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Analysis of Spatial Development Possibilities of Properties Endangered by Road Noise in the Context of Permissible L_N and L_{DWN} Indicators

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ABSTRACT

The paper deals with the problem of road noise pollution in the context of spatial development. The analysis was motivated by the changes in the permissible noise levels that occurred on 1 October 2012 and the high urban pressure on areas located along the main traffic routes. On selected examples of sites located in the districts of Bemowo and Białołęka in Warsaw, the location of land functions is shown on the background of the course of isophones of acceptable noise levels. The analysis was based on data from acoustic maps for Warsaw developed in 2012 and 2017, planning studies, database of topographic objects and current state of development. Based on 20 features and 9 surface and quantitative indicators, determined using ArcGis software, the degree of road noise pollution in planning terms was shown. The analysis has been demonstrated that the changes in legislation have resulted in the acoustic "freeing up" significant areas along the main road, express and accelerated main roads and a reduction in the number of buildings that were considered to be at risk of noise pollution by the law before 2012. The acoustic release indicators for the general area were in the range of 0.71–0.74 for L_N and 0.56–0.74 for L_{DWN}. In relation to acoustically sensitive areas the results were in the range of 0.81–0.84 for L_N and 0.64–1.00 for L_{DWN}.

Keywords: spatial planning, road traffic noise, acoustic release, L_N and L_{DWN} indicators

INTRODUCTION

Noise is the second environmental problem in the European Union after air pollution. It is the policy of the European Union to achieve a sufficiently high level of health and environmental protection by, among other things, protecting against noise. The directive aims to jointly address the prevention, avoidance and reduction of the destructive effects of noise exposure and the mitigation of noise from various sources, including traffic noise[Directive 2002/49/WE].

The sound of 120–130dB is considered to be the threshold that, when exceeded, causes pain and, in the long term, can be dangerous to health. [Leśnikowska-Matusiak and Wnuk 2014].

People are exposed to noise almost 24 hours a day, at work, on a walk or at home. The result is an inability to rest and regenerate the human hearing organ comfortably. The product is a shift in the hearing threshold, causing a systematic weakening of the hearing organ. According to epidemiological data, prolonged noise makes the risk of vascular and circulatory diseases 1.7 to 3.0 times more likely in the people exposed to high sound values than those affected by the sounds with lower decibel values. [Babisch at al. 2003] According to a 2008 report commissioned by the Transport & Environment Federation, the negative impact of noise may be responsible for 50,000 heart attacks per year and 5% of strokes in European countries [Babisch et al. 2010]. Noise can also causepsychophysiological changes, depression. [Hurtley 2009] Given the adverse effects of noise on health, the World Health Organization has proposed that the noise levels measured outside a building at night should not exceed 42 dB. It is estimated that the costs associated with above-standard transport noise of public health significance, oscillate around €40 million annually, 90% of which is generated by road noise. [Gierasimiuk and Motylewicz 2014].

The literature on road noise is very comprehensive. Many authors approach the issue from different perspectives. In addition to the publications related to the health effects of noise mentioned earlier, many items pertain to the physics of acoustic waves, noise modelling and monitoring [Poplawska et al. 2012, Pervez 2020], technical methods to reduce excessive noise in urban spaces and their effectiveness [Profaska et al. 2012, Galińska and Kopania 2017, Perzyński et al. 2019] and their impact on the urban landscape [Podawca 2017a, Podawca 2017b]. It is also possible to find the publications directly related to the road noise measurements along the main roads of Szczecin agglomeration[Barański and Deja 2014], Radom [Perzyński et al. 2019], Piła [Gorzelańczyk 2016], Bielsko-Biała [Vaverkova et al. 2021], Lublin [Malec and Borowski 2018] not counting the evaluations of the acoustic state of the environment in provinces, programmes of environmental protection against noise or obligatory acoustic maps for agglomerations with more than 100 thousand citizens [Poś Law].

Ubiquitous noise has to be considered in land development. However, this should be done in accordance with the law and the existing restrictions. The changes in the Polish law regarding the permissible noise levels in the environment give more and more freedom to carry out investments in the areas classified as noise-sensitive. Urbanisation and suburbanisation processes are inevitable, and the most vulnerable areas are those on the periphery of cities and agglomerations but well-connected municipalities [Podawca et al. 2019]. The attempts to assess the impact of noise on the land use options have already been studied [Podawca 2014, Podawca and Staniszewski 2019], and the methodology used will be used in the following study.

THE GOAL OF THE STUDY

The aim of the performed analyses encompassed showing the possibilities included in spatial development regarding the increase of permissible noise levels caused by roads with heavy traffic, which came to force on 1 October 2012. [Journal of Laws 2012, item. 1109] As the central part of the scientific objective, the following research tasks (RT) were formulated:

- showing changes in the "acoustic climate" in selected areas, which took place between 2012 and 2017 – RT1 [Journal of Laws no. 120, item 826; Journal of Laws of 2012, item 1109] ;
- presentation of road traffic noise hazard in the analysed regions, according to the regulations on permissible noise levels from 2007 and 2012, based on the developed list of 20 superficial and quantitative features related to this hazard – RT2;
- difference analysis of the possible phenomena appearing while performing spatial research on the areas due to the reduction of the permissible levels of road traffic noise – RT3.

The territorial scope of the analysis was narrowed down to three areas meeting the following criteria:

- occurrence of road class G, GP or E;
- proximity of noise-sensitive functions;
- varying degree of urbanisation;
- location within the administrative borders of the city.

All selected sites lie within the boundaries of the city of Warsaw (Fig. 1). The first area is located in the Bemowo district. It covers three precincts: 6–12–08, 6–12–09, and 6–12–14, hereinafter referred to as "POW-I". The analysed area covers a total of 84.30 ha. The area is crossed by Powstańców Śląskich Street (10.35 ha) which has the main road class (G), the southern boundary is Połczyńska Street which has the main accelerated traffic class (GP) and the northern border is Człuchowska Street – a collective road. This area is highly urbanised.

The second analysis area 'MOD-II' is located in the area of Białołęka district, comprising precincts no: 4–02–31, 4–02–34, 4–01–09, 4–01–15, 4–01–28 and occupies a total area of 113.31 ha. The main road generating noise is Modlińska Street, which has the status of a main accelerated traffic road, a two-lane road with three lanes in each direction. The acoustic climate is also influenced by Mehoffera Street of the collective road class. This area is moderately urbanised.

The third analysed area is not very urbanised in comparison with the two previous ones. Administratively, it is located in the Bemowo district. It includes precincts: 6–13–01, 6–13–02, 6–13–03, 6–13–04 and 6–13–07. Obrońców Grodna Avenue, which is an expressway (S), runs through the area in the north-south direction, and in the east-west direction the area is crossed by Szeligowska Street, which has the status of a collector road. The analysed area named "OBR-III" occupies 119.20 hectares. It provides a good perspective example as we can expect it to undergo significant spatial development in the future, given its proximity to the S8 route and the planned metro line including a station.

METHODS

Due to the character of the problem and the research methodology, the analysis should be considered the case study. The case study has become a prevalent analytical method in architecture and urban planning. The case study used in the article encompasses an in-depth analysis of specific objects by distinguishing the features and qualitative elements of a defined metropolitan area [Niezabitowska 2014].

In order to proceed the RT1 research task, the authors utilised acoustic maps for Warsaw from 2012 and 2017, produced using a digital method in the Polish national 'PUWG 2000' coordinate system by the publishing houses BMTcom, SVANTEK and PVO at the request of the Mayor of the Capital City of Warsaw. In order to overlay the course of individual isophone on the plan of separate research areas, the ArcGIS software was used. With regard to road communication areas, the areas exposed to road noise of different levels have been designated. As a result, a spatially-oriented map data exemplifying the deterioration or improvement of the acoustic climate was obtained.

The implementation of task RT2, as a detailed characteristic of road traffic noise hazard, was based on the analysis of 20 features already used in the subject literature [Podawca and Staniszewski 2019]. These features (all abbreviations and

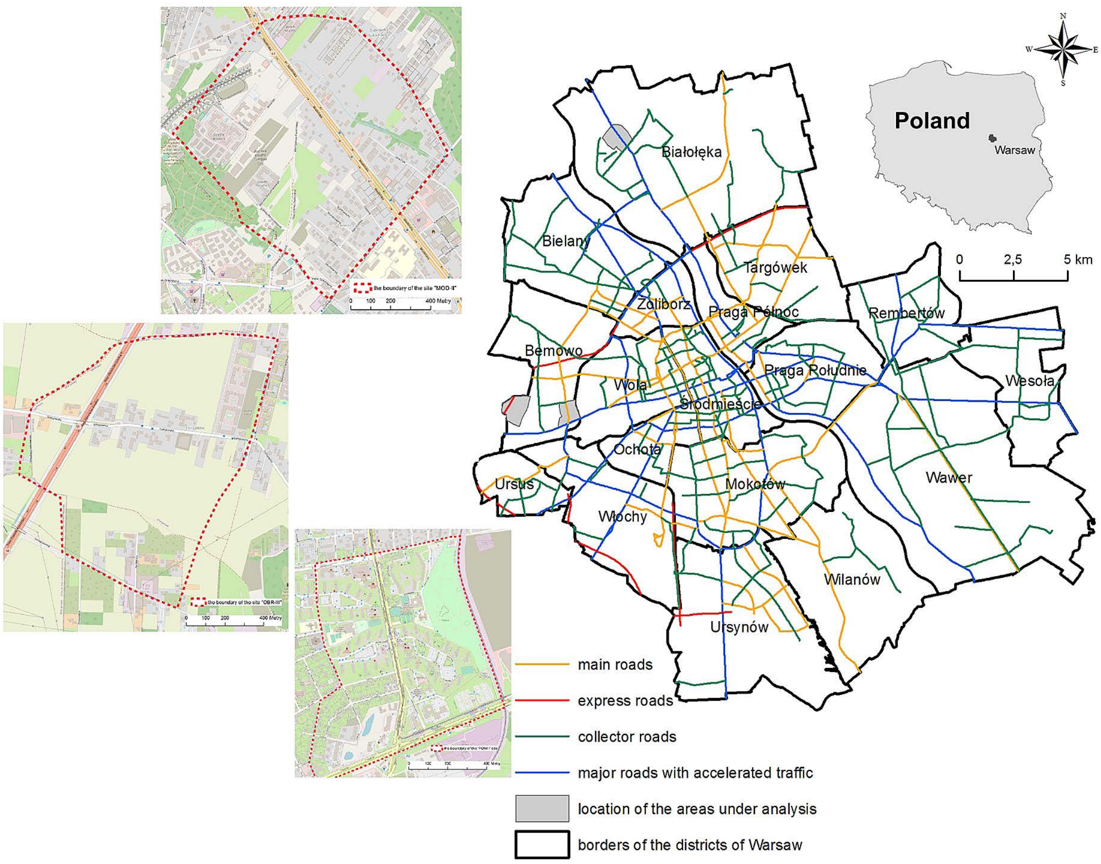

Fig. 1. Location of the analyzed areas, Warsaw, Poland (own elaboration)

marks follow the domestic terminology officially accepted) include:

- the terrain surface from the border of the road traffic area to the range of the isophone L_N 50dB for night time marked as $A_{LN\text{-}50dB}$ (feature No. 1) and to the range of the isophone L_N 59dB for night time marked as $A_{LN - 59dB}$ (feature No. 2);
- the terrain surface: from the border of the road traffic area to the range of the isophone L_{DWN} 55dB for the day-evening-night time, marked as A_{LDWN} – 55dB (a feature No. 3), to the range of the isophone L_{DWN} 60dB for the day-evening-night time, marked as A_{LDWN} – 60dB (feature No. 4), to the range of the L_{DWN} isophones 64dB in the day-evening-night time, marked as A_{LDWN} – 64dB (feature No. 5), to the range of the L_{DWN} isophone 68dB for the day-evening-night time, marked as A_{LDWN} – 68dB (feature number 6);
- number of buildings exposed to an over-normative noise situated within the L_N 50dB isophone at night time according to the regulations from 2007, marked as B_{50dBLN} (feature No. 7), located within the isophone L_N 59dB at night time according to the rules from 2012, as $B_{LN\text{-}59dB}$ (feature No. 8), located within the isophone L_{DWN} 55 dB in the day- evening-night time according to the regulations from 2007, marked as $B_{LDWN\text{-}55dB}$ (feature No. 9), situated within the isophone L_{DWN} 60 dB in the day-evening-night time according to the rules from 2007, as $B_{LDWN\text{-}60dB}$ (feature No. 11), located within the L_{DWN} 68 dB isophone in the day-evening-night time according to the rules of 2012, as $B_{LDWN\text{-}68dB}$ (feature No. 12);
- distance of the nearest multi-family residential buildings from the edge of the roadway, as $L_{DMFB\text{-}ER}$(feature No. 13);
- the distance of the nearest one-family residential buildings from the edge of the roadway, as $L_{DOFB\text{-}ER}$ (feature No. 14);
- the residential, one-family housing area, connected with a permanent or temporary stay of children and adolescents, nursing homes, hospitals in the cities located within the range of the $L_{DWN\ 55dB}$ isophone, as $FTU_{LDWN - 55dB}$ (feature No. 15), located within the range of the L_{DWN} 64dB isophone, as $FTU_{LDWN - 64dB}$(feature No. 16);
- the areas of a multi-family and collective residence, farm buildings, recreation and leisure, residential and service areas located within the isophone L_{DWN} 60dB, as $FTU_{LDWN\text{-}60dB}$ (feature No. 17), located within the isophone L_{DWN} 68dB, marked as $FTU_{LDWN\text{-}68dB}$ (feature No. 18);
- the area of one-family housing tied with permanent or temporary stay of children and youth, social care homes, hospitals in cities, multi-family and collective housing, farm buildings, recreation and leisure, residential and service buildings located within the isophone L_N 50dB, marked as $FTU_{LN\text{-}50dB}$ (feature No. 19), located within the range of the isophone L_N 59dB, marked as $FTU_{LN\text{-}59dB}$(feature No. 20).

Task RT3, as the most analytical one, was based on utilising the own set of indicators. The indicators were based on the Regulation of the Ministry of the Environment from 1 October 2012 considering the permissible environmental noise levels according to art. 113 § 1 of the Legal Act from 27 April 2001 – Environment Protection Law (Diary of Laws of 2008, No. 25, item 150, as amended) and the Regulation of the Ministry of the Environment from 14 June 2007 on permissible noise levels in the environment. Nine relevant indicators of the so-called "Acoustic release" were proposed and listed in Table 1.

RESULTS

Due to the changes in the permissible noise levels that do not coincide with the main isophones determined in the acoustic maps, a digital interpolation of the course of the 59dB, 64dB and 68dB isophones for the two periods of 2012 and 2017 was made.

While analysing the data in Table 2, it is possible to observe a worsening of the acoustic climate in two areas. In the "POW-I" area, the fragments of the areas exposed to the sound above 68dB in the day-evening-night time increased by 2.48% and for 64dB by 3.32%. At night time, noise above 59dB was recorded in an area 1.02% larger than in 2012. Fairly minor negative changes in the acoustic climate may have been caused by the deterioration of the pavement and increased traffic on Powstańców Śląskich Street while maintaining the state of land use. The definitely worse situation can be observed in the area of "OBR-III". The percentage of the areas exposed to the noise of 68dB and 64dB for L_{DWN} index increased

Table 1. Analysis indicators (own elaboration)

No. Indicator	Indicator name	Indicator symbol	Indicator formula
1.	„Acoustic release" – Night	WAR_{LN}	$(A_{LN-50dB} – A_{LN-59dB})/A_{LN-50dB}$
2.	„Acoustic release" – Day-Dawn-Night	W_1AR_{LDWN}	$(A_{LDWN-55dB} – A_{LDWN-64dB})/A_{LDWN-55dB}$
3.		W_2AR_{LDWN}	$(A_{LDWN-60dB} – A_{LDWN-68dB})/A_{LDWN-60dB}$
4.	„Acoustic-functional release"- Night	$WAFR_{LN}$	$(FTU_{LN-50dB} – FTU_{LN-59dB})/FTU_{LN-50dB}$
5.	„Acoustic-functional release" – Day-Dawn-Night	W_1AFR_{LDWN}	$(FTU_{LDWN-55dB} – FTU_{LDWN-64dB})/FTU_{LDWN-55dB}$
6.		W_2AFR_{LDWN}	$(FTU_{LDWN-60dB} – FTU_{LDWN-68dB})/FTU_{LDWN-60dB}$
7.	„Construction-acoustic" -General/Night	WCA_{LN}	$(B_{LN-50dB} – B_{LN-59dB})/B_{LN-50dB}$
8.	„Construction-acoustic" – General/Day-Dawn-Night	W_1CA_{LDWN}	$(B_{LDWN-55dB} – B_{LDWN-64dB})/B_{LDWN-55dB}$
9.		W_2CA_{LDWN}	$(B_{LDWN-60dB} – B_{LDWN-68dB})/B_{LDWN-60dB}$

Table 2. Areas and percentage shares of the terrains with exceeded noise levels caused by road traffic noise within the analysed boundaries according to acoustic maps from 2012 and 2017 (own elaboration)

Isophone name	STUDY AREA	Year 2012		Year 2017	
		Noise-endangered area	Terrain percentage	Noise-endangered area	Terrain percentage
		[ha]	[%]	[ha]	[%]
L_N – 59 dB	POW-I	9.97	11.83	10.83	12.85
L_{DWN} – 64 dB		18.84	22.35	22.35	25.67
L_{DWN} – 68 dB		7.40	8.78	9.49	11.26
L_N – 59 dB	MOD-II	17.62	15.55	9.62	8.49
L_{DWN} – 64 dB		31.44	27.75	20.94	18.48
L_{DWN} – 68 dB		15.83	13.97	9.90	8.74
L_N – 59 dB	OBR-III	16.41	13.77	28.32	23.76
L_{DWN} – 64 dB		34.46	28.91	46.39	38.92
L_{DWN} – 68 dB		12.80	10.74	25.51	21.40

by 10.66% and 10.01%. For an L_N of 59dB the increase was 9.99%. Such large negative increases may have been caused by a significant increase in the operation of the S8 route section, which was opened in 2011 and its impact on the 2012 acoustic maps may have been much smaller. The only area where the acoustic conditions improved is the "MOD-II" area. The area exposed to the 68dB noise during daytime and evening/night-time decreased by 7.06%, 64dB by 9.27% and 59dB at night by 5.23%. This improvement was probably related to the modernisation of the street and the intersections along Modlińska Street.

The results concerning the spatial and construction features resulting from the risk of a road traffic noise are shown in Table 3.

DISCUSSION

The values of the acoustic and spatial indicators for the analysed areas are presented in Table 4.

While analysing the values above, it should be stated that the changes in the permissible road noise levels significantly influence the interpretation of acoustic risk in urbanised areas. In terms of acreage, night-time noise pollution under the amended legislation resulted in a reduction of the acreage of areas considered noise-sensitive by as much as 74% within the boundaries of the "POW-I" site (Fig. 2), 77% on MOD-II (Fig. 4) and 71% on "OBR-III" (Fig. 6). This had a direct effect on reducing the number of buildings treated as noise-exposed, and thus the number of people living in them. There was an 82% reduction in their number in Site I, and a 77% reduction in Sites II and III. Increasing the L_{DWN} limit for day/evening/night from 55dB to 64dB reduced the area considered to be affected by road noise by 62% in Site I (Fig. 3), 69% in Site II (Fig. 5) and 56% in Site III (Fig. 7). Similarly, for the buildings themselves, this was a reduction of 65% within Site I, 63% in Site II and 69% in Site III. The changes looked even more unfavourable regarding the increase of the LDWN noise levels from 60dB to 68dB.

Table 3. Features of sensitivity to noise within the boundaries of the analysed areas (own elaboration)

Feature No.	Feature symbol	Feature unit	Feature value		
			POW-I	MOD-II	OBR-III
1.	$A_{LN–50dB}$	m^2	421054	419562	970051
2.	$A_{LN–59dB}$	m^2	108317	96244	283239
3.	$A_{LDWN–55dB}$	m^2	573004	694655	1062875
4.	$A_{LDWN–60dB}$	m^2	359743	381368	841343
5.	$A_{LDWN–64dB}$	m^2	216361	209362	463928
6.	$A_{LDWN–68dB}$	m^2	94916	99007	255143
7.	$B_{LN-50dB}$	szt.	139	125	32
8.	$B_{LN-59dB}$	szt.	25	29	4
9.	$B_{LDWN-55dB}$	szt.	120	186	46
10.	$B_{LDWN-60dB}$	szt.	32	3	20
11.	$B_{LDWN-64dB}$	szt.	42	69	14
12.	$B_{LDWN-68dB}$	szt.	7	0	4
13.	$L_{DMFB-ER}$	m	22	283	512
14.	$L_{DOFB-ER}$	m	7	13	18
15.	$FTU_{LDWN–55dB}$	m^2	115107	198494	64713
16.	$FTU_{LDWN–64dB}$	m^2	32020	69628	21046
17.	$FTU_{LDWN–60dB}$	m^2	77145	77145	34592
18.	$FTU_{LDWN–68dB}$	m^2	13222	0	3498
19.	$FTU_{LN–50dB}$	m^2	171722	129847	50420
20.	$FTU_{LN–59dB}$	m^2	27595	25096	8069

Table 4. Values of acoustic indicators within the analysed areas (own elaboration)

Indicator No.	Indicator symbol	Indicator value		
		POW-I	MOD-II	OBR-III
1.	WAR_{LN}	0.74	0.77	0.71
2.	W_1AR_{LDWN}	0.62	0.69	0.56
3.	W_2AR_{LDWN}	0.74	0.74	0.70
4.	$WAFR_{LN}$	0.84	0.81	0.84
5.	W_1AFR_{LDWN}	0.72	0.64	0.67
6.	W_2AFR_{LDWN}	0.83	1.00	0.90
7.	WCA_{LN}	0.82	0.77	0.77
8.	W_1CA_{LDWN}	0.65	0.63	0.69
9.	W_2CA_{LDWN}	0.78	1.00	0.80

In the area of "POW-I" and "MOD-II", the areas were reduced by 74% (Fig. 3) and in "OBR-III" by 70% (Fig. 7). Considering the release of the buildings themselves, it was analogically 78%, 100% and 80%.

The indicators of functional-acoustic release are more objective as they refer only to the areas that, according to the Regulation of the Minister of Environmental Protection, are considered sensitive to noise. Concerning the areas of single-family housing, housing connected with permanent or temporary residence of children and young people, nursing homes and hospitals in cities, the change of the permissible value of the L_{DWN} parameter from 55dB to 64dB resulted in a reduction of the areas at risk by 72% in the "POW-I" area, 64% in the "MOD-II" area and by 67% in the "OBR-III" area. Concerning multi-family housing and collective residence, farmsteads, recreational and leisure areas as well as residential and service areas, the amendment to the regulations resulted in a reduction of the area of land considered under the rule as threatened by railway noise by 83% in Area I, 100% in Area II and 90% in Area III. In the context of the night time, the change of acceptable noise level from 50dB to 59dB sensitive areas was reduced by 84% in the area of "POW-I" and "OBR-III" and 81% in the area of "MOD-II".

It should be emphasised that the degree of urbanisation of the area did not cause significant differences in the acoustic release of the area in terms of surface.

CONCLUSIONS

The analyses carried out clearly showed how critical the introduction of new regulations, liberalising the permissible sound levels in the environment, was for the acoustic climate. Increases of the maximum road noise indicators L_N and

L_{DWN} prove very beneficial from the investors' point of view. Acoustic unblocking of quite many areas, at the level of 71–77% for night time and 56–74% for day/evening/night time allows realizing housing, service and residential and recreational investments without additional protection. Concerning the current situation of the so-called acoustically sensitive areas, these have been reduced by 81–84% at night and 64–72% for single-family residential buildings and 83–100% for multi-family residential buildings during daytime, evening and night time. The values above clearly show that the implementation of residential development functions near main accelerated, main and express roads will not pose a significant legislative problem.

The situation is much worse in the social and health context. Comparing the WHO recommended maximum night-time noise level of 42dB with the Polish limit of 59dB, there is a difference of 17dB. When assessing whether this is a lot and balancing the economic, social and health interests by giving equal weight to all of the above, it is necessary to refer to the basics of acoustics. A decibel (dB) is ten decimal logarithms of the ratio of the pressure of a sound wave to a reference pressure of 2x10–5 N/m^2. It means that a 1dB increase in noise causes a 1.26-fold increase in sound pressure. A doubling of the pressure at which a person begins to feel the difference in perceived noise corresponds to a 3 dB change in sound level. [Leśnikowska-Matusiak and Wnuk 2014]. No one seems to have taken this into account when raising the permissible values of acoustic indicators by 9dB, causing a tenfold increase in sound pressure–even using the scale of the subjective annoyance of traffic noise [www.profon.pl] it can be observed that the current values of permissible sound levels fall within the medium disturbance in terms of L_N and high in terms of L_{DWN}.

Unfortunately, the analyses performed confirmed the general view that Poland's standards of noise protection are deficient. Simultaneously, in Europe, the Ministry of Environment raised the permissible communication noise levels, which means that practically every inhabitant of the areas along the higher-level roads will be exposed to the noise harmful to their health, but compliant with the Polish regulations.

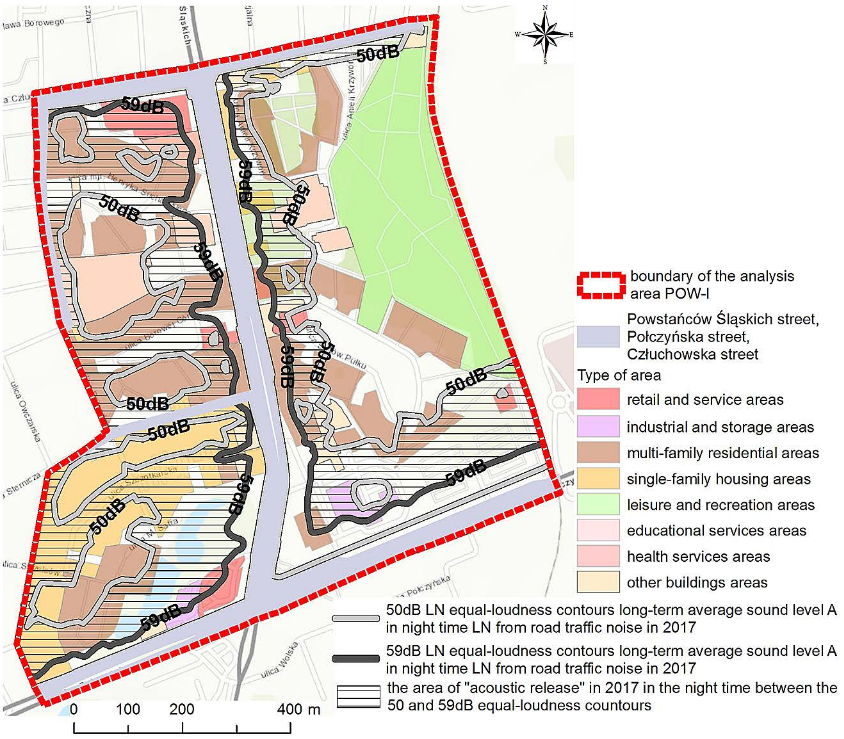

Fig. 2. The area of "acoustic release" when changing the permissible sound levels in the night time of the analysis area "POW-I" (own elaboration)

Fig. 3. The area of “acoustic release” when changing the permissible sound levels in the day-evening-night time of the analysis area “POW-I” (own elaboration)

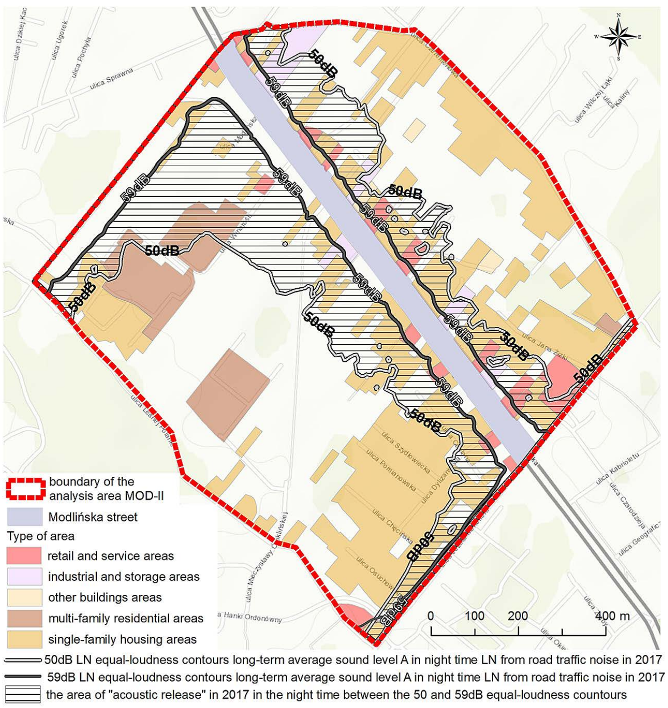

Fig. 4. The area of “acoustic release” when changing the permissible sound levels in the night time of the analysis area “MOD-II” (own elaboration)

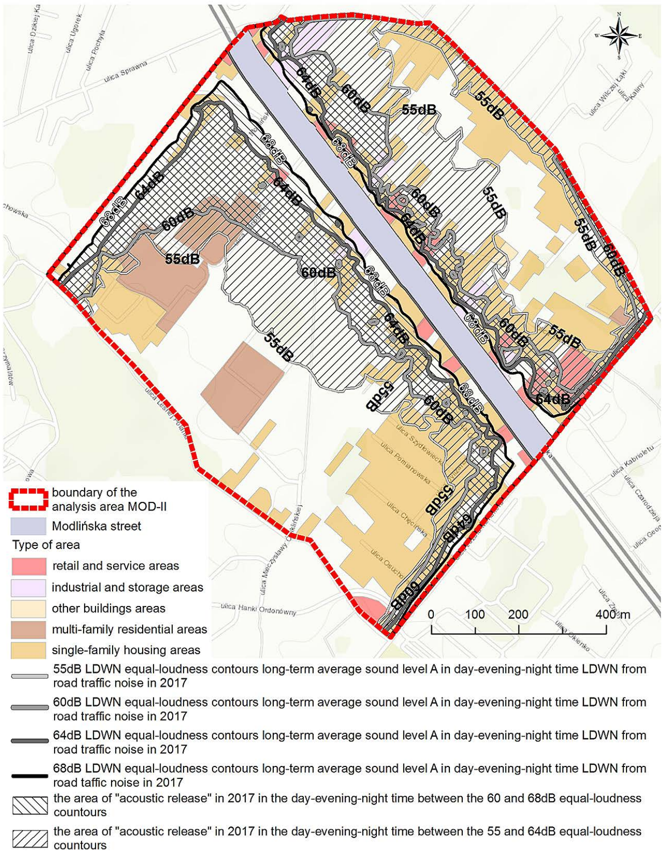

Fig. 5. The area of "acoustic release" when changing the permissible sound levels in the day-evening-night time of the analysis area "MOD-II" (own elaboration)

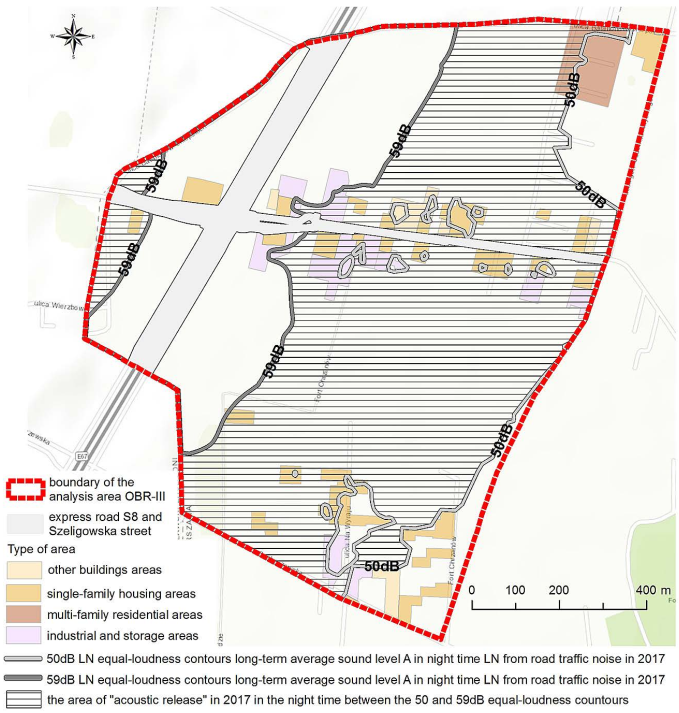

Fig. 6. The area of "acoustic release" when changing the permissible sound levels in the night time of the analysis area "OBR-III" (own elaboration)

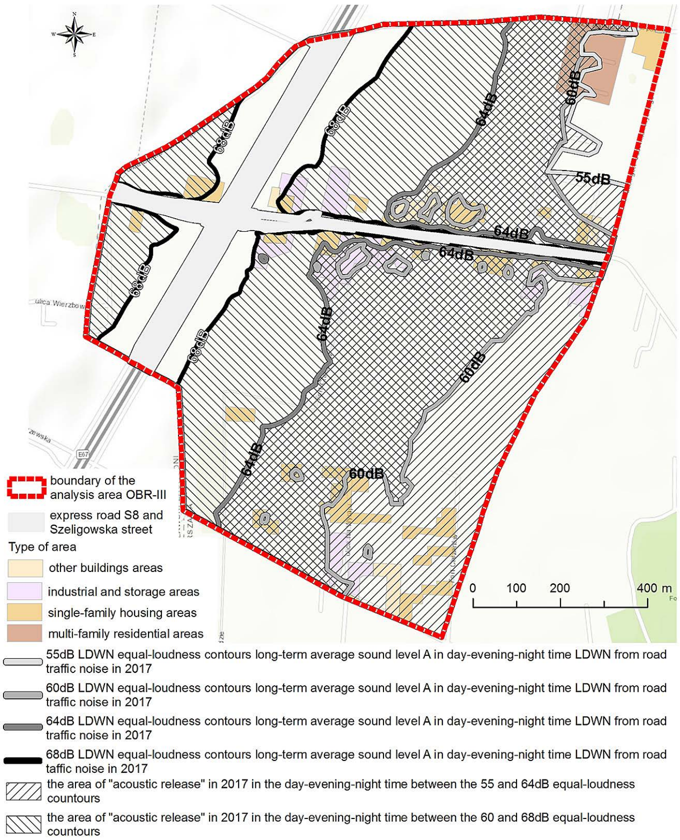

Fig. 7. The area of “acoustic release” when changing the permissible sound levels in the day-evening-night time of the analysis area “OBR-III” (own elaboration)

REFERENCES

1. Babisch W., Dutilleux G., Paviotti M.,Backman A., Gergely B., McManus B., Bento Coelho L., Hinton J.,Kephalopoulos S., Van den Berg M., Licitra G., Rasmussen S., Blanes N., Nugent C., De Vos P., Bloomfield A. 2010. Good practice Guide on noise exposure and potential health effects, European Environment Agency, Technical Report, 11, 1–36.
2. Babisch W., Ising H., Gallacher J. 2003. Health status as a potential effect modifier of the relation between noise annoyance and incidence of ischaemic heart disease. Occupational and Environmental Medicine, 60, 739–745.
3. Barańska M., Deja A. 2014. Analiza natężenia hałasu generowanego przez transport samochodowy w bezpośrednim sąsiedztwie portu morskiego w aglomeracji szczecińskiej. Czasopismo Logistyka, 3, 305–311.
4. 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.
5. Galińska B., Kopania J. 2017. Organizational and technical methods of noise reduction in urban space. Autobusy: Technika, Eksploatacja, Systemy Transportowe, 18(6), 163–167 (in Polish).
6. Gierasimiuk P., Motylewicz M. 2014.Traffic noise in the vicinity of roads and streets – assessment problems and protective actions, w: Inżynieria środowiska – młodym okiem, Skoczko I., Piekutin J. (Ed.), Politechnika Białostocka, Białystok, 59–94 (in Polish).
7. Gorzelańczyk P. 2016. The road transport noise emission in Pila. Autobusy 6, 876–880 (in Polish).
8. Hurtley C. (Ed.) 2009. Night Noise Guidelines for Europe, World Health Organization.
9. Leśnikowska-Matusiak I., Wnuk A. 2014. The effects of traffic noiseon the state of acoustic environment of man, Transport samochodowy, 3, 37–63 (in Polish).
10. Malec A., Borowski G. 2018. Monitorung of Road Noise in the Urban Environment of Lublin, Journal of Ecological Engineering, 19(4), 159–166.
11. Niezabitowska E.D. 2014. Metody i techniki badawcze w architekturze, Wydawnictwo Politechniki Śląskiej, Gliwice (in Polish).
12. Pervez A., Kafeel A., Shakil S.A., Nasim A. 2020. Noise Monitoring, Mapping, and Modelling Studies – A Review, Journal of Ecological Engineering, 21(4), 82–93.

13. Perzyński T., Pietruszczak D., Poneta A. 2019. The noise analysis of road transport in selected points of the Radom city. Autobusy, 6, 81–85 (in Polish).
14. Podawca K. 2014. Hałas drogowy jako ograniczenie możliwości zagospodarowania przestrzennego na wybranych przykładach, Problemy Rozwoju Miast, 1, 5–19.
15. Podawca K. 2017. Ekrany akustyczne w krajobrazie i architekturze miasta –wybór czy konieczność, Zeszyty Naukowe Uczelni Vistula, 53(2), 130–142.
16. Podawca K. 2017. Ekrany akustyczne w mieście – bariera w zagospodarowaniu przestrzeni urbanistycznej, Studia Miejskie, 27, 91–106.
17. Podawca K., Karsznia K., Pawłat-Zawrzykraj A. 2019. The assessment of the suburbanisation degree of Warsaw Functional Area using changes of the land development structure. Miscellanea Geographica, 23(4), 215–224.
18. Podawca K., Staniszewski R. 2019. Impact of Changes of the Permissible Railway Noise Levels on Possibilities of Spatial Management in Urban Areas. Rocznik Ochrona Środowiska / Annual Set the Environment Protection, 21(2), 1378–1392.
19. Popławska K., Fijałkowska A., Osińska-Skotak K. 2012. Evaluation of traffic noise buffer zones delimitationusing gis technology. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 23, 327–336 (in Polish).
20. Profaska M., Korban Z., Kernert R. 2012. Przykładowe badania uciążliwościemisji hałasu z ciągu komunikacyjnego. Rocznik Ochrona Środowiska / Annual Set the Environment Protection, 14, 800–813.
21. Rozporządzenie Ministra Środowiska z dnia 1 października 2012 r. zmieniające rozporządzenie w sprawie dopuszczalnych poziomów hałasu w środowisku (Dz.U. 2012 poz. 1109).
22. Rozporządzenie Ministra Środowiska z dnia 14 czerwca 2007 r. w sprawie dopuszczalnych poziomów hałasu w środowisku (Dz.U. Nr 120 z dnia lipca 2007 r., poz. 826).
23. Ustawa – Prawo ochrony środowiska (Dz.U. 2001 Nr 62 poz. 627, stan na 02.02.2021)
24. Vaverkova M.D., Koda E., Wdowska M. 2021. Comparison of Changes of Road Noise Level Over a Century Ouarter: A Case Study of Acoustic Environment in the Mountainous City, Journal of Ecological Engineering, 22(1), 139–150.
25. www.profon.pl/podstawy/podstawy3.html [dostęp 15.02.2021]