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Spatial Analyses in the Planning of Quiet Areas: A Case Study of Radom and Lublin (Poland)

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Abstract: The 2020 Environmental Noise in Europe report shows that a vast majority of European countries have legal definitions of quiet areas and criteria for their designation. As much as 60% of them have designated at least one quiet area in their territory and have taken measures to protect the acoustic climate in these areas. In Poland, although the instrument was introduced in the national environmental legislation, guidelines for delimitation have not been defined yet in the form of a binding legal act. The objective of this article is to propose the method for identifying quiet areas through spatial analysis and present it on the example of two cities—Radom and Lublin. These cities represent different approaches to the designation of quiet areas. This work is a continuation of the survey conducted and published by the authors in 2023. At the outset, the legislation and literature on the subject were analysed. Based on that, the conditions that potential quiet areas must meet were determined. Spatial analyses were then conducted for the quiet areas proposed earlier in the survey and in the environmental noise programme to see if the criteria selected by the authors were actually met in these areas: acoustic, functional, related to land cover, size, as well as temporal, spatial and transport accessibility, and location, including distances from areas with the highest noise emissions and adequate population density. Quiet areas are forest areas, public green areas, and surface water areas with recreational functions. The criteria for the elimination of the selected quiet areas were mainly location related (distance from main roads and population density). The accessibility of the quiet areas is also important. A method devised by the authors enables the delimitation of quiet areas in cities. Furthermore, this method is primarily based on publicly available data, which makes it applicable to other cities as well.

Keywords: quiet areas; noise; soundscape; urban greenery; GIS; Poland

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1. Introduction

Sound is an integral element of geographical space [1]. Whenever society appears, sound also appears [2], although it is also part of animate ("biophony") and inanimate ("geophony") nature [3]. While sounds are perceived by each person individually, in a positive or negative light, they have a unique impact on the environment [4] and on its perception. Noise is a component of the environment. In acoustics, the perception of sound as noise is increasingly regarded as a result of a complex and dynamic process that involves sound, the environment, and people [5]. Noise constitutes a particular challenge, especially in heavily urbanised areas. Long-term exposure to noise may have negative effects on the health and lives of residents [6]. Furthermore, noise has a significant impact on the quality of life, as the acoustic environment is an important determinant of an individual's well-being and mental comfort [7]. Unfortunately, the human right to quietness or silence is often downplayed [8]. It is worth noting that as early as 1969, Polish composer Lutosławski made an appeal to UNESCO calling for the right to quietness. At the same time, Canadian composer Schafer popularised the concept of soundscape as a response to the growing

threat of noise. As Kang pointed out, researchers and practitioners paid more attention to this concept only when the Directive of the European Parliament and of the Council of 25 June 2002 emphasised the need to create and protect quiet areas [9].

In 2014, soundscape was included in an international standard (ISO 12913-1:2014) as "the acoustic environment perceived or experienced and/or understood by a person or people, in context" [10]. According to this standard, the soundscape concept focuses on the mutual relationship between sound, person and environment, both in space and time. The context of sound perception is important. It should be noted here that the above standard was developed in 2018 and 2019 through ISO 12913-2: 2018 [11] and ISO 12913-3: 2019 [12]. Another standard (design and intervention) is currently under preparation. These standards contribute to the UN Sustainable Development Goals [13]. After all, proper noise management and protection of places that are not exposed to the negative impact of noise are important for the sustainable development of cities and non-urbanised areas.

Quietness or silence is perceived as the absence of sound. However, this state does not naturally occur in the environment. Quietness is actually a mental concept because it includes factors not related to sound pressure levels, but primarily to human expectations and feelings [14]. Technological change occurs very fast nowadays. As a result of the continuous increase in traffic intensity, noise has become part of the everyday experience in cities. Changes in the functional and spatial structure of urban areas can provide a solution to the problem of noise. In particular, increasing the area of green spaces and their number, or designating a greater number of pedestrian zones and bicycle routes can have a positive effect on the acoustic climate of cities [4]. The protection of places not exposed to noise, i.e., quiet areas, is also significant. It is a key initiative aimed at optimising urban acoustic environment and improving the quality of life in cities [15].

One of the main documents related to the assessment and management of environmental noise is Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 [16]. It presents assessment methods and imposes obligations, including those related to preparing strategic noise maps to identify hazards from various sources and develop ways to minimise noise pollution. The directive introduces the concept of quiet areas, referring to areas with low levels of noise generated by human activity, and distinguishes between quiet areas in an agglomeration and open country. It leaves Member States a lot of room for interpretation both with regard to defining a quiet area as well as the applicable criteria for designating quiet areas. These areas should provide the possibility of relaxation, rest from the hustle and bustle of the city, and relief from stress, furthermore they are also an instrument for the protection of soundscape [17].

It should be noted that properly designated and protected quiet areas can bring not only economic but, above all, social and environmental benefits because they have a particularly beneficial effect on the health and well-being of both city dwellers and tourists [18–20]. Enjoying nearby quiet areas existing in noisy surroundings, helps reduce irritation, improve well-being, or mitigate stress [21,22]. Quiet areas also benefit from biodiversity, understood as the occurrence of numerous plant and animal species, because the natural sounds of nature are valued positively by the public [23,24]. Quiet areas should be designated in places with considerable amounts of greenery ensuring the existence of natural corridors without disruptive sound sources, and to prevent the destruction and fragmentation habitats [23]. Extensive quiet areas may provide a safer place to live for animals. Many animal species rely on acoustic communication, and there is evidence that anthropogenic noise has a negative impact on wildlife reproductive success, population size, species richness, as well as behaviour. Therefore, quiet areas could offer a refuge to some animals species [25]. The benefits of quiet areas are also manifested in increased property prices [26].

Quiet areas must meet certain requirements that differ across countries. For the most part, however, these criteria are different for areas designated in cities on the one hand and in open country on the other. Research conducted by the European Environment

Agency (EEA) shows that at least one quiet area has been designated in 60% of European countries [17]. The EEA also proposes recommendations for limits on noise levels in cities.

The criteria indicated by the European Environment Agency for delimiting quiet areas in agglomerations include not exceeding the noise threshold (Lden < 55 dB); land use and land cover: recreation and leisure areas, cultural heritage sites, and public spaces, sensitive sites (hospitals, schools), considerable vegetation cover; safe distance from sources of noise disturbance (1–10 km depending on the level of disturbance); minimum area (0.3–9 ha, preferably 1 ha), high scenic (aesthetic) value, including a pleasant soundscape and accessibility (10 min walk) [14]. The EEA has also proposed the use of the Quietness Suitability Index (QSI), which is designed to indicate the current acoustic status of an assessed site and its suitability for creating a safe oasis of tranquillity. It takes into account distance from the source of noise, land cover according to the CORINE database, and population density [25].

The Polish Act on Environmental Protection Law of 27 April 2001 (JoL 2001 No. 62, item 627 as amended) refers to quiet areas located within and outside agglomerations [27]. The latter are areas where noise levels expressed with the LDEN index have not been exceeded (JoL No. 2001 no. 62, item 627. Art. 3 par. 1 item 10a). Quiet areas outside agglomerations are not defined by the permitted noise levels, but rather by the absence of noise caused by traffic, industry, or recreational and leisure activities (JoL No. 2001 no. 62, item 627. Art. 3 par. 1 item 10b).

The designation of quiet areas in Poland is not mandated by national legislation, but a borough (poviat) council may adopt a resolution to designate such an area. Such a resolution is binding for spatial planning instruments (JoL No. 2001 no. 62, item 627. Art. 73 par. 1 item 2a) [27]. This means that local legislation may not be used to allocate land for "activities that could increase noise levels" [28]. However, no criteria for designating quiet areas have been formulated so far. Potential quiet areas are often overlooked in environmental protection programmes against noise, or are designated without an accepted methodology. An analysis of environmental protection programmes against noise in Polish agglomerations demonstrated that noise protection was often limited to the screening off of the main traffic arteries with sound barriers or replacing window joinery [29]. The crucial role of spatial planning, including the designation of quiet areas, is overlooked. It should be noted, however, that the findings of studies on the soundscape of urban parks have been published in recent years [30,31], which is probably thanks to the growing interest in green areas within conurbations as potential quiet areas.

The acoustic state of the environment and the changes occurring are supervised by the Chief Inspector of Environmental Protection, within the state environmental monitoring framework. Assessment is carried out based on strategic noise maps or the results of measurements of noise levels expressed with noise indicators LAeqD, LAeqN, LDEN, LN, taking into account demographic, land management, and land use data (Art. 117 par. 1 item 1 of the Act on Environmental Protection Law) [27]. Acoustic maps serve a primarily informational function and are prepared for major railways, roads and airports, as well as cities with more than 100,000 inhabitants (Art. 118 par. 2 of the Act on Environmental Protection Law) [27]. As part of a project to strengthen noise monitoring with regard to the preparation of noise maps, a study on good practices for establishing quiet areas was recently prepared, which included the identification of quiet areas for two cities: Koszalin and Sosnowiec, as a pilot action using the criteria proposed by the EEA [32]. However, this is not an officially approved method.

The objective of this paper is to propose the method for identifying quiet areas through spatial analysis and present it on the example of two cities in Poland (Radom and Lublin), representing different approaches to the identification of quiet areas. Quiet areas are not designated in Poland by resolution, which may be due to the lack of a method generally accepted and introduced by an appropriate legal act. Therefore, the definition of such a method is an important step towards the designation of quiet areas in Poland. The discourse on quiet areas already has many approaches, but this topic is not popular in

Poland. The only officially proposed methodology was presented in the draft Program of Environmental Protection from Noise for Warsaw (2009). Other methodologies (including the previously mentioned method used for Koszalin and Sosnowiec) are only a set of informal recommendations based on EEA criteria. Therefore, it is not possible to indicate whether this method used for Warsaw is the most appropriate because it has been proposed and verified for only one and the largest city in Poland. Nevertheless, the method has some shortcomings, which, based on the literature review, it was decided to fill using the additional criteria proposed by the EEA. A review of the literature showed that mainly social surveys and spatial analyses are carried out to identify quiet areas [33–37]. Our proposed method is based on spatial analyses. However, public opinion was also addressed through previous surveys. As shown in many publications [33–35,37], the opinion of residents is important when delimiting quiet areas. Accordingly, surveys were carried out among residents in Radom and Lublin in 2022, and their results were published in 2023 [38]. They showed that the quiet areas are forest areas, public green areas, and surface water areas with recreational functions. Their accessibility is also important. This research was the base as the areas identified in the survey were analysed in this article, which focuses on spatial analyses as the next stage of the research, following the survey. Will they confirm the indications of the respondents? Will the quiet areas be all those they typified? Which criteria could possibly influence the elimination of certain areas? In this way, this research fills a research gap.

2. Materials and Methods

The present study is based on case studies of two cities, Lublin (located in eastern Poland) and Radom (in central Poland) (Figure 1). They are characterised by different locations and conditions and vary in size and rank. Despite a relatively small distance between them (100 km/62 miles), these cities are in different voivodeships (Lublin in the Lubelskie Voivodeship, Radom in Mazowieckie Voivodeship). They also differ in the approach to identifying quiet areas, which are reflected in Environmental Protection Programmes Against Noise. Quiet areas were proposed for Radom, while in Lublin they were not. One wonders, therefore, whether Lublin really does not have the potential to designate quiet areas? Is the absence of such areas in the programme due to the lack of an official method of identifying them?

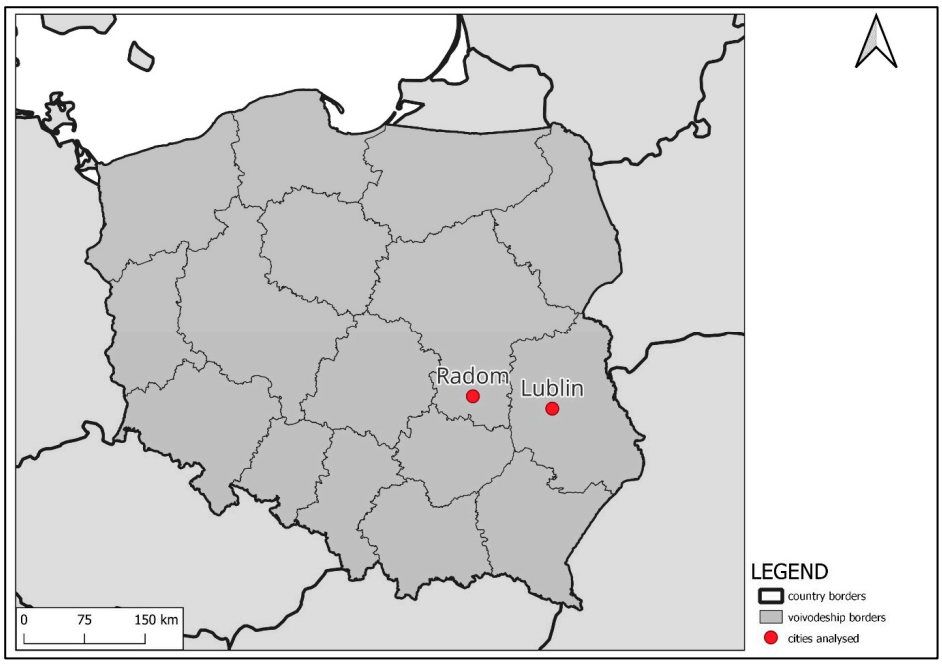


Figure 1. Location of Radom and Lublin.

Radom is a city with borough status. It is located in Mazowieckie Voivodeship approximately 100 km south of Warsaw and 100 km west of Lublin. It covers an area of 112 km^2, and its population was 197,848 people in 2022 [39]. While the city of Radom serves many functions, similarly to Lublin, it is Warsaw, the voivodeship and national capital, that fulfils most of the central administration functions. According to the physical–geographic regionalisation by Solon et al. [40], the city is located within the South Mazovian Hills macroregion, the Radom Plain mesoregion, and (in a small part) the Kozienice Plain. Mleczna (tributary of Radomka) is the largest river flowing through Radom. In the 1970s, a water retention reservoir was built in Radom's Borki district; it also serves for recreation and leisure. The city has a high percentage of tall greenery areas (57.5%) and a high percentage of people (64.5%) living within walking distance (less than a 5 min walk) from these areas [41].

Lublin, similarly to Radom, is a city with borough status, but is also the capital of Lubelskie Voivodeship. It covers an area of 148 km^2, and its population was 331,243 people in 2022 [39]. Lublin is Poland's largest urban centre in the east and serves economic, administrative, cultural, and scientific functions. According to the physical–geographical division of Poland by Solon et al. [40], Lublin lies in the Lublin Upland macroregion encompassing three adjacent mesoregions: Bełżyce Plain, Nałęczów Plateau, and Świdnik Plateau. Many erosion and denudation valleys and gullies occur in the western part of Lublin located within the loess-covered Nałęczów Plateau. The Bystrzyca, a tributary of the Wieprz, flows through the city. Zemborzycki Reservoir, a reservoir built on the Bystrzyca river in the 1970s, is now used for water retention and recreation. Green areas cover 36% of the city's area, while 39.5% of residents are within walking distance (less than a 5 min walk) from these areas [41].

The proposed method for identifying quiet areas is a two-stage process. It involves conducting a social survey using a survey questionnaire and spatial analyses. It is based on qualitative data obtained from respondents and official, publicly available, validated qualitative and quantitative data (from national databases). Spatial analyses for the identification of quiet areas in Radom and Lublin were carried out using QGIS software (version 3.22.4). The analyses focused on the existing, publicly available, acoustic maps for Radom and Lublin (municipal geoportals), the functional and spatial structure (Database of Topographic Objects, BDOT10k) [42], and population density (data from the Central Statistical Office) [39].

The method for identifying quiet areas was created by the authors based on the method used in the draft Environmental Protection Programme Against Noise developed in 2009 for Warsaw as well as the EEA guidelines [17,43]. The proposed method involves checking whether specific areas (indicated by respondents in the survey) meet the criteria for quiet areas used in the 2009 draft Noise Protection Programme for Warsaw from 2009 (<55 dB noise level, <30 people/ha population density, 100 m and 250 m distance from main roads and 500 m from railway) and supplemented by EEA guidelines (recreational function and public spaces, >1 ha size, good accessibility on foot up to 10 min or by public transport). It is primarily based on publicly available data, which is analysed using a GIS program (in this case QGIS). The assumption is that on this basis it is possible to single out areas that meet the required criteria and reject those that do not. The accuracy and reliability of the method was checked by analysing the convergence of results in two spatial analyses for each of the cities studied by two members of the author's team.

Spatial analyses were carried out for the areas indicated in the surveys based on subjective opinions (areas that received 5 or more votes) and for those currently proposed in the Environmental Protection Programme Against Noise for Radom (The Kapturski Forest, Gołębiów Park, Jacek Malczewski Park, Leśniczówka Park) [44]. Such areas were not indicated in the documents for Lublin. The respondents had the option to indicate any area located within the administrative boundaries of the cities under study (the question was open-ended). The following quiet areas were indicated in Radom: The Kapturski Forest (Las Kapturski) (1), Gołębiów Park (2), Jacek Malczewski Park (Park Jacka Malczewskiego)

(3), Leśniczówka Park (4), Stary Ogród Park (5), Mleczna River Boulevard (Bulwary nad Mleczną) (6), and Borki Lake (Zalew Borki—an artificial reservoir) (7). In Lublin, the following were indicated: Open-air Rural Heritage Park (Muzeum Wsi Lubelskiej) (8), MCSU Botanical Gardens (Ogród Botaniczny UMCS) (9), Górki Czechowskie Park (10), Saxon Gardens park (Ogród Saski) (11), The People's Park (Park Ludowy) (12), John Paul II Park (park Jana Pawła II) (13), Stary Gaj Forest (14), Zemborzycki Resevoir (Zalew Zemborzycki—an artificial reservoir) (15). In addition, the Centre for the Meeting of Cultures (Centrum Spotkania Kultur—a cultural venue) in Lublin received more than 5 votes, but it was not included in this study because it is a building, not an open area.

Based on the spatial analyses and after compiling the final results, areas that met all the p criteria were identified. Areas that did not meet even one criteria were eliminated. The survey process is shown in Figure 2.

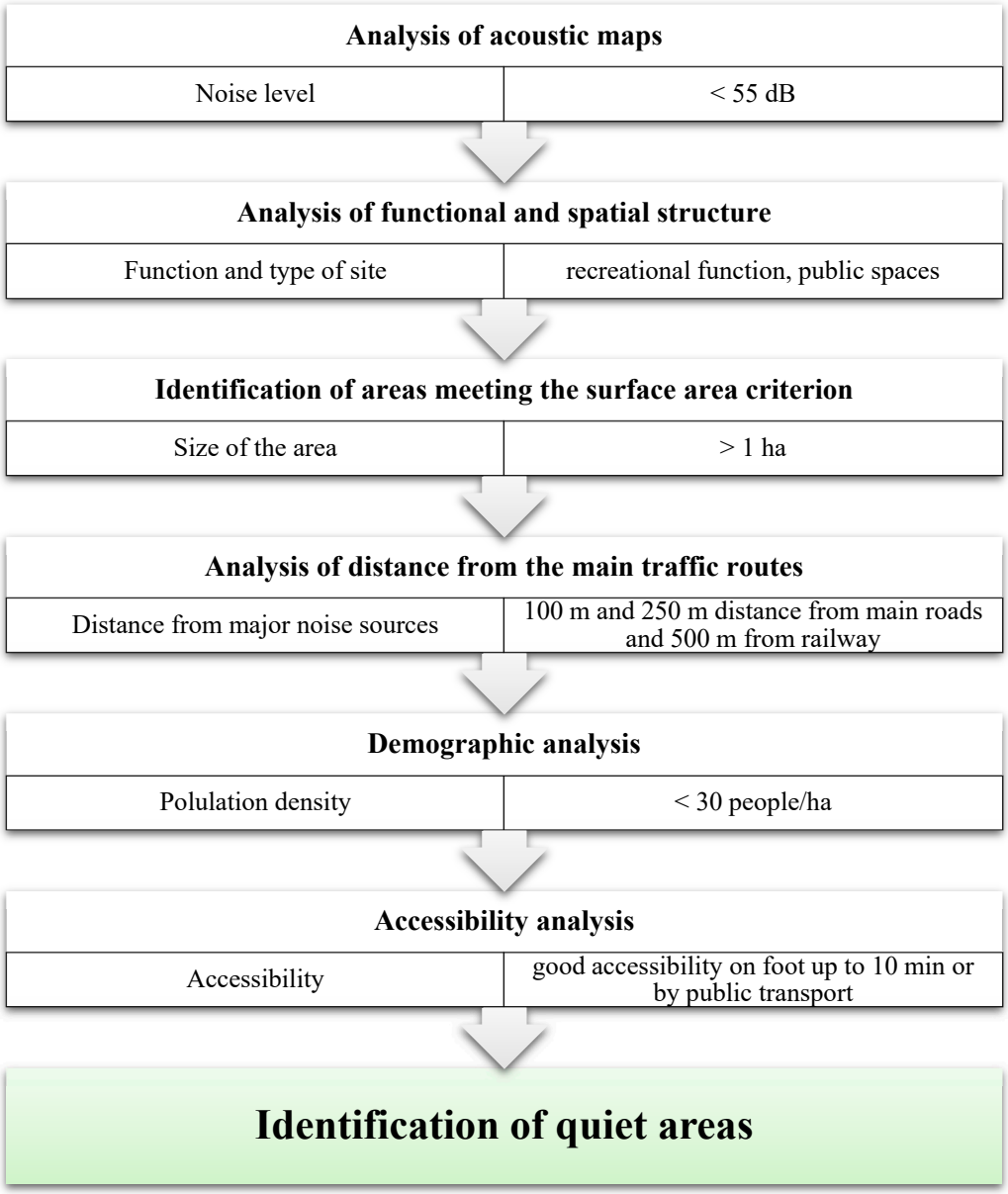


Figure 2. Outline of the survey process.

The first step in the delimitation of quiet areas was analysing the acoustic map and looking for "blank spots", i.e., areas not exposed to any type of noise. An acoustic analysis taking into account the LDWN indicator for road noise emissions was carried out based

on the publicly available noise map for Radom and noise map for Lublin. In Poland, the Ordinance of the Minister of Environment of 14 June 2007 on permissible noise levels (as amended) specifies the boundary values of LAeq noise at 50–68 dB (daytime) and 45–60 dB (nighttime) for traffic noise, 45–55 dB (daytime) and 40–45 dB (night) for other sources of noise (except for aviation), and LDWN at 50–70 dBA and LN at 45–65 dBA (traffic noise), LDEN at 45–55 dBA and LN at 40–45 dBA (other sources of noise except for aviation), depending on the type of land. Based on this document and the acoustic criteria defining the ways of identifying quiet areas in an agglomeration [17] and WHO recommendations [45], it is accepted that LDWN should not exceed 55 dB for potential quiet areas. In addition, no area exposed to aviation noise may be recognised as a quiet area.

The next step was to analyse the functional and spatial structure. It was assumed that quiet areas should have a recreational function and should be public spaces. Furthermore, in accordance with EEA (2020) guidelines, they should cover 1 hectare or more [17]. The criterion for the location of quiet areas also defines the distance from roads and industrial areas. Based on the draft Environmental Protection Programme Against Noise for the city of Warsaw, a 100-metre buffer was designated for national and provincial roads. It was also noted that an insulation or buffer zone, at least 250 m wide and free from noise-emitting sites, should exist inside a quiet area [43]. The minimum distance from railway sites should be 500 m.

The next step was to conduct demographic analyses. If the population density is too high, maintaining favourable acoustic conditions will be impossible. The demographic analysis was conducted based on the population density criterion used in the Environmental Protection Programme Against Noise for the city of Warsaw [43]. The key assumption is that in the case of high population density, there is no chance for maintaining appropriate acoustic conditions required by quiet areas. The draft Environmental Protection Programme Against Noise for the city of Warsaw presents the following dependency: population density should not be greater than 30 people per hectare when LDWN < 55 dBA. It was concluded that population density of not more than 30 people per hectare is the most favourable for the designated quiet areas [43].

Finally, the necessary accessibility of quiet areas was examined. Spatial, transport, and temporal accessibility is distinguished according to the definition of accessibility, i.e., defining it as a relationship between at least two different points that reflect the selected locations on the map [46]. Geographic information systems (GIS) are used in accessibility analyses, including those concerning urban greenery [47]. In the study on the identification of quiet areas in Radom and Lublin, a 10 min walk from one's place of residence, as proposed in EEA guidelines [17], was adopted. For the purposes of the study, it was assumed that a human being moves at an average speed of 5 km per hour and can thus cover approximately 833.33 m within 10 min. In addition, transport accessibility (municipal public transport stops) was considered. The accessibility was determined using QGIS software and its "buffer" tool. The data used (roads, public transport stops) were obtained from the BDOT10k database for Lublin and Radom.

The analyses were presented using a cartographic survey method (CSM). Its theory was developed by Salishchev in the mid-20th century and developed by Berlant in the 1970s and 1980s [48]. Nowadays, as digital information processing techniques have become more widespread, the classical methodology for applying CSM is generally referred to as data enrichment and/or Spatial Data Mining. The applicability of the cartographic survey method and its reliability as a scientific method can only be claimed if the source data (spatial database and/or analogue maps) meet certain accuracy criteria. The results obtained are influenced, inter alia, by the timeliness of the collected data. Cartographic methodology, therefore, allows maps (and nowadays spatial databases) to be used not only to visualise objects and phenomena, but also to study and show their interrelationships [48].

3. Results

3.1. Analysis of Acoustic Maps

The acoustic map (Figure 3) presents the spatial distribution of road noise pollution in the quiet areas distinguished in the Radom 2018 Environmental Protection Programme Against Noise and proposed in the survey; these areas are marked with numbers 1–7. The Stary Ogród park, located along J. Mireckiego St and S. Wernera St, is the most exposed to noise which reaches 60 dB within most of this area. The main reason is the location of the park along major roads that generate noise. In the western part, comprising of a playground and paths, the noise levels reach 55 dB. The Leśniczówka Park (no. 4), located along 25 czerwca St, Wodna St, and Zbrowskiego St, lies within an area with the maximum mean noise levels reaching 55 dB. The Gołębiów Park (no. 2) lies within an area where the permissible noise levels were not exceeded (less than 55 dB). The Mleczna River Boulevard, marked with number 6 on the map, is a large green area with cycling infrastructure included. The noise map shows that, due to its location (western part of the city) and distance from roads, it is not exposed to noise hazards (emission levels are below 55 dB). The Borki Lake (no. 7) and The Kapturski Forest (no. 1), similarly to the Mleczna River Boulevard (no. 6), lie outside an area with high noise emission threshold (below 55 dB) and thus meet the relevant acoustic criteria. The acoustic criteria, according to which the set noise emission threshold (55 dB), were met by all areas proposed in the Programme and the survey, except for the Stary Ogród Park, where these criteria were not met.

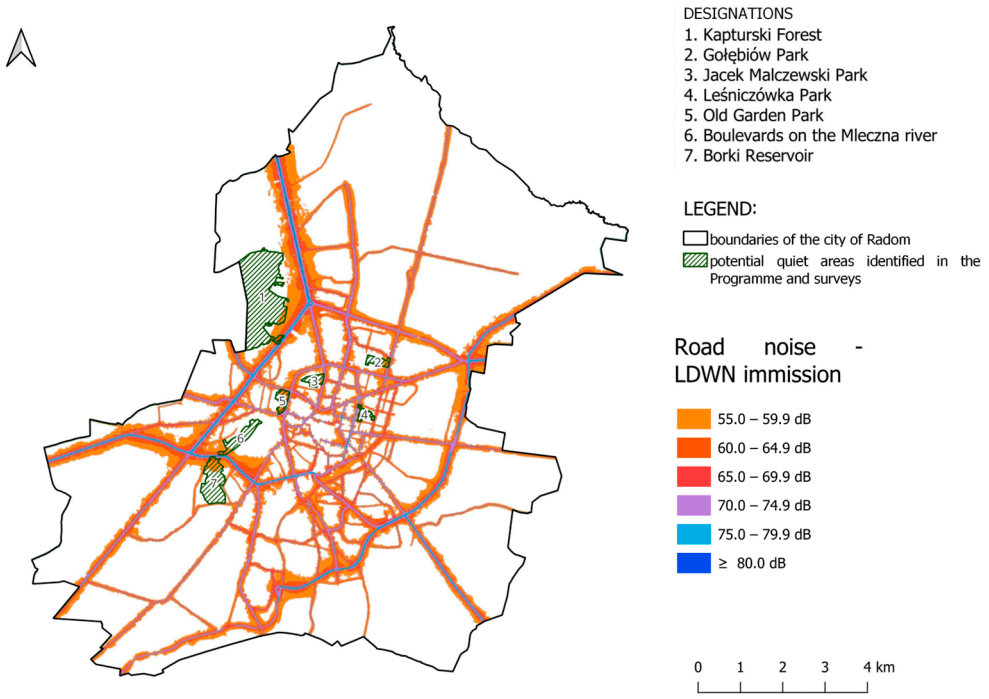


Figure 3. Potential quiet areas in Radom in the noise map for the city of Radom.

Figure 4 shows noise pollution from major roads in Lublin and the potential quiet areas identified in the survey, numbered 8 to 15. An analysis of the acoustic map has shown that some potential quiet areas are partially, or fully, exposed to noise. The area of the Rural Heritage Park (no. 8) and MCSU Botanical Gardens (no. 9) are exposed to a small extent to motor traffic noise from Solidarności Ave and Warszawska Ave; in the case of the latter, it is also the noise from Sławinkowska St (from the west) and Willowa St (from the north). However, the central parts of the Rural Heritage Park and MCSU Botanical Gardens are not exposed to noise. In the case of the Górki Czechowskie Park (no. 10), only the western part of the area is slightly exposed to noise from Bohaterów Września St. The Saxon Gardens (no. 11) is exposed to noise from Racławickie Ave. Nearly all of

the park's area is within the upper threshold of noise for quiet areas (55 dB). The People's Park (no. 12) is situated between Lubelskiego Lipca '80 St, Józefa Piłsudskiego Ave, and Stadionowa St. These streets generate considerable noise levels. Only the central part of the park is exposed to noise levels of 50–55 dB. The eastern and central parts of John Paul II Park (no. 13) are exposed to considerable noise levels from John Paul II Ave. The other parts of the park are outside zones exposed to noise.

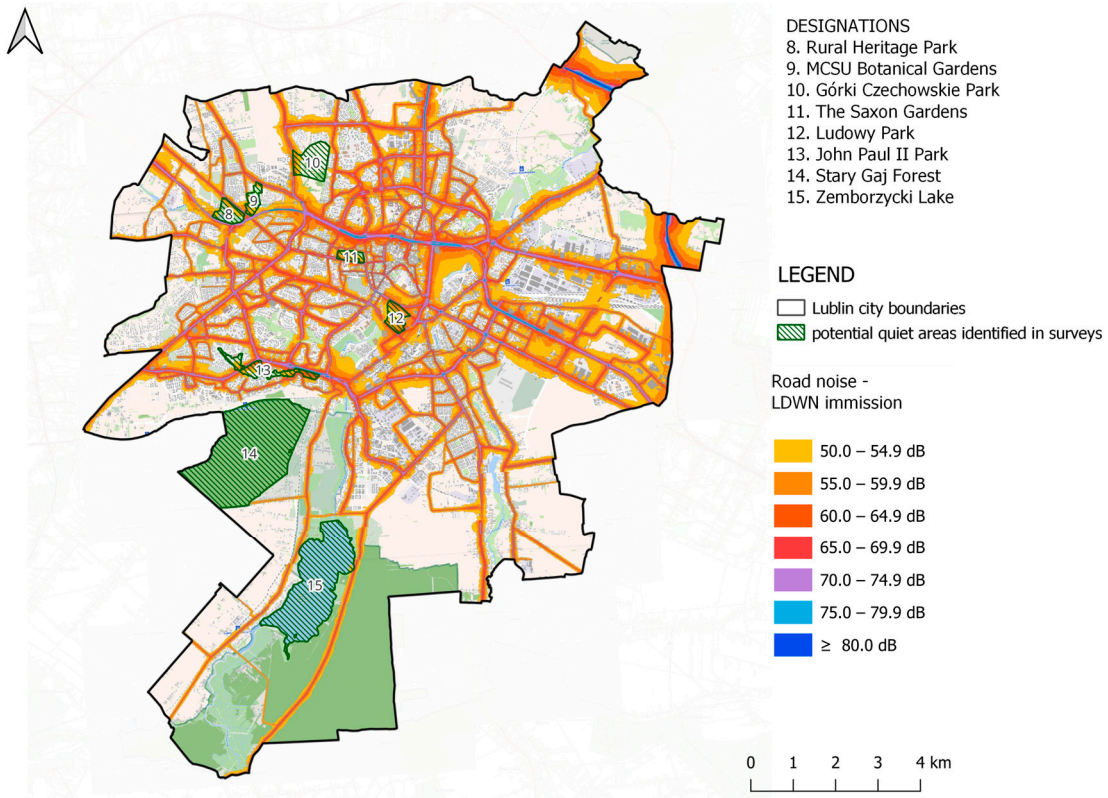


Figure 4. Potential quiet areas in Lublin against the Noise map for the city of Lublin.

3.2. Analysis of the Functional and Spatial Structure

The functional and spatial structure of Radom is presented in Figure 5. The central part of the city consists primarily of multi-family housing and service areas, as well as a considerable number of public spaces. Green areas cover a small portion of the centre, but much greater concentrations of these areas occur in the northern and southern park of the city. Industrial buildings are located in the centre, along the main roads (e.g., the Łucznik Zone—premises of the former Łucznik Metal Works). Single-family housing is located primarily on the outskirts. The potential quiet areas identified both in the Environmental Protection Programme Against Noise and in the survey are mostly forest areas, public green areas, and surface water areas (Borki Lake) with recreational functions [44]. All the quiet areas proposed meet the land cover criteria.

Figure 6 shows the current functional and spatial structure of Lublin. Multi-family housing is situated primarily in the central and northern part of the city. The oldest districts, located in the heart of the city (Old Town, Wieniawa, Śródmieście, and Czwartek) have service and commercial as well as residential functions. The Old Town, encompassing historic buildings in a medieval urban layout, has a very high cultural and historic value. It is an area with administrative, service, and residential functions. The city centre is surrounded by areas of post-World War Two multi-family housing. Single-family housing is located in the peripheries. Most industrial areas are located in a few clusters, mainly in the eastern part of the city. Publicly accessible green areas in Lublin mainly consist of parks and gardens. The largest forest areas are located in the southern and western part of the

city. The survey respondents indicated similar areas as in the case of Radom, i.e., public green, forest, and surface water areas (Zemborzycki Reservoir).

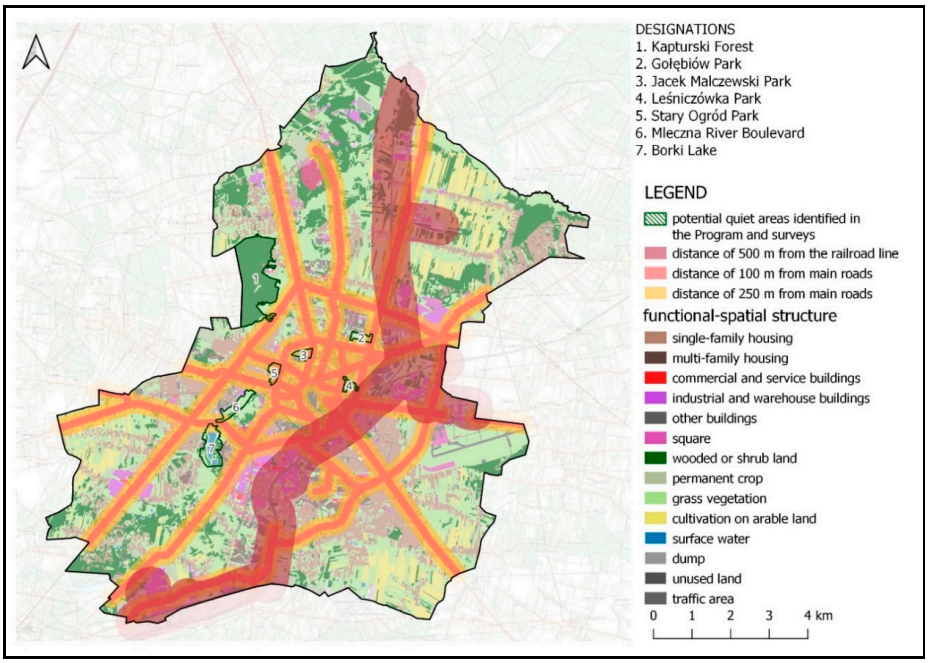


Figure 5. Potential quiet areas in Radom against the background of functional–spatial structure and distance from main roads and railways.

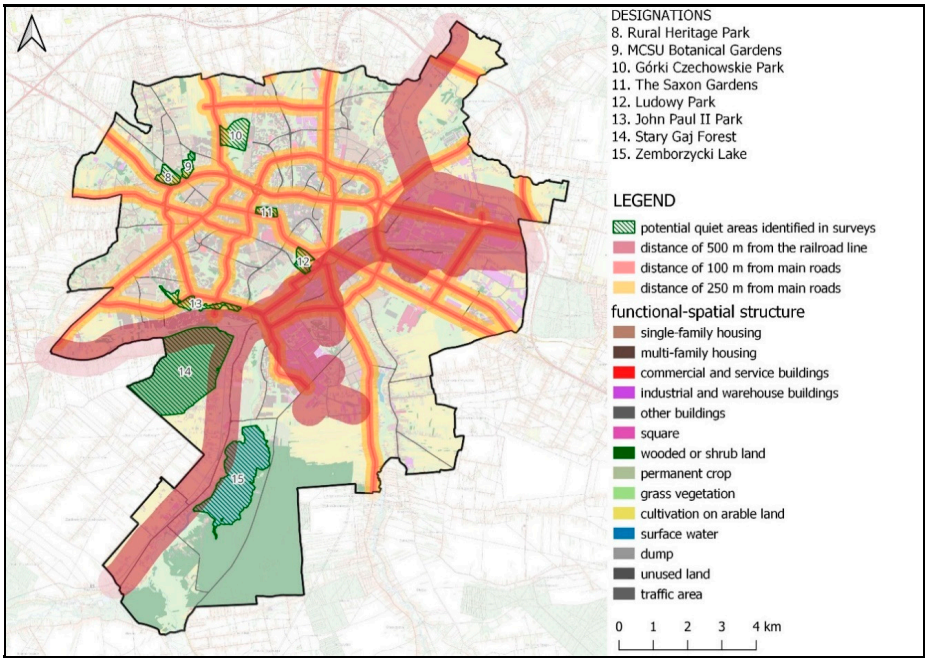


Figure 6. Potential quiet areas in Lublin against the background of functional–spatial structure and distance from main roads and railways.

3.3. Identification of Areas Meeting the Surface Area Criteria

Table 1 lists the potential quiet areas identified in the Programme for Environmental Protection Against Noise for the City of Radom [44] and in the survey, together along with their surface area. All the areas indicated both in Radom and Lublin meet the criteria of minimum size. The smallest area indicated in Radom is Leśniczówka Park (6.8 ha), whereas

the largest areas is The Kapturski Forest (176.2 ha). In Lublin, the smallest area is covered by the Saxon Gardens (13.2 ha), and the greatest by the Stary Gaj Forest (450 ha).

Table 1. The surface area of potential quiet areas in Radom and Lublin.

Radom			Lublin		
	Potential Quiet Areas	**Surface Area (ha)**		**Potential Quiet Areas**	**Surface Area (ha)**
1	The Kapturski Forest	176.2	8	Rural Heritage Park	25.5
2	Gołębiów Park	9.4	9	MCSU Botanical Gardens	17.7
3	Jacek Malczewski Park	9.8	10	Górki Czechowskie Park	57.0
4	Leśniczówka Park	6.8	11	Saxon Gardens Park	13.2
5	Stary Ogród Park	10.8	12	Ludowy Park	24.8
6	Mleczna River Boulevard	22.9	13	John Paul II Park	38.5
7	Borki Lake	45.7	14	Stary Gaj Forest	450.0
			15	Zemborzycki Lake	294.8

3.4. Analysis of the Distance from the Main Traffic Routes

The zones of distance from roads and railway lines in Radom are shown in Figure 5. The quiet areas selected in the Environmental Programme and survey are located in close proximity to roads. Most of the area of Jacek Malczewski Park (3) and Leśniczówka Park (4) are located within the 250 m buffer zone, i.e., does not meet the set distance criteria. The parks of Gołębiów (2) and Stary Ogród are only partially within the buffer zone, hence they meet the criterion in part. Other areas (The Kapturski Forest, Mleczna River Boulevard, and Borki Lake) are located further than the set distance from the main roads; hence they meet the distance criterion. Furthermore, none of the quiet areas proposed are within zone of exposure to railway noise.

The results of the analyses of the distance from the main noise sources for Lublin are shown in Figure 6. Parts of the Rural Heritage Museum (8), MCSU Botanical Garden (9), Górki Czechowskie Park (10), The People's Park (12) and John Paul II Park (13) are located at a short distance from roads. The Saxon Gardens (11) in their entirety do not meet the set criteria. Other areas are beyond the distance assumed in the study. In addition, parts of The People's Park (12), John Paul II Park (13), Stary Gaj (14), and Zemborzycki Reservoir (15) lie relatively close to railway lines. Other areas are not exposed to railway noise.

3.5. Demographic Analysis

In the light of the population density map for districts in Radom (Figure 7) and Lublin (Figure 8), the potential quiet areas located in the centre of Radom (Leśniczówka Park, Gołębiów Park) do not meet the set criteria, as the population density significantly exceeds the set threshold. These are the districts of Śródmieście (65.333 people/ha), Miasto Kazimierzowskie (74.727 people/ha), Gołębiów I (104.544 people/ha), and Gołębiów II (109.113 people/ha). Areas such as Stary Ogród Park, Mleczna River Boulevard, or Borki Lake are located in districts where the population density is close to the set threshold, i.e., the districts of Kaptur (30.425 people/ha), Glinice (30.289 people/ha), and Borki (35.164 people/ha). Areas that fall within the set limit are The Kapturski Forest (Młynek Janiszewski with 2.808 people/ha, Koniówka with 1.976 people/ha), Jacek Malczewski Park (Obozisko with 25.157 people/ha).

Figure 8 shows the division of Lublin into districts along with population density expressed in the number of people per hectare. Areas located in the central part of Lublin (Saxon Gardens), in the districts of Śródmieście (45.16 people/ha), Wieniawa (48.40 people/ha), Czuby Północne (102.71 people/ha) and Czuby Południowe (86.05 people/ha), where John Paul II Park is located, do not meet the set criteria. Other areas are located in districts where the population density does not exceed 30 people/ha, i.e., in the districts of Sławin (16.68 people/ha), Czechów Północny (27.88 people/ha) Za Cukrownią (12.19 people/ha), and Zemborzyce (1.19 people/ha).

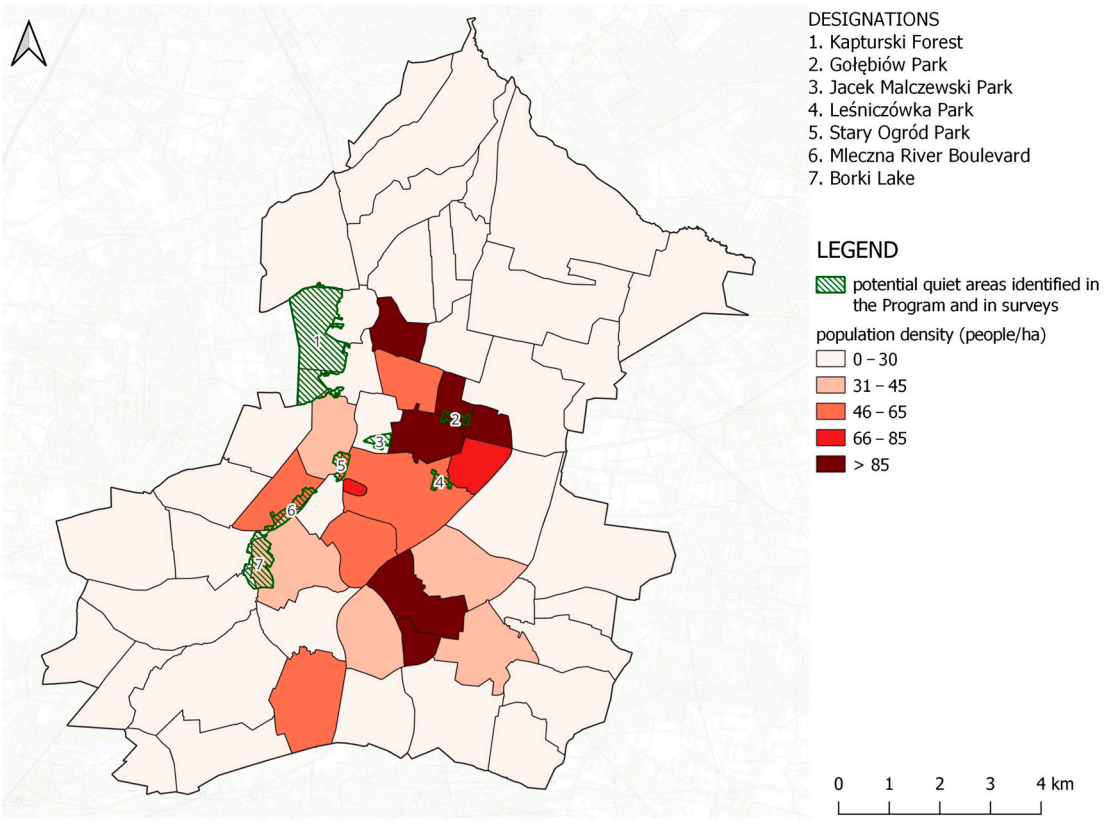


Figure 7. Potential quiet areas in Radom on the population density map for the districts of Radom.

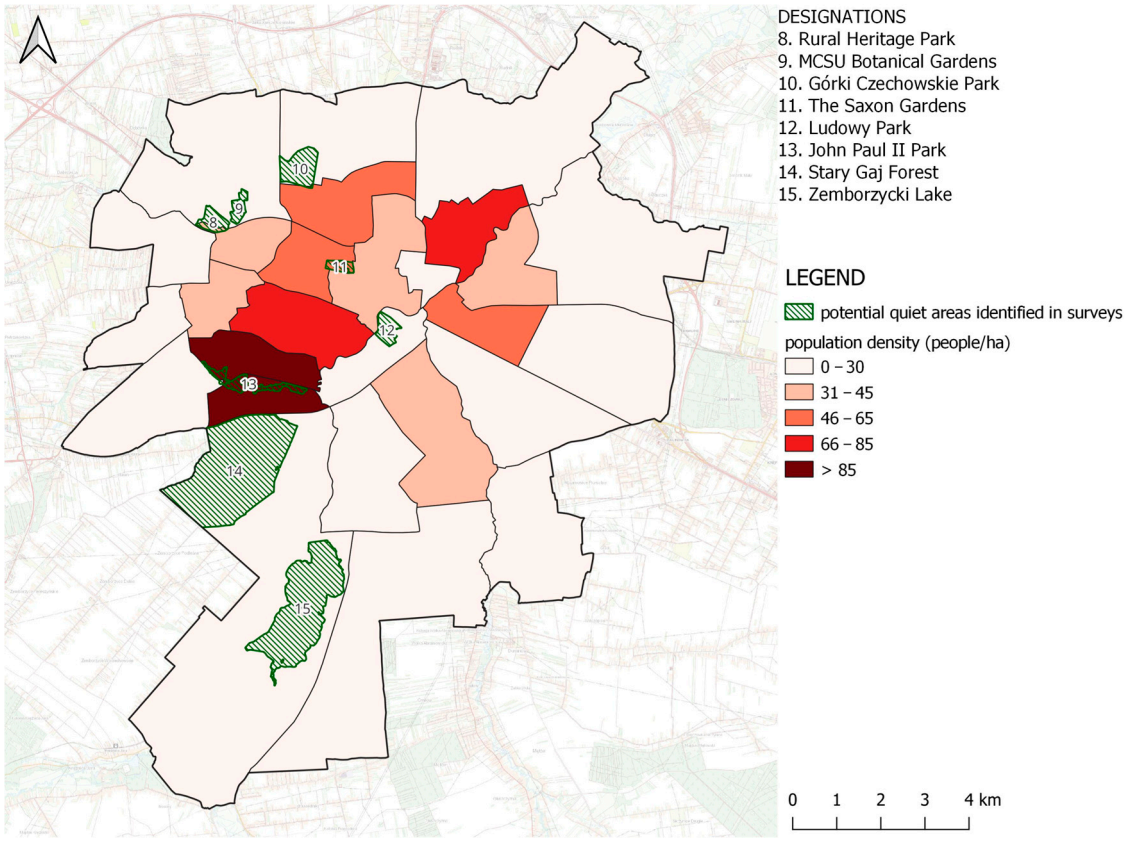


Figure 8. Potential quiet areas in Lublin on the population density map for the districts of Lublin.

3.6. Accessibility Analysis

The analysis of temporal accessibility of the potential quiet areas in Radom and Lublin is shown in Figure 9. These areas meet the previously defined accessibility criteria. They are located in close proximity to residential areas. Each of these areas has access to selected traffic routes and bus routes. Their location is a major advantage because they are situated in the central part of the city, except for the Kapturski Forest, which lies in the north-western part of Radom and is, therefore, the least accessible although it covers the greatest area. It is the most accessible to residents of the districts of Koniówka and Młynek Janiszewski. Thus, all the areas analysed in Radom meet the accessibility criterion.

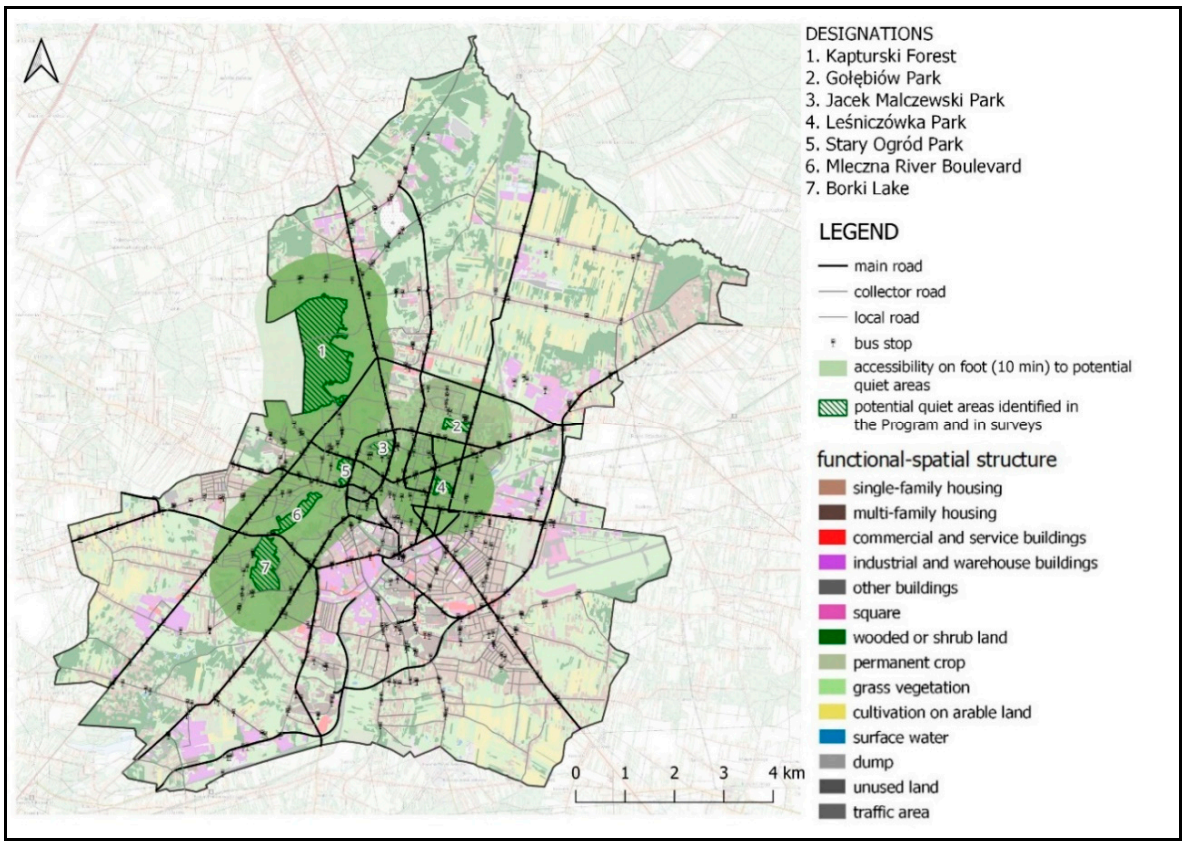


Figure 9. The accessibility of the potential quiet areas in Radom.

The areas analysed in Lublin also meet the accessibility criteria defined (Figure 10). They are located in close proximity to built-up areas, close to major traffic routes and bus routes. Areas located in the central part of the city, i.e., Saxon Gardens and The People's Park, are the most accessible. Although areas located outside the centre, such as the Rural Heritage Park, MCSU Botanical Gardens, Górki Czechowskie Park, or John Paul II Park, are slightly less accessible, they are located within residential areas. In addition, they have good transport links, including municipal transport. The least accessible area areas on the outskirts, in the southern part of the city such as the Stary Gaj forest and Zemborzycki Reservoir. Only single-family housing, often dispersed, exists in their close proximity. However, considering the existence of roads, bus routes and bus stops, they have been recognised as meeting the good accessibility criteria.

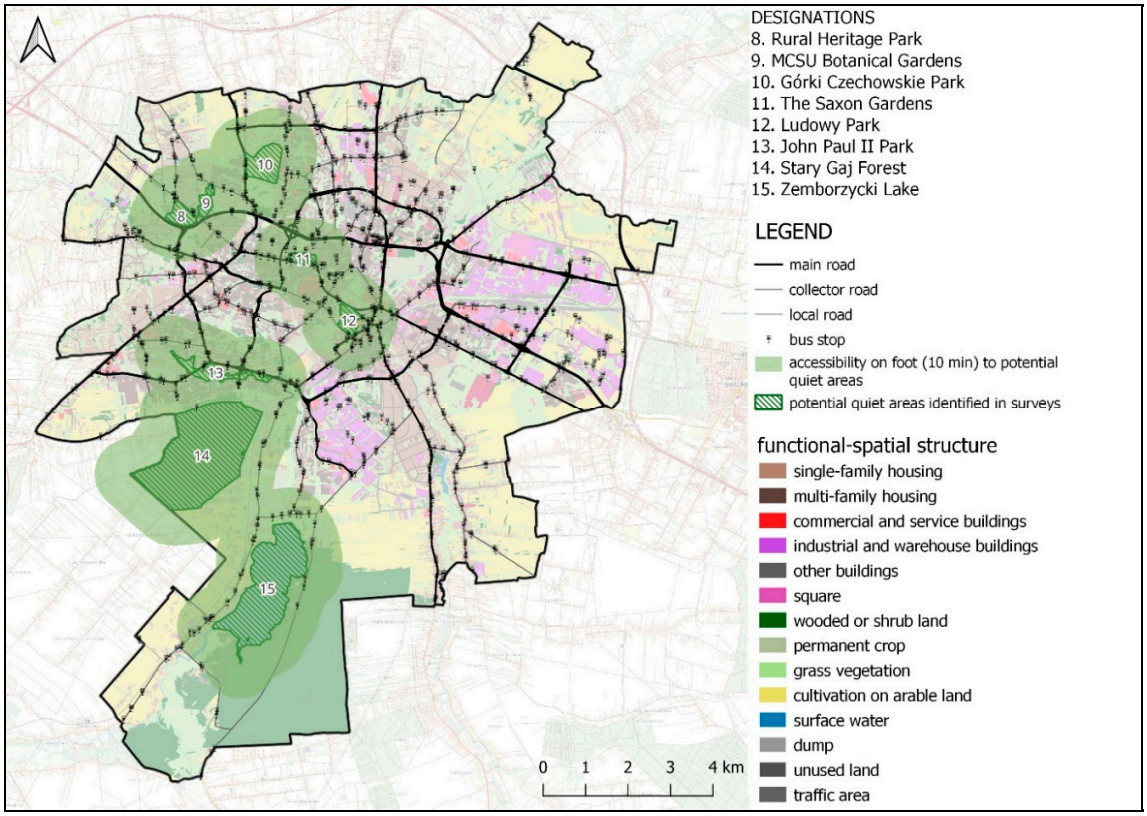


Figure 10. The accessibility of the potential quiet areas in Lublin.

4. Discussion

The delimitation of quiet areas in Radom and Lublin was carried out using a method developed by the authors and taking into account the EEA criteria for designating quiet areas in agglomerations [17]. Spatial analyses were carried out for all the areas indicated in the survey and for those currently proposed in the Environmental Protection Programme Against Noise for Radom [44]. Eventually, areas that received five or more votes in the residents' survey conducted for Radom and Lublin were included. The respondents were not provided a list of places to choose from, they could indicate any place or area located in the city's administrative borders.

The final results of the survey are shown in Table 2. The following areas in Radom meet the acoustic criteria: Leśniczówka park, Borki Lake, Mleczna River Boulevard, The Kapturski Forest, Gołębiów park. The Stary Ogród park is the only area that does not meet these criteria, which results from its location. In Lublin, the acoustic criteria was met by all areas except for parts of the Saxon Gardens and The People's Park due to their location by the main roads. The next criteria were the type of land cover, i.e., a high degree of green cover. All the potential quiet areas meet these criteria both in Radom and Lublin. In the case of the next criteria, i.e., the function of an area, all the potential quiet areas are public spaces or recreational areas.

Table 2. The delimitation of quiet areas in Lublin and Radom.

		Criteria for Designating Quiet Areas in Agglomerations						
						Location of the Area		
	Potential Quiet Areas	Acoustic Criteria	Land Cover Type	Functional and Spatial Structure	Accessibility to the Area	Distance from the Main Traffic Routes	Demographic Criteria	Size of the Area
				Radom				
1	The Kapturski Forest	✓	✓	✓	✓/✘	✓	✓	✓
2	Gołębiów Park	✓	✓	✓	✓	✓	✘	✓
3	Jacek Malczewski Park	✓	✓	✓	✓/✘	✓	✓	✓
4	Leśniczówka Park	✓	✓	✓	✓	✘	✘	✓
5	Stary Ogród Park	✘	✓	✓	✓	✘	✓/✘	✓
6	Mleczna River Boulevard	✓	✓	✓	✓	✓	✓	✓
7	Borki Lake	✓	✓	✓	✓	✓	✓	✓
				Lublin				
8	Rural Heritage Park	✓	✓	✓	✓/✘	✓	✓	✓
9	MCSU Botanical Gardens	✓	✓	✓	✓/✘	✓	✓	✓
10	Górki Czechowskie Park	✓	✓	✓	✓	✓	✓	✓
11	Saxon Gardens park	✓	✓	✓	✓	✘	✘	✓
12	Ludowy Park	✓/✘	✓	✓	✓	✓	✓	✓
13	John Paul II Park	✓	✓	✓	✓	✓/✘	✘	✓
14	Stary Gaj Forest	✓	✓	✓	✓/✘	✓	✓	✓
15	Zemborzycki Lake	✓	✓	✓	✓/✘	✓	✓	✓

✓ meets this criterion; ✓/✘ partially meets the criterion; ✘ does not meet the criterion.

The accessibility criteria were fully met by five areas in Radom. These criteria were met only partially by two areas, i.e., the Kapturski Forest and Jacek Malczewski Park, due to their location and insufficient transport links with the rest of the city. However, their location has the advantage of being close to single-family housing estates. It is also important to ensure an appropriate distance for quiet areas away from major traffic routes: main roads (100 m), buffer zones (250 m), railway areas (500 m). The Stary Ogród and Leśniczówka parks are the only areas in Radom that do not meet the set criteria. In Lublin, the accessibility criterion is fully met by four areas: Górki Czechowskie park, Saxon Gardens, The People's Park, and John Paul II Park. The other potential quiet areas meet this criterion only partially. The Rural Heritage Park and the MCSU Botanical Gardens have a favourable location in close proximity to residential housing and roads, but entry to these areas requires purchasing a ticket. Stary Gaj forest and Zemborzycki Reservoir are located at a considerable distance from the city centre and are adjoined mainly by dispersed single-family housing, but they are close to roads and municipal transport stops.

The location of an area is also linked to the appropriate population density. Based on the draft Environmental Protection Programmes Against Noise for Warsaw [43], it was assumed that the population density may not exceed approximately 30 people per hectare. In Radom, this criterion is not met by the Leśniczówka and Gołębiów parks. Stary Ogród Park is located at the border of three districts: Kaptur, Śródmieście and Stare Miasto. In Lublin, this criterion was not met by the Saxon Gardens and the John Paul II Park. All the areas indicated both in Radom and Lublin meet the criterion of minimum size (1 ha or more).

Based on the studies conducted, the following quiet areas in Radom can be categorised as quiet areas: The Kapturski Forest, Jacek Malczewski Park, Mleczna River Boulevard, and Borki Lake. In Lublin, the following can be recognised as quiet areas: Rural Heritage Park, MCSU Botanical Gardens, Górki Czechowskie Park, The People's Park, Stary Gaj forest, and Zemborzycki Reservoir. The above areas have met all the proposed criteria for designating quiet areas in agglomerations. These are primarily municipal green areas with recreational functions. These conclusions are consistent with the findings of studies conducted in other cities [34,35]. Green areas are indeed potential quiet areas with good acoustic quality provided they are properly designed and planned [49].

It showed that in Lublin, six areas met the proposed criteria, while in Radom only four did. This can be justified by the smaller size of the latter city and its lower natural diversity. The lack of proposals for quiet areas in the environmental noise protection programme for Lublin may be due to the lack of official methods for their identification. In the case of Radom, on the other hand, the identified quiet areas are not the same as those proposed in the programme. This may be due to the inclusion of only three criteria there: LDWN < 55 dB, recreational and leisure functions, minimum land area < 1 ha. Among others, the opinions of local residents and the accessibility analysis were omitted.

The acoustic criterion was not met by only one area. The proposed indicator is in line with indicators used in some countries, including the UK and Finland [17]. In Norway it is even 50 dB, in Denmark it is 45 dB [17] and in Sweden the applicable noise level limits were 45–50 dB [18]. In addition, as recommended by the Dutch Health Council, pleasant sounds and undesirable sounds should be distinguished during the preparation of an acoustic assessment. Pleasant sounds primarily include the sounds of nature, that should not be subject to any limits, while undesirable sounds are mainly associated with noise emitted by human activity. Defining the continuity of sounds is also significant. Intermittent noise can be caused by a single car passing by. This does not have such a significant impact on the surroundings as, for example, a nearby motorway that produces continuous noise.

The criterion of functional and spatial structure and land cover type was met by all areas. This criterion is taken into account in the designation of quiet areas in Amsterdam, for example [33]. The 2020 Environmental Noise in Europe report also recommends that these areas should be biologically active (green areas) and publicly accessible (public) areas to the greatest extent possible [17]. The proximity of residential areas is also significant.

The accessibility criterion was not fully met by six areas. However, it was considered that this was not sufficient reason to eliminate them. However, the accessibility of an area for the largest possible number of potential users is one of the factors determining the planning of quiet areas. This is influenced by the area's links with the city centre and the number of residents in the neighbourhood, which is confirmed by good planning practices for quiet areas [35].

The location/neighbourhood criteria proved to be the most important, influencing the elimination of as many as five areas. Distance from major noise sources (roads, railways) and a population density of no more than 30 people per hectare are important. However, this requirement is a limitation of accessibility. The lower the population density around a potential quiet area, the more it is in the range of good accessibility for a smaller number of residents. These criteria can, therefore, be considered in two ways.

The size criteria (>1 ha) was met by all areas. The largest of these were forest areas (170–460 ha). However, according to Radicchi [50], a network of numerous small quiet areas can ensure a greater economic advantage than one huge quiet area.

It should be added that quiet areas should be characterised not only by low noise levels, but also visual qualities (e.g., views of green areas or bodies of water), and they should give users a sense of security [16]. As the study by Yan et al. [15] showed, positive perceptions of tranquillity were influenced by visuospatial perceptions, while acoustic perceptions of the environment influenced negative perceptions. Quiet areas also represent a pleasant soundscape and are related to the visual and natural qualities of an area and, above all, with the subjective perception.

Quiet areas should also be the subject of planning and design, as exemplified by the proposals for London with noise barriers using vegetation and water [23]. Noise management includes here not only counteracting the negative effects of the already existing noise, but above all improving and protecting places with favourable acoustic conditions through a soundscape approach. In addition, the obligation to identify and protect quiet areas is imposed by the national planning policy framework.

The designation of quiet areas can be a strategic measure giving the right direction to the city's transformation in the longer term, by enabling residents to live in an environment with appropriate acoustic conditions, even in the very city centre. Considering the global problem of traffic noise in cities, the presence of quiet areas in an urbanised environment is a sign of appropriate management of urban space and the successful development of environmentally friendly attitudes, thanks to which conditions in the city are adapted to the inhabitants rather than to the means of transport. Quiet areas are also related to climate change [23,51]. As strategies for the adaptation of cities to climate change are developed, the important role of green space is emphasised, plans are made to increase the size of green areas, and, for example, pocket parks and towns squares are created. Thus, new quiet areas available to residents can be created. However, it is important that they are sufficiently distanced/isolated from noise sources (at least 250 m, preferably 1 km) and of sufficient size (at least 1 ha). Identification of quiet areas in cities is made possible by the proposed method. This is supported by the increasing functionality of GIS, the availability of spatial information infrastructure as dictated by the INSPIRE directive (2007) and the abundance and verified quality of digital databases [52].

However, carrying out the identification of quiet areas has limitations related to, among other things, the availability of data. For the purposes of this study, no noise measurements that could enhance the acoustic analysis were carried out. Only publicly available acoustic maps were used. This article focuses on the possibility of using this method to identify quiet areas in cities. Thus, the focus is on publicly available and easily obtainable data (acoustic maps). For the method to be commonly used, it must be relatively easy to apply. In addition, no field inventory or analysis of the landscape context (aesthetic values, soundscape) was conducted. They could verify the delimitation of quiet areas, reinforce or reject the results of spatial analyses. An attempt was made to base only on publicly available geospatial data and survey results, without taking into account the subjective opinion and feelings of the authors. The provisions of local plans (criteria proposed in the draft programme for protection of the environment against noise for Warsaw) were not taken into account due to incomplete coverage. The analyses primarily concerned areas indicated by residents as potential quiet areas. That is why, other areas, particularly less well-known areas that we believe could meet the criteria for quiet areas, were not included. The exception is Radom, for which the Jacek Malczewski Park, designated as a quiet area in the Environmental Protection Programme Against Noise, is additionally included. Only selected guidelines for the identification of quiet areas [14,25] were taken into account, i.e., no exceedances of permissible noise levels expressed in terms of LDWN noise index < 55, areas used by residents for recreation and leisure (parks and Kaptur Forest) and a minimum land area (1 ha). The accessibility of the area was not analysed and no social survey was carried out. Our research has shown that the designated quiet areas in the programme partly coincide with the indications of the respondents. It is, therefore, proposed that residents' opinions are taken into account only after potential quiet areas have been identified in spatial analyses. In this case, all areas that meet the criterion of function (recreation areas, public areas) would first need to be separated. Then, the other analyses used in this study would be carried out on these areas. Once potential quiet areas have been designated, respondents would have to be asked their opinions on these areas. Testing this approach will be subject of further research like acoustic measurements, verifying data obtained from the acoustic map, and conducting field surveys with inventory state of development and perceptual analyses of the landscape (including visual landscape and soundscape). It should also be noted that it is possible to use other numerical values when analysing

the distance of potential quiet areas from sources of noise, as exemplified in the study by Chacinska et al. [32]. The method for identifying quiet areas requires further refinement.

5. Conclusions

Noise pollution is widespread in cities. The number of vehicles generating traffic noise is increasing. Railway, industrial or airport-generated noise is also widespread. The identification of quiet areas is an important measure to ensure friendly and noise-free places, which has an impact on quality of life constituting the essence of sustainable development.

According to Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, the reduction in noise exposure and finding appropriate tools to combat noise pollution are the main objectives [16]. Among these tools are strategic noise maps, thanks to which it is possible to determine the degree of exposure to noise pollution. These maps are prepared using the same methods for all Member States. Qualitative and quantitative research methods were used during the process of identifying quiet areas in Lublin and Radom. Strategic and planning documents, legislation, and literature on quiet areas and soundscape were analysed. Based on those, the main criteria for designating quiet areas in agglomerations were identified. Subsequently, as part of the research procedure, surveys were carried out among residents of both towns, resulting in, among other things, proposals for areas of quiet. The results of this research are presented in detail in another publication. The spatial analyses carried out for them, i.e., noise map analysis, functional–spatial analyses, population analysis, and accessibility analyses, made it possible to identify potential quiet areas, as presented in this article.

In the case of Radom, all the criteria for the designation of quiet areas in agglomerations were met by only two areas: Borki Lake and Mleczna River Boulevard. But the accessibility of The Kapturski Forest and Jacek Malczewski Park is sufficient enough to include them in this group as well. Gołębiów Park and Leśniczówka Park do not meet the location criteria both in terms of population density and distance from disruptive noise sources. Stary Ogród Park performed the worst: it does not meet acoustic and location criteria, as it is the most exposed to noise pollution.

In Lublin, only Górki Czechowskie Park met all the set criteria completely. Similarly to Radom, it was assumed that if an area meets a criteria only partially, it can still be regarded as a potential quiet area. The Rural Heritage Park, MCSU Botanical Gardens, and the Stary Gaj Forest meet the accessibility criterion only partially due to their location in an area of single-family housing, on the outskirts of the city. Part of The People's Park was also recognised as a potential quiet area because while part of it, located close to a road, is exposed to excessive noise levels, a considerable part of it meets all the criteria.

This research showed that the quiet areas identified in Radom and Lublin are forest areas, public green areas, and surface water areas with recreational functions. The criteria for the elimination of the selected quiet areas were mainly location-related (distance from main roads and population density). The accessibility of the quiet areas is also important.

This methodology presented in this article has a practical dimension and can be useful in the planning of quiet areas. The studies focused on two cities in Poland, each characterised by a different approach to the identification of quiet areas. However, the method used is universal and can be used for other cities as well. The proposed methodology takes into account the main criteria defined in the European Environmental Agency document [17] and the draft Environmental Protection Programme Against Noise for Warsaw [42], based on which quiet areas were identified in the cities under study. The criteria used are consistent with the proposed methods for identifying quiet areas presented in numerous international publications.

It should be emphasised that although the proposed method of delimiting quiet areas is easy to use, the cooperation of a geographer and an acoustician is recommended for the precise interpretation of data. The task of the latter is primarily to proper interpretation of acoustic maps or identify the factors influencing the existing and planned changes in the

acoustic climate of a place. A geographer should be responsible mainly for spatial analyses of the areas identified by the acoustician. Additionally, a landscape architect and an urban planner should cooperate in planning quiet areas. They should be responsible for assessing the feasibility of creating a quiet area, conducting the design work aimed at the appropriate development of the designated area, and conducting the formal proceedings.

Further recommendations as additional measures affecting the identification of quiet areas are carrying out acoustic measurements, verifying data obtained from the acoustic map, and conducting field surveys with inventory and perceptual analyses of the landscape (including visual landscape, soundscape and smellscapes). However, they were not included in this study. This article covers only spatial analyses using GIS, for which verification through further surveys is advisable. It is also proposed to focus on sacred sites as potential quiet areas [53] and on the role of natural, landscape and socio-cultural factors in identifying quiet areas.

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