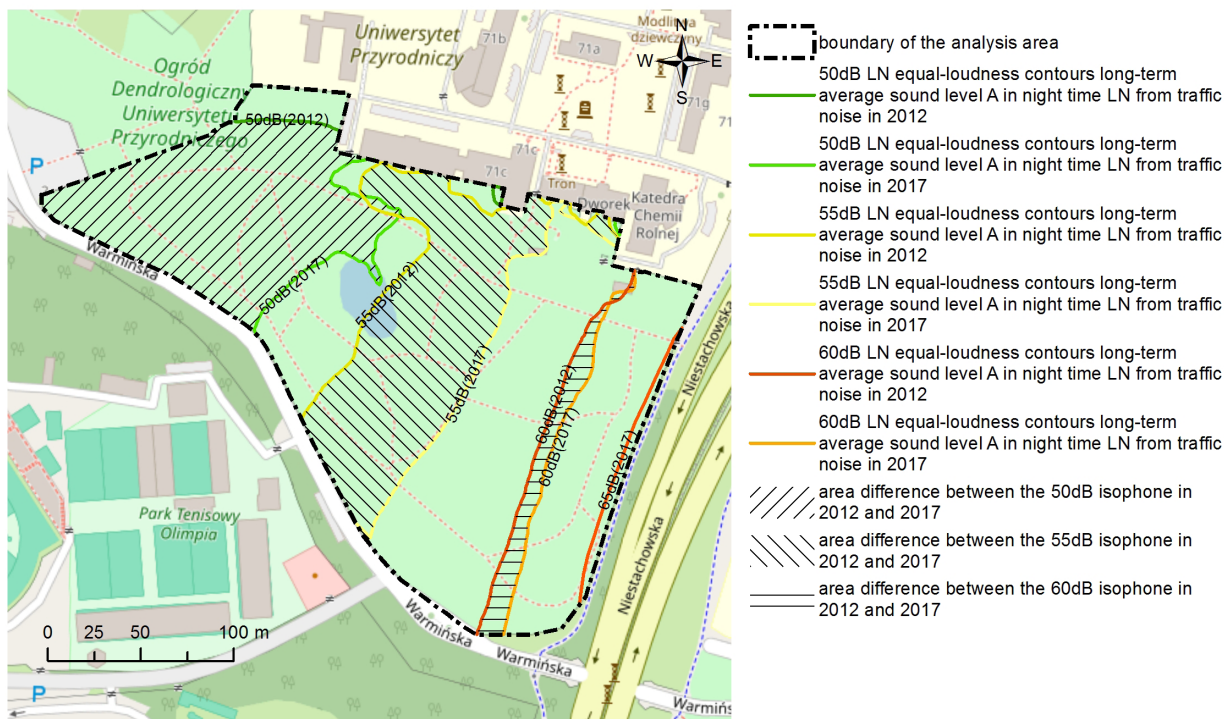


Figure 4. Changes in the course of L_N noise contours for 2012 and 2017
Source: own elaboration

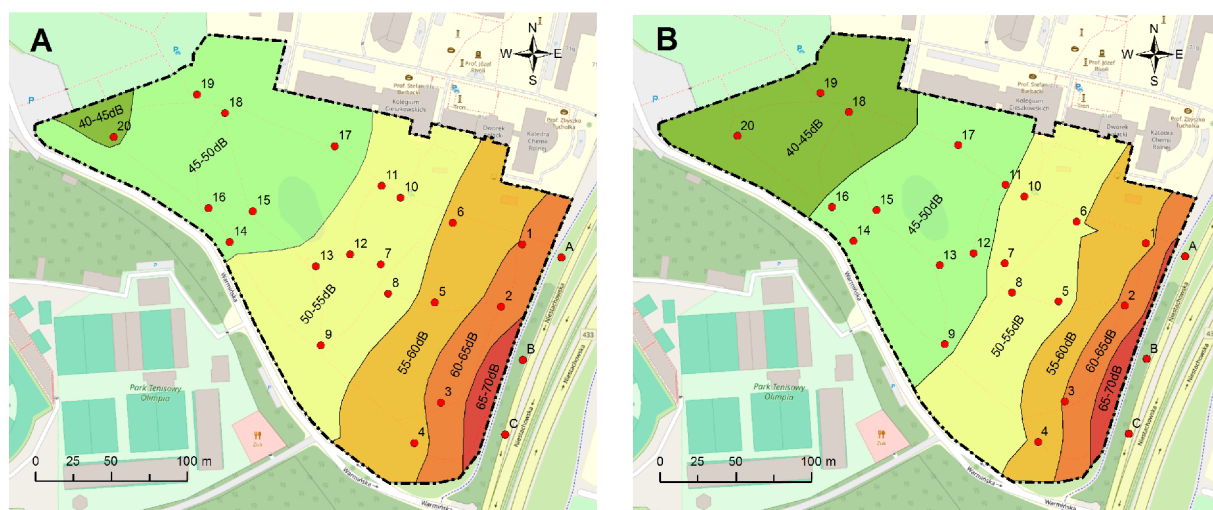


Figure 5. Areas exposed to road noise within the limits of the study area on weekdays: A - LAeq 27 May 2014 (Tuesday), B - LAeq 9 June 2020 (Tuesday).

Source: own elaboration



Figure 6. Areas exposed to road noise within the limits of the study area on public holidays: A - LAeq 25 May 2014 (Sunday), B - LAeq 16 May 2020 (Saturday)

Source: own elaboration

are presented in Table 2 for both studied years and courses of selected noise contours, as shown in Figures 5 and 6.

The L_N and L_{DWN} indicators are mainly used for long-term spatial policy, in order to allocate land for new functions, taking into consideration acoustic criteria. These indicators do not illustrate the actual road traffic noise exposure for a person spending, for example, an hour in a green area. Therefore, an interpretation has been made in terms of direct noise exposure based on direct measurements.

The differences detected during holidays were much smaller, and the area of the 45–65 dB noise range increased by less than two times (Table 2, Figure 6). This was in the range of 3–7% for the 45–65 dB noise levels for the total study area. A minor

change in the area of the zone most exposed to noise was noted, while the section least exposed to noise (40–45 dB) significantly expanded, by almost 20% in relation to the area of the entire analysed terrain (Table 2, Figure 5). On holidays (Saturdays), the changes were similar (within 2–5% for 45–65 dB noise levels). The area of the zone with noise levels of 65–70 dB decreased by only 0.4%, while the 40–45 dB zone increased by more than 16% of the total area of the analysed site (Table 2, Figure 6). Those parts of the area which had above-normal noise levels occupied about 2.5% on weekdays, but on holidays it was only about 1.5%. The reduction in area between 2014 and 2020 for the above 65 dB noise levels was insignificant. Comparing the results obtained for Tuesdays, there was an improvement in the acoustic

Table 2. Results of the LAeq analyses

Site	25 May 2014	27 May 2014	16 May 2020	9 June 2020
		LAeq	[dB]	
1	59.2	60.1	57.3	56.8
2	59.3	61.0	56.6	60.7
3	60.0	62.2	60.1	60.4
4	56.1	57.2	54.1	54.9
5	55.7	56.4	56.2	52.3
6	55.1	55.6	52.0	54.6
7	51.9	52.3	50.5	52.2
8	52.0	52.4	53.4	50.6
9	50.6	52.9	48.4	49.4
10	52.4	52.6	47.9	52.8
11	50.0	51.2	44.2	49.3
12	49.9	50.9	47.7	47.5
13	49.1	50.3	47.0	47.2
14	47.0	49.9	44.0	46.6
15	46.1	49.1	43.8	46.5
16	45.2	48.7	43.7	45.3
17	45.7	48.2	43.8	44.9
18	44.5	46.0	43.2	44.1
19	43.3	45.6	43.1	43.2
20	42.9	44.6	42.0	40.7
A	66.1	67.3	67.3	72.4
B	71.1	71.3	71.1	71.7
C	72.9	72.6	72.4	74.1

Source: own elaboration

environment, which was evidenced by the increasing 40–45 dB area for LAeq. This may have happened due to the changing density of the park's vegetation (deciduous and coniferous trees and shrubs). The area of the zone with LAeq above 65 dB decreased from 2.64% to 2.48%. The shrub vegetation had also become denser in the study area, especially in front of sites 1–4, 6, 10, 11, 14, 15, 17, and 18 (Figure 1).

Discussion

Recent changes to every aspect of human life, including increasing exposure to noise, have been observed in most parts of the globe, both on land and in water, triggering countermeasures and new methodologies (Myrberg 1980; Mazaris et al. 2009; Farina et al. 2014; Pawlat-Zawrzykraj et al. 2021). Acoustic pollution is one of the primary factors of land degradation (Farina 2019; Can et al. 2020; Podawca et al. 2021), especially in cities and all kinds of urban

Table 3. Changes in area of zones affected by road noise according to studies from the years 2014 and 2020 (average values)

No	Feature	Acoustic range [dB]	Code	Area [m ²]		W _{CAR} Index [-]
				27th May 2014 Tuesday	9th June 2020 Tuesday	
1.	Area exposed to road noise according to the index	40-45	A ₄₀₋₄₅	1058	10981	0.196
2.		45-50	A ₄₅₋₅₀	17143	15088	-0.041
3.		50-55	A ₅₀₋₅₅	15294	12858	-0.048
4.		55-60	A ₅₅₋₆₀	10575	6779	-0.075
5.		60-65	A ₆₀₋₆₅	5301	3744	-0.031
6.		65-70	A ₆₅₋₇₀	1338	1259	-0.002
7.	Percentage of area exposed to above-normal noise L _{AeqD}	>65	PA _{>65}	2.64%	2.48%	
				25th May 2014 Sunday	16th May 2020 Saturday	
8.	Area exposed to road noise according to the index	40-45	A ₄₀₋₄₅	9951	18237	0.163
9.		45-50	A ₄₅₋₅₀	13502	10857	-0.052
10.		50-55	A ₅₀₋₅₅	12899	10589	-0.046
11.		55-60	A ₅₅₋₆₀	9416	7219	-0.043
12.		60-65	A ₆₀₋₆₅	4053	3109	-0.019
13.		65-70	A ₆₅₋₇₀	888	698	-0.004
14.	Percentage of area exposed to above-normal noise L _{AeqD}	>65	PA _{>65}	1.75%	1.38%	

Source: own elaboration

green areas. Botanical and dendrological gardens are examples of quiet zones, which can play a crucial role in the well-being of local communities and tourists. Our studies were conducted in a dendrological garden, while additional data for further analyses were retrieved from documents containing acoustics maps of Poznań. An improvement in acoustic environment can be observed between 2012 and 2017 within the studied green area.

To some extent, this could be a result of the modernisation of the neighbouring road which took place in 2013 (new asphalt pavement), but may also be due to plant growth rate in the area between the road and the park, as observed from the eastern side. Analysing road noise maps using data from weekday studies shows that between 2014 and 2020, most of the areas of zones exposed to specific sound ranges decreased, excluding zones which had low noise. The area of the 45–65 dB noise zone was significantly more extensive for weekdays in 2020, while the area of the 65–70 dB zone decreased by over nine times (Table 2, Figure 5).

An observed expansion of the belt of above-normal noise to the north may be related to the increase in traffic on the

neighbouring crossroads from the west (near Site A). Similar trends can be observed when analysing the differences between the results obtained on non-working days in 2014 and 2020, as in the case of Tuesdays. To some extent, the more significant reduction in the area of those zones exposed to noise exceeding the LAeqD (from 1.75% to 1.38%) may also have occurred due to the restrictions imposed during COVID-19, when vehicle traffic was lower than in 2014. The pandemic caused an unusual reduction in traffic, and a significant decrease in the noise index was to be expected. Such an anomaly is difficult to interpret, especially when associated with increased vehicle speeds. If a traffic reduction situation emerges in the future, relevant studies are planned for the presented area.

Conclusions

The studied area—a dendrological garden—is a valuable part of Poznań's city green areas, both during work days and on weekends, providing shelter from road noise and contact with nature; thus, even small spaces (about 5 ha) which are located in urban areas can provide zones for resting. Dense and well-maintained vegetation can help create excellent spots with acceptable noise conditions while also offering a place for educational activities. Introducing speed limits with speed bumps

could improve the resting quality in such areas. An ideal solution would be using low-noise thin surface layers of asphalt (TALs) at the same time as using the concepts mentioned above, and in the case of the studied park, a noise level range of 40–45 dB could cover most of the analysed area. Findings from presented studies could be an important contribution to urban planning practice due to the clear message presented, based on the results of the studies that have been carried out. The presence of such green zones can improve the quality of life in cities and the number of green zones should be increased if possible.

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References

- Bednorz, L & Urbaniak, A 2005, 'Phenology of the wild service tree (*Sorbus torminalis* (L.) Crantz) in Poznań and Wielkopolski National Park', *Dendrobiology*, vol. 53, pp. 3–10.
- Borkowska, S & Pokonieczny, K 2022, 'Analysis of OpenStreetMap data quality for selected counties in Poland in terms of sustainable development', *Sustainability*, vol. 14, no. 7, article number 3728.
- Can, A, L'hostis, A, Aumond, P, Botteldooren, D, Coelho, M C, Guarnaccia, C & Kang, J 2020, 'The future of urban sound environments: Impact in mobility trends and insights for noise assessment and mitigation', *Applied Acoustics*, vol. 170, article number 107518.
- Center – Product information, website. Available from: <https://www.centertek.com/product_d.php?lang=en&tb=1&cid=82&id=253>. [25.03.2024].
- Cohen, P, Oded, P & Schnell, I 2014, 'The impact of an urban park on air pollution and noise levels in the Mediterranean city of Tel-Aviv, Israel', *Environmental Pollution*, vol. 195, pp. 73–83.
- Celewicz-Goldyn, S & Boryca, I 2012, 'The phytoplankton community in the permanent pond of the Dendrological Garden, Poznań University of Life Sciences in springtime 2011', *Botanika-Steciana*, vol. 391, no. 16, pp. 67–74.
- Dendrological Garden of the Poznań University of Life Sciences. Available from: <<https://www1.up.poznan.pl/ogrod>>. [25.03.2024].
- Directive 2002/49/EC of the European Parliament and of the Council of June 25 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise, p. 25. Available from: <<https://eur-lex.europa.eu/eli/dir/2002/49/oj>>. [25.03.2024].
- Farina, A, Buscaino, G, Ceraulo, M & Pieretti, N 2014, 'The soundscape approach for the assessment and conservation of Mediterranean landscapes: principles and case studies', *Journal of Landscape Ecology*, vol. 7, no. 1, pp. 10–22.
- Farina, A 2019, 'A quantitative approach to investigate the ecological role of environmental sounds', *Mathematics*, vol. 7, no. 1, article number 21.
- Filimon, C, Tatar, CC, Luminița Anisoara Filimon, LA & Herman, LM 2021, 'Urban green spaces – A support for physical activities and tourism. Case study Oradea Municipality, Bihor, Romania', *Baltic Journal of Health and Physical Activity*, vol. 13, no. 6 pp. 27–39.
- Grangeiro de Barros, A, Kampen JK & Vuye, C 2021, 'The impact of thin asphalt layers as a road traffic noise intervention in an urban environment', *Sustainability*, vol. 13, article number 12561.
- Kołaska, A 2002, *Acoustic climate of the City of Poznań (1997–1999)*, Biblioteka Monitoringu Środowiska WIOŚ, Poznań. Available from: <<https://poznan.wios.gov.pl/monitoring-srodowiska/publikacje/klimat/lit.html>>. [25.03.2024].
- Kucharski, RJ, Chyla, A, Koszarny, Z, Kraszewski, M, Szymański, Z, Sakowska, P & Taras, A 2002, *Stan klimatu akustycznego w kraju w świetle badań WIOŚ*, [The state of the acoustic climate in the country in the light of the National Environment Protection Inspectorate study], Biblioteka Monitoringu Środowiska, Warsaw, Poland.
- Kucharski, R, Kraszewski, M & Kurpiewski, A 1996, *Metody pomiaru hałasu zewnętrznego w środowisku*, [Methods for measuring external noise in the environment], Biblioteka Monitoringu Środowiska, Warsaw, Poland.
- Kucharski, RJ 2011, *Wytyczne do opracowania map akustycznych*, [Guidelines for developing acoustic maps], Instytut Ochrony Środowiska, Warsaw, Poland.
- Margaritis, E, Kang, J, Filipan, K & Botteldooren, D 2018, 'The influence of vegetation and surrounding traffic noise parameters on the sound environment of urban parks', *Applied Geography*, vol. 94, pp. 199–212.
- Mazaris, AD, Kallimanis, AS, Chatzigiannis, G, Papadimitriou, K & Pantis, JD 2009, 'Spatiotemporal analysis of an acoustic environment: interactions between landscape features and sound', *Landscape Ecology*, vol. 9, no. 24, pp. 817–831.
- Mitincu, CG, Grădinaru, IC, Hartel, T, van Lierop, M & Hossu, CA 2023, 'The public consultation is open: Insights from urban green infrastructure planning in Romania', *Urban Forestry & Urban Greening*, vol. 86.

- Myrberg, AA, 1980, 'Fish bio-acoustics: its relevance to the 'not so silent world', *Environmental Biology of Fishes*, vol. 5, pp. 297–304.
- Naji, DA, Akin, MK & Cabalar, FK 2019, 'Mapping of F_{s30} and N_{30} for Kahramanmaraş City, Turkey with topo to raster technique', *Proceedings of ISADET - International Symposium on Advanced Engineering Technologies*, KSU Faculty of Engineering and Architecture, pp. 636–639.
- Oliveira, JDD, Biondi, D & Reis, ARND 2022, 'The role of urban green areas in noise pollution attenuation', *Dyna*, vol. 89, no. 220, pp. 210–215.
- Ozdemir, B, Bayramoglu, E & Demirel, O 2014, 'Noise pollution and human health in Trabzon parks', *Studies on Ethno-Medicine*, vol. 8, no. 2, pp. 127–134.
- Pawłał-Zawrzykraj, A, Ogłęcki, P & Podawca, K 2021, 'Analysis of the noise pollution in the Bielański Forest NATURA 2000 Area in light of existing avifauna (Warsaw, Poland)', *Forests*, vol. 12, no. 10, article number 1316.
- Petrovici, A, Tomozei, C, Nedeff, F, Irimia, O & Panainte-Lehadus, M 2016, 'Review on the road traffic noise assessment', *Journal of Engineering Studies and Research*, vol. 22, no. 1, pp. 81–89.
- Podawca, K & Staniszewski, R 2019, 'Impact of changes of the permissible railway noise levels on possibilities of spatial management in urban areas', *Rocznik Ochrony Środowiska*, vol. 21, no. 2, pp. 1378–1392.
- Podawca, K & Karpiński, A 2021, 'Analysis of spatial development possibilities of properties endangered by road noise in the context of permissible LN and LDWN indicators', *Ecological Engineering*, vol. 22, no. 5, pp. 238–248.
- Podawca, K, Karsznia, K & Jewuła, K 2021, 'Land development policy as related to real estate influenced by railway noise in the context of allowable indicators that have been recently modified in Poland', *Miscellanea Geographica*, vol. 25, no. 3, pp. 155–168.
- Portal of the Spatial Information System of the City of Poznań. Available from: <<https://195.216.117.150/sip/news>>. [25.03.2024].
- Rey Gozalo, G, Suárez, E, Montenegro, AL, Arenas, JP, Barrigón Morillas, JM & Montes González, D 2020, 'Noise estimation using road and urban features', *Sustainability*, vol. 2, article number 9217.
- Regulation of the Minister of Environment of October 1, 2012 amending the Regulation on permissible levels of noise in the environment. Available from: <<https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20120001109>>. [25.03.2024].
- Rozporządzenie Ministra Klimatu i Środowiska z dnia 7 września 2021 r. w sprawie wymagań w zakresie prowadzenia pomiarów wielkości emisji, [Regulation of the Minister of Climate and Environment, dated September 7, 2021, on the requirements for conducting emission measurements]. Available from: <<https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20210001710>>. [25.03.2024].
- Rozporządzenie Rady Ministrów z dnia 14 lutego 2023 r. zmieniające rozporządzenie w sprawie szczegółowego zakresu i sposobów realizacji niektórych zadań Agencji Restrukturyzacji i Modernizacji Rolnictwa, [Regulation of the Council of Ministers of February 14, 2023, amending the Regulation on the detailed scope and methods of implementation of certain tasks of the Agency for the Restructuring and Modernization of Agriculture]. Available from: <<https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20230000308>>. [25.03.2024].
- da Silva Santos, A, Inti de Souza, J, Tesserolli de Souza, M, Schaffrath, V R, Galvão, F & Bohn Reckziegel, R 2023, 'Urban parks in Curitiba as Biodiversity Refuges of Montane Mixed Ombrophilous Forests', *Sustainability*, vol. 15, no. 2, article number 968.
- Środowisko 2024, *Więcej zieleni w Poznaniu*, [More green areas in Poznań]. Available from: <<https://www.poznan.pl/mim/wos/news/1016/wiecej-zieleni-w-poznaniu,198555.html>>. [25.03.2024].
- Tashakkor, S, Chamani, A, Nadoushan, MA & Moshtagie, M 2020, 'Acoustics in urban parks: Does the structure of narrow urban parks matter in designing a calmer urban landscape?', *Frontiers of Earth Science*, vol. 14, pp. 512–521.
- Tashakor, S & Chamani, A 2021, 'Temporal variability of noise pollution attenuation by vegetation in urban parks', *Environmental Science and Pollution Research*, vol. 28, pp. 23143–23151.
- Tashakor, S, Chamani, A & Moshtagie, M 2023, 'Noise pollution prediction and seasonal comparison in urban parks using a coupled GIS-artificial neural network model', *Environmental Monitoring and Assessment*, vol. 195, no. 2.
- Tse, MS, Chau, CK, Choy, YS, Tsui, WK, Chan, CN & Tang, SK 2012, 'Perception of urban park soundscape', *Journal of the Acoustical Society of America*, vol. 131, no. 4, pp. 2762–2771.
- Ustawa z dnia 27 kwietnia 2001 r. Prawo ochrony środowiska, [Legal Act of Parliament from April 27, 2001, 'Environmental Protection Law']. Available from: <<https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdU20010620627>>. [25.03.2024].
- Urząd Miasta Poznania 2017, *Acoustic map of Poznań in 2017*, AkustiX, Lemitor, Przeźmierowo, Poznań. Available from: <http://195.216.117.150/sip/inc/data/akustyka_tekst/Mapa_akustyczna_opis_pliki/2017/tekst/Mapa_akustyczna_miasta_Poznania_2017.pdf>. [25.03.2024].
- Wilson, JD, McGinnis, N, Latkova, P, Tierney, P, Yoshino, A 2016, 'Urban park soundscapes: Association of noise and danger with perceived restoration', *Journal of Park and Recreation Administration*, vol. 34, no. 3.
- Xing, Y & Brimblecombe, P 2020, 'Traffic-derived noise, air pollution and urban park design', *Journal of Urban Design*, vol. 25, no. 5, pp. 590–606.
- Yalili Kilic, M & Abus, MN 2020, 'Determination of noise pollution in the Hudavendigar Urban Park of Bursa, Turkey', *Applied Ecology Environmental Research*, vol. 18, no. 2, pp. 2073–2085.
- Yofianti, D & Usman, K 2021, 'Relationship of plant types to noise pollution absorption level to improve the quality of the road environment', *IOP Conference Series: Earth Environmental Science*, vol. 926, article number 012074.
- Zannin, PHT, Ferreira, AMC & Szeremetta, B 2006, 'Evaluation of noise pollution in urban parks', *Environmental Monitoring and Assessment*, vol. 118, p. 423–433.
- Zarząd Dróg Miejskich 2024, [Administration of Municipal Roads], Poznań. Available from: <<https://zdm.poznan.pl>>. [25.03.2024].