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ACOUSTIC CLIMATE IN THE ENVIRONMENT OF THE SELECTED ROAD SECTIONS IN POLAND

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Abstract. Traffic noise is an inherent element of contemporary societies' life. Its volume systematically increases as the car number is growing and the road network is developed. Traffic noise, especially road-induced noise, is so widespread in our environment that it is hard to isolate ourselves from it.
This paper presents the results of acoustic climate studies conducted in the vicinity of selected road sections in Poland: national road DK8 in the vicinity of Budzisko and Augustów, S8 road near Wyszków and at the final stretch of DK 8 in the vicinity of Kudowa-Zdrój. The studies also covered two areas adjacent to A1 motorway in the vicinity of Kamionek and Pelplin and next to road DK 91, which runs in parallel to A1 motorway. Acoustic climate studies were also carried out along A4 motorway and national road DK 94 in the vicinity of Lewin Brzeski. Measurements were made along the Buszyce–Magnuszewice profile. Noise measurements were made on a total of 11 profiles. The analysis covered certain features of the acoustic climate (equivalent sound level, its maximum and minimum values and duration of noise of a given level). Acoustic climate features were compared with data on traffic intensity and vehicle type structure along the road sections under analysis. The paper also discusses sound propagation in the vicinity of transport routes and the impact of local environment characteristics (landscape relief and humidity) on noise propagation. Possible noise level reduction means to be applied in the vicinity of roads are also discussed.

Keywords: noise, acoustic climate, car traffic, sound propagation.

Introduction

Acoustic climate is understood as a description of acoustic stimuli in a given environment in time and space[1]. The stimuli are due to differences in acoustic air pressure as a result of mechanical vibrations (sound waves) transmitted through the air. They stimulate the ear and other human body organs. There are many sound sources, both natural (such as trees swooshing, birds singing, sea waves hitting the shore) and human-generated. Where sounds are undesirable, unpleasant, irritating or harmful, we

[1] The paper presents the findings from the research project under the grant agreement no. NN 306 564940 financed with the resources from the National Science Center.

refer to them as noise (Augustyńska et al. 2014). The Dictionary of Polish defines noise as "undesirable or harmful sound". The PWN Encyclopaedia defines noise similarly: "noise – undesirable sound which may be irritating or harmful to humans". Excessive noise causes fatigue, irritability, higher blood pressure, headache, vertigo and even hearing loss (Kalinowski 1969).

For humans the major source of noise is traffic (road, rail and air traffic noise). Other common sources of environmental noise include municipal sources (such as neighbours, radio, TV, bars and restaurants), social and leisure sources (e.g. music players, toys, open cultural events, fireworks) as well as industrial plants and construction works (WHO, *Burden of disease*... 2011).

While we are able to isolate ourselves from municipal, social and industrial sources of noise to some extent, the traffic noise, road traffic in particular, is widely present. Studies carried out in the Netherlands show that the percentage of people affected by excessive noise at night increased from 20% to 27% between 1998 and 2003. The most numerous group were people affected by road traffic noise (*Night noise*… 2009). It is estimated that about 35% of Poland's population is exposed to noise that exceeds the norms during the day and at night. About 80% of this nuisance results from noise from public roads (*National Environmental Policy*… 2008).

The problem of exposure of individuals or entire populations to noise has become global in recent years. It has been addressed by the World Health Organization (WHO) in its periodic reports that summarise the state of the art in research in the influence of noise on human health (*Burden of disease*… 2011; *Night noise*… 2009). In view of the increasingly pressing problem of noise in the human environment and the risks to human health reported by physicians, Directive 2002/49/EC of the European Parliament and of the Council (*Directive*… 2002) commits European Union Member States to developing national strategies to monitor and combat noise.

The borderline between annoying and not annoying noise is flexible and depends not only on the type of noise, but also on the nervous and psychological resilience of individuals, their mood or type of work. It is frequently the case that the same set of sounds may be pleasant at one time but unpleasant at other times. All these factors cause difficulties in evaluating actual threat to the society in a situation where we only have information on noise volume. Therefore, noise volume measurement results are confronted with opinions expressed in surveys. Such studies, carried out in Warsaw by the National Institute of Hygiene (NIH), led to developing the following scale of subjective traffic noise annoyance (Koszarny & Szata 1987):

Noise annoyance:	**Noise level L_{Aeq} [dB][2]:**
Low	< 52
Medium	52–62
High	63–70
Very high	> 70

Another noise categorisation (Engel & Sadowski 2005) takes into account varying noise effect on human body and thus different harmfulness levels. It divides audible noise into five groups depending on its level:

1. below 35 dB(A): not harmful, possibly irritating or disturbing work that requires concentration,

[2] L_{Aeq} is the basic noise level measure. It defines the so-called *equivalent noise level* understood as "the value of sound pressure from a continuous sound, adjusted by reference to the A frequency characteristics, which equals the average square of the sound pressure of the analysed sound in a specific period of reference time" (Environmental Protection Law, Dz. U. of 2001, No 62, item 627, Article 3(32b)).

2. 35–70 dB(A): fatigue of human nervous system, seriously hinders speech understanding, the process of falling asleep and the rest,
3. 71–85 dB(A): considerable reduction of work productivity, may be harmful and cause hearing loss,
4. 86–130 dB(A): numerous illnesses, prevents speech understanding even at 0.5 m,
5. above 130 dB(A): permanent hearing loss, induce vibrations of body organs causing illnesses.

WHO reports (*Burden of disease*… 2011; *Night noise*… 2009) claim it cannot be unambiguously concluded that specific health effects described in medical studies result from exposure to excessive noise alone. In the specific environments humans are exposed to a number of external stimuli, noise being one of them. Nonetheless the WHO highlights many health hazards caused by noise. According to WHO, the most frequent effects of prolonged exposure to noise are: blood pressure fluctuation, intensification of hypertension and ischaemic heart disease, impaired cognitive abilities (particularly in children and young adults), sleep disorders, hearing disorders and impairment, as well as subjective annoyance by noise (*Burden of disease*… 2011).

Z. Engel and J. Sadowski (2005) concluded that long-lasting exposure to excessive noise environment may result in the so-called noise exposure syndrome that entails impairment of physiological and psychological functions (headache, vertigo, weakness, higher excitability, sleep disorders, higher perspiration, hearing loss). The limit value for physiological function disorder is 70 dB.

The same limit value of noise harmfulness was determined by M. van den Berg (2005) on the basis of studies on the Dutch population (Tab. 1). Subjective annoyance and sleep quality deterioration were caused by noise of 40–42 dB(A). Sleep was fitful when the volume of noise in the bedroom was 35 dB.

Table 1. Proven health effects of exposure to audible noise of various volumes

Health effect	**Critical noise volume**		
	noise indicator	**dB(A)**	**place**
Hearing loss	L_{Aeq}, 8 hrs	75	indoors
	L_{Aeq}, 24 hrs	70	indoors
Blood pressure fluctuation	L_{Aeq}, 8 hrs	85	indoors
	L_{Aeq}, 6 am – 10 pm	70	outdoors
Ischaemic heart disease	L_{Aeq}, 6 am – 10 pm	70	outdoors
Annoyance	L_{dn}	42	outdoors
Insomnia	SEL[3]	55	indoors
Fitful sleep	SEL	35	indoors
Subjective sleep quality deterioration	L_{Aeq}, night	40	outdoors
Intellectual fitness	L_{Aeq}, day	70	outdoors

Source: van den Berg 2005.

In view of the above-mentioned noise effect on humans, the purpose of this paper is to present the results of acoustic climate studies, with particular emphasis on noise volume in the area of selected sections of national roads and motorways in Poland. Social and environmental studies, including studies on acoustic climate, were carried out in a number of Polish landscape types. This

[3] SEL stands for sound exposure level, or any noise level L_{eq} normalised to 1 second.

paper presents the results of studies conducted in the vicinity of national road DK 8 in the vicinity of Budzisko and Augustów, S8 road next to Wyszków and at the final stretch of DK 8 road in the vicinity of Kudowa-Zdrój. The studies also covered two areas adjacent to A1 motorway, in the vicinity of Kamionek and Pelplin and next to road DK 91 (in Lignowy Szlacheckie and Pieniążkowo), which runs in parallel to A1 motorway. Similar acoustic climate studies were carried out next to A4 motorway and national road 94 in the vicinity of Lewin Brzeski. Measurements were made along the Buszyce–Magnuszewice profile. Noise measurements were made on a total of 11 profiles. The analysis covered some features of the acoustic climate (equivalent sound level, its maximum and minimum values and the duration of noise of a given volume) as a function of: traffic intensity, day time, distance from the road, landscape features and land cover.

Materials and research method

Noise is measured on selected road sections using integrating sound level meters SON-50 and DSA-50 by SONOPAN. The meters were mounted on stands at about 1.7 m above the ground. The assumed measurement level is consistent with the recommendations of the International Society of Biometeorology (ISB) for studies concerning the effect of the atmospheric environment on humans. The measurements were made in adequate weather conditions (wind below 5 m/s, air temperature above –5°C, no precipitation, no or weak ground temperature inversion) defined in Appendix 1 to the Ordinance of the Minister of the Environment of 2 October 2007 on the requirements for measurements in the environment of substance or energy levels (Dz. U. No 192, item 1392). The measurements were made using the direct method of constant measurement by sampling. The acoustic climate was described using the average equivalent sound level expressed in decibels, adjusted according to adjustment curve A (L_{Aeq}). Also, example maximum noise level values (L_{Amax}) and duration of exposure to sounds of various volumes were provided. The measurements also included the number of vehicles using the road, divided into cars, lorries, vans, buses and other vehicles: motorbikes, tractors and farming machinery.

In each area, measurements were made twice in 24 hours at times of the highest traffic intensity during the day (between 10 am and 6 pm) and at night (between 9 pm and midnight).

Each time noise volume and the number of vehicles, divided into the four above-mentioned categories, were registered at the edge of the main road in a continuous manner. Measuring stations were located along profiles perpendicular to the main road. The distance between the measuring stations and main road edge was determined taking into account landscape features, the vegetation cover and development. The measurement profiles were set in places where it was possible to measure noise from the main road directly and where the burden of local noise sources was the lowest. As a rule, measuring stations the closest to the road were 100 m away and the farthest were 500 m or 1,000 away (Tab. 2). Selection of measuring station locations followed a rule that they should describe the acoustic climate affected by traffic on a selected road section best. An example of measuring profile location on three road sections under analysis is presented in Figure 1.

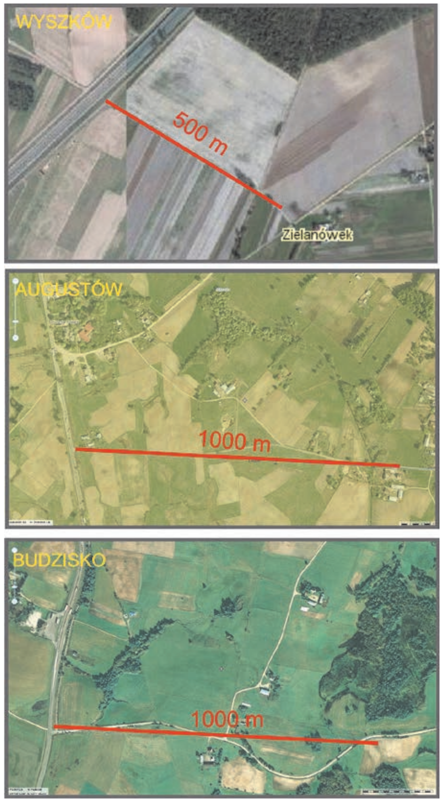

Figure 1. Measuring profile location on selected road sections
Source: own elaboration on the basis of https://mapy.google.pl/.

Table 2. Distances of noise measurement stations from road edges on the road sections under analysis

No.	Road number and section name	Distance of the measurement station from the road (m)							
		0	100	200	300	400	500	750	1,000
1	DK8 Budzisko	x	x		x		x	x	x
2	DK8 Augustów	x	x		x		x	x	x
3	S8 Wyszków	x	x	x	x	x	x		
4	DK8 Niemcza	x	x		x		x	x	x
5	DK8 Jeleniów	x	x		x		x	x	x
6	A1 Pelplin	x	x		x		x		
7	A1 Kamionka	x	x		x		x	x	x
8	DK91 Lignowy Szlacheckie	x	x		x		x	x	x
9	DK91 Pieniążkowo	x	x		x		x	x	x
10	A4 Magnuszowice	x	x	x	x	x	x		x
11	DK94 Buszyce	x	x	x	x	x	x		

The ‘x’ stands for noise measurement.
Source: own study.

Evaluation of the effect of noise on the population is based on sanitary norms laid down in the Ordinance of the Minister of the Environment of 1 October 2012 on admissible levels of noise in the environment (Dz. U. of 2012, item 1109). These norms depend on the emission source type, land development and time of the day. It should be added that the above document replaced an analogous Ordinance of 2007. The admissible levels of road and rail traffic noise in areas with farm buildings, single-family and multi-family houses and collective accommodation facilities were increased by 5–6 dB for the day and for the night. In cities with population in excess of 100,000 the admissible levels were increased by 3 dB for the day and by 5 dB for the night (Table 3).

Table 3. Admissible noise levels in the environment (Ordinance of the Minister of the Environment of 1 October 2012 (Dz. U. of 2012, item 1109)

No.	Land type	Admissible noise level in [dB]			
		Roads or railways		Other facilities and activity generating noise	
		$L_{Aeq\ D}$ Period of reference time equal to 16 hours during the day	$L_{Aeq\ N}$ Period of reference time equal to 8 hours during the night	$L_{Aeq\ D}$ Period of reference time equal to eight successive least favourable hours	$L_{Aeq\ N}$ Period of reference time equal to one least favourable hour during the night
1	a) Resort buffer zone “A” b) Hospital grounds outside a city/town	50	45	45	40
2	a) Areas with single-family houses b) Areas with facilities accommodating children and young people on a permanent or temporary basis c) Areas with welfare care homes d) Hospital grounds within cities/towns	61 (55)	56 (50)	50	40
3	a) Areas with multi-family houses and collective accommodation facilities b) Areas with farm buildings c) Recreation and leisure areas[2)] d) Residential and commercial areas	65 (60)	56 (50)	55	45
4	Centre areas of cities with a population in excess of 100,000	68 (65)	60 (55)	55	45

Admissible noise levels valid from September 2012 are given in brackets
Source: own study.

As noise measurements were conducted outside cities and towns, normative values of 65 dB during the day and 56 dB at night were applied to evaluate the effect of noise on humans.

Results of studies

The road sections under analysis are situated in areas which vary in terms of landscape features (mountains, valleys, upland, lakeland), land cover (forest, fields and meadows, dispersed farm buildings) as well as density of residential houses and of local road network. Therefore the measurement material allowed determination of basic environment characteristics affecting the acoustic climate at each section under analysis.

National road DK8 and expressway S8

Measurements on DK8 and expressway S8 were taken on profiles: “Budzisko”, “Augustów”, “Wyszków”, “Niemcza” and “Jeleniów”. Each of the sections under analysis has different landscape features and development. In “Budzisko” and “Jeleniów” profiles diversified relief modelled the acoustic environment of the studied areas to a large extent. Also the structure of vehicles was different than on other sections of the road: it was dominated by lorries which cross the Polish border in Budzisko and Kudowa-Słone. In “Wyszków” profile landscape features allowed measuring the sound waves propagation at increasing distances from the road. For “Niemcza” and “Augustów” profiles traffic noise was studied against the background of sounds generated by other anthropogenic sources.

Study results show that admissible noise levels were exceeded on all measurement profiles both during the day and at night (Table 4). Noise was the greatest right next to the roadway edge. In the case of “Augustów” profile noise level was as high as 75.4 dB(A), and the value for “Budzisko” profile was only slightly lower: 74.2 dB(A). In “Wyszków” profile the equivalent sound level stood at 67.9 dB(A). In the southern part of national road DK8 noise recorded on “Niemcza” profile was at the level of 70 dB(A) and was 1.4 dB(A) lower than on “Jeleniów” profile. It should be noted that in the two latter cases measurements were made in built-up areas, in Niemcza it was made at the town bypass road and in Jeleniów it was made along the local road in the village.

Smooth traffic on the roads generated less noise than traffic characterised by frequent braking and speeding up (especially of heavy vehicles). This is particularly apparent in maximum noise levels. The admissible levels were exceeded to the lowest extent in “Wyszków” profile, only by 5 dB(A), as vehicles travel smoothly there, both during the day and at night. Also on Niemcza bypass road the noise level was relatively low. Equally high values were recorded during measurements at night. For “Budzisko” and “Jeleniów” profiles, where traffic is not smooth, equivalent sound level was 75 dB(A) during the day and at night.

Table 4. Results of noise measurements on profiles: Wyszków, Budzisko, Augustów, Niemcza and Jeleniów

No.	**Noise level characteristics**	**Equivalent sound level L_{Aeq} [dB]**											
		Day						**Night**					
Wyszków, 9 October 2013, N 52°33'33", E 21°27'57"													
Distance from the road (m)		*0*	*100*	*200*	*300*	*400*	*500*	*0*	*100*	*200*	*300*	*400*	*500*
1	Average	**66.3**	63	59.7	54.9	51.3	51.3	**61.4**	**62**	**57.9**	55.2	48.5	47.1
2	Maximum	**78.2**	**69.5**	**65.8**	58.7	56.5	62.8	**76.7**	**70.6**	**65.9**	**60.7**	**56.6**	51.6
3	Minimum	51.4	52.7	51.6	47.3	45.5	43.8	48	47.6	45.6	46.5	42.4	39.6
Budzisko, 24 July 2012, N 54° 17' 49", E 23° 06' 53"													
Distance from the road (m)		*0*	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**74.2**	51	57.7	53.2	49	47.8	**75**	**59.9**	**57.7**	47.5	53.5	53.6
2	Maximum	**88.9**	59.5	61.5	**77.7**	52.1	55.8	**91.2**	**66.5**	**59.3**	53.2	**64.4**	**56.6**
3	Minimum	51.6	40.5	48.0	33.8	44.2	43.3	53.6	51.8	**56.3**	43.0	51.4	52.3
Augustów, 24 July 2012, N 53° 58' 08", E 22° 57' 15"													
Distance from the road (m)		*0*	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**75.4**	55.3	47.2	52.3	44.6	45.9	**74.6**	**59.3**	**57.3**	53.9	47.3	43.5
2	Maximum	**91.3**	61.2	52.9	**74.0**	**65.6**	64.6	**89.9**	**65.5**	**74.8**	**58.1**	52.7	50.7
3	Minimum	40.8	44.8	40.4	36.8	39.1	33.5	47.1	49.9	43.4	49.1	43.1	38.6
Niemcza*, 31 August 2012, N 50° 43' 15", E 16° 49' 28"													
Distance from the road (m)		0	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**70.0**	**72.1**	**66.7**	**65.9**	**67.9**	**70.5**	–	–	–	–	–	–
2	Maximum	**83.2**	**91.5**	**81.7**	**84.4**	**82.1**	**86.2**	–	–	–	–	–	–
3	Minimum	46.8	–	–	44.7	42.3	39.7	–	–	–	–	–	–
Jeleniów, 30 August 2012, N 50° 25' 18", E 16° 15' 32"													
Distance from the road (m)		*0*	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**71.4**	59.8	64.4	62.6	58.2	57	**75.1**	**60.6**	54.9	**60.6**	48.1	**58.5**
2	Maximum	**85.9**	**85.3**	**82.9**	**75.3**	**75.5**	**74**	**88.2**	**77.2**	**72**	**73.9**	**57.3**	**75**
3	Minimum	46	42.1	–	41.1	36.4	44.6	47.7	49.4	48.9	56	46.2	43.8

* Lack of night measurements for "Niemcza" profile due to bad weather during field work.

Source: own study.

National road DK 8 is of high significance in terms of transit as it runs between the Polish–Czech border in Kudowa-Zdrój and Polish–Lithuanian border in Budzisko. It connects Wrocław, Łódź, Warsaw and Białystok agglomerations. Its total length exceeds 560 km. Various noise levels are recorded at various sections of the road due to the diversified structure of vehicles using it. Apart from transit, local traffic is intensive in the vicinity of large agglomerations as residents commute to work. This is illustrated by a high number of cars in Wyszków profile.

Studies show that traffic intensity on selected sections of national road DK8 was diversifies in terms of both the total number of vehicles and their structure at the measuring point. The highest number of vehicles per hour was recorded at "Wyszków" measurement station. During the day, traffic intensity was about 2,000 vehicles per hour. It was higher than at station "Augustów" (by ca. 67%) and "Budzisko" (by 76%). Also at night the highest traffic was recorded at station "Wyszków" (about 640 vehicles per hour). Yet traffic intensity near Augustów and Budzisko was different than during the day. At night higher traffic was recorded at "Budzisko", where traffic intensity compared to "Wyszków" profile was 32% lower, while at "Augustów" measurement station the difference was very large: 83%. At the other end of the road, 35% traffic intensity was higher near Niemcza than near Jeleniów, which lies closer to the border with the Czech Republic. Closer to the border, the share of lorries in the total number of vehicles increased from 12% near Niemcza to 26% in Jeleniów (Fig. 2).

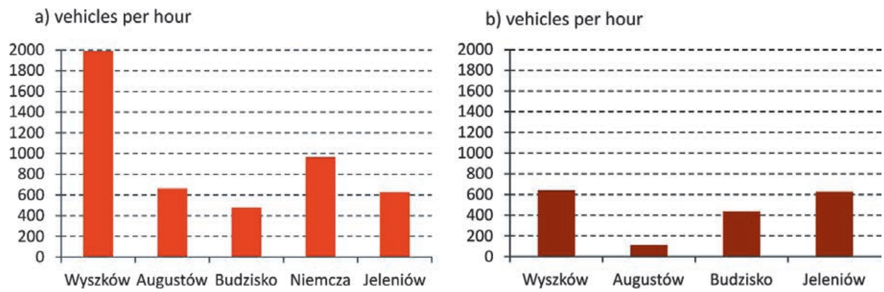

Figure 2. Traffic intensity at traffic noise monitoring points next to roads DK8 and S8 during the day (a) and at night (b)
Source: own study.

Although sound volume is closely linked with traffic intensity, studies show it is not always the case that the highest total number of vehicles translates into the greatest noise. In "Wyszków" profile, where traffic intensity was the highest, equivalent sound level was the lowest: 67.1 dB(A). In the case of "Budzisko" measurement station, where total traffic was much lower than in Wyszków, acoustic climate conditions were much worse. Equivalent sound level at that place was 74.2 dB(A) during the day and even 75 dB(A) at night. One of the reasons behind this situation was the structure of vehicles using these road sections. Cars generated noise with average value of about 60 dB(A), while lorries generated ca. 70 dB(A).

The structure of vehicles using the selected road sections was highly diversified (Fig. 3). This proportion was slightly different during the day than at night. Considering daytime measurements, as much as 69% of vehicles were cars at "Wyszków". Near the Polish–Lithuanian border, at "Augustów" station, cars had a 46% share in the total number of vehicles, while only 31% at "Budzisko". At night, a similar proportion was recorded at "Augustów" station. For "Wyszków" profile cars constituted nearly half of the vehicles, and in Budzisko one in four vehicles. The situation in terms of the share in the structure of vehicles was different in the case of lorries. As the distance from the road border was increasing, their share in the total stream of vehicles was decreasing. In Budzisko, lorries constituted about 60% of vehicles, while for "Wyszków" profile only – 20%. At night, the share of lorries at the former point was as much as 70%, while at the latter it was about 37% (Fig. 4). At the other end of national road DK 8 car traffic was higher by nearly 48% at station "Niemcza" than at profile "Jeleniów". If we consider heavy vehicle traffic, mainly lorries, their share on "Jeleniów" station was 26% higher than in "Niemcza" profile. Also here, the closer to the border, the share of lorries in the total number of vehicles increased visibly.

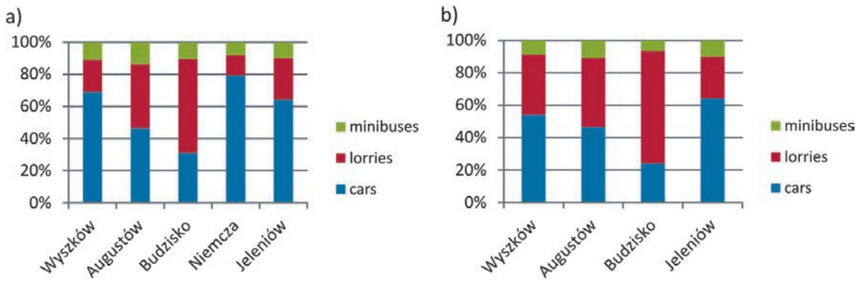

Figure 3. Vehicle type structure at the analysed sections of roads DK 8 and S8 during the day (a) and at night (b)
Source: own study.

Considering the results of measuring equivalent sound level on roadway edge and traffic intensity, the increase in noise with the increase in the share of lorries in total traffic structure is clearly visible. This concerns primarily places where vehicles must change speed frequently due to restrictions in built-up areas and due to landscape features. It is thus advised to direct heavy vehicle traffic outside residential areas.

Acoustic climate of a given place is shaped not only by road traffic, but also by environmental factors that affect sound wave propagation. In Wyszków area lorries travelling at high speed, but on flat surface, are less annoying than lorries travelling at a lower speed but up and down hills, as is the case near Budzisko (Fig. 4 and 5). The analysis shows that on flat land ("Wyszków" measurement station), with no orographic barriers, recorded noise is decreasing relatively steadily when distance from road S8 increases. The difference between the values of average equivalent sound level recorded at individual measuring stations located 100 m away from each other was very close and ranged between 2.3 and 4.8 dB(A) during the day.

Sound propagation on land with diversified landscape features in "Jeleniów" and "Budzisko" profiles was quite different. The greatest decrease in noise level was recorded 100 m away from noise source. In "Jeleniów" profile equivalent sound level was 11 dB(A) lower, and in "Budzisko" profile it was 23.2 dB(A) lower. At night the values were 14.5 dB(A) and 17.3 dB(A), respectively. The farther from the noise source, the influence of landscape features is more pronounced. In "Jeleniów" profile noise values were 3–5 dB(A) higher at a distance of 300–500 m than at 100 m. The situation was similar in "Budzisko" profile, where 300 m away from the road average sound level was 6.7 dB(A) higher than at 100 m. The landscape features considerably modified propagation of sound waves. Hills constitute quite effective barriers to sound waves, while lows, especially valleys, enable sound to travel at considerable distances. Also slopes reflecting sound waves and higher humidity of the ground and the air at bottoms of hollows contribute to strengthening propagation of sound along hollows.

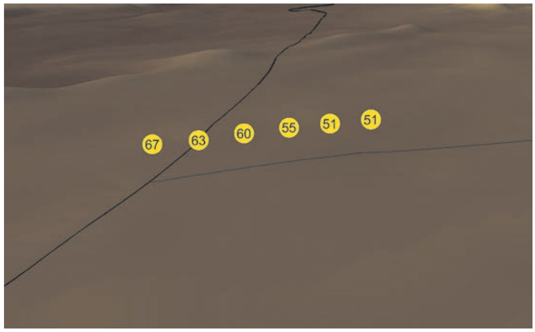

Figure 4. Values of average equivalent sound level (L_{Aeq}) in "Wyszków" profile at various distances from roadway edge
Source: own study.

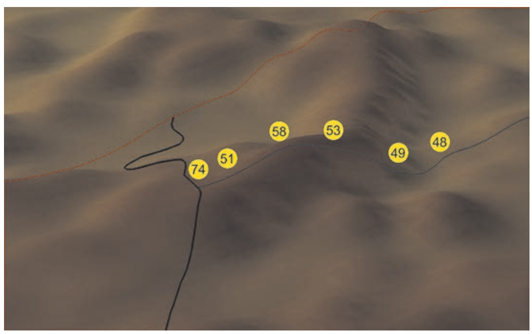

Figure 5. Values of average equivalent sound level (L_{Aeq}) in "Budzisko" profile at various distances from roadway edge
Source: own study.

The maximum recorded sound levels were generated mainly by lorries, whose share in the total number of vehicles varies depending on the road section under analysis (farming machines were very rare). The maximum temporary noise values at station "Wyszków" during the day ranged from 78 dB at road edge to 56 dB 400 m away from the road. At station "Augustów" the highest temporary values were recorded right next to road edge were 91 dB, and the lowest, 300 m away, were 53 dB. In "Budzisko" profile maximum sound volume was recorded at road edge (about 89 dB). Similarly high maximum noise values were recorded at night. The situation is more ambiguous in the case of built-up areas where noise generated by cars is compounded by sounds from other anthropogenic sources, whose volume is sometimes higher than of noise from vehicles. This situation was observed in "Niemcza" and "Jeleniów" profiles.

Studies show that in not built-up areas and in areas with farm buildings noise emitted by vehicles travelling on a high-speed road decreases evenly with distance from the road edge. It can be assumed that noise decreases considerably about 500 m away from the road. In excess of this distance, local factors play greater role in shaping the acoustic climate of a given place and traffic noise from the road is heard as relatively monotonous buzz. In absolute terms, it is lower than noise emitted by local vehicle traffic, sounds from farms and natural sounds. The situation is more ambiguous in the case of built-up areas where local car traffic plays the leading role in shaping the acoustic climate.

The duration of sounds of a given volume is an important element of acoustic climate. In the case of areas with farm buildings, covered by this analysis, the admissible noise level during the day, laid down in the above-mentioned Act, is 65 dB(A) and at night it is 56 dB(A). Table 5 presents the equivalent duration of admissible sound level during the day and at night.

Table 5. Duration (% of the measurement period) of sounds above 56 dB and 65 dB during the day and at night

Section under analysis	Noise threshold (dB)	Distance from the road (m)							
		Day							
		0	100	200	300	400	500	750	1,000
Wyszków	56	99.2	99.2	97.7	46.6	26.3	11.8	–	–
	65	64.7	15.6	0.9	.	.	.	–	–
Budzisko	56	88.1	4.2	–	90.0	–	2.5	.	.
	65	57.7	.	–	.	–	0.8	.	.
Augustów	56	83.3	49.2	–	0.0	–	3.3	1.7	1.7
	65	68.8	.	–	.	–	1.7	.	.
Niemcza	56	92.1	42.4	–	32.2	–	28.8	39	33.9
	65	59.8	27.1	–	22	–	13.6	25.4	22
Jeleniów	56	97.2	30.5	–	23.9	–	25.4	10.2	8.5
	65	64.3	6.8	–	9.9	–	11.9	3.4	3.4
		Night							
Wyszków	56	81.1	92.5	71.8	45.8	.	.	–	–
	65	10.3	9.5	0.2	.	.	.	–	–
Budzisko	56	99.6	70.0	–	100.0	–	.	1.7	.
	65	62.2	1.7	–	.	–	.	.	.
Augustów	56	86.4	80.0	–	30.0	–	25.0	.	.
	65	53.6	.	–	1.7	–	.	.	.
Jeleniów	56	84.9	54.2	–	5.1	–	100	.	10.2
	65	61.4	6.8	–	3.4	–	8.5	.	5.1

Source: own study.

Studies show that for “Wyszków” profile the sound level exceeded 56 dB for about 98% of measurement time 200 m away from the road edge in daytime. At night it lasted between 92% of the time 100 m away and 72% at 200 m (Table 5). The level of 65 dB was exceeded during the day for over 64% of measurement time only at road edge. At 100 m it lasted only for 15% of measurement time. In “Augustów” and “Budzisko” profiles the level of 56 dB was exceeded for quite a long time at the station next to road edge. During the day it was exceeded for 83% and 88% of measurement time, respectively. Similarly, the level of at least 65 dB was recorded the longest at road edge (69% and 58%, respectively). At other measurement stations in the majority of cases the average level of sound with volume in excess of 56 and 65 dB has not been registered at all or for only several percent of measuring time. The only exception is the point situated 300 m away from the road for “Budzisko” profile where level of 56 dB was recorded for 90% of measuring time during the day and 100% of measuring time at night, while the level of 65 dB has not been registered. Maximum noise volume in this place was 61.5 dB during the day and 59.3 dB at night. It is noteworthy that at night the admissible sound level (56 dB) was exceeded most of the time 100 m away from the road in Augustów, 200 m away in Wyszków and 300 m away in Budzisko. It can be thus assumed that to ensure a good night's rest roads should run more than 200–300 m away from residential buildings. The relationship between duration of sound of specific volume and distance from the road was slightly different for "Niemcza" and "Jeleniów" profiles. In those places the duration of sound with a specific volume shortened to a distance above which the time increased due to noise from local sources. For example for "Niemcza" profile 300 m away from the road the sound level of at least 56 dB lasted for 32% of measuring time, while 750 m away it lasted for 39% of measuring time.

The final feature of acoustic climate under analysis is the amplitude of noise level fluctuations. Figure 6 presents average equivalent noise level in "Wyszków" and "Budzisko" profiles. Not only the decrease in noise level with the distance from the road is clearly visible, but also the influence of other factors on the sound wave. The analysis of the presented levels clearly shows that the noise level along with the amplitude of its temporary values are decreasing with the growing distance from the main road. In "Wyszków" profile this amplitude was attenuated 500 m away from the road and local sound sources of high volume (tractor) are marked as a peak 200 m away. In the case of "Budzisko" profile amplitudes at the measurement station next to the road edge are higher than in "Wyszków" profile. The sound wave recorded 300 m away from the road is characterised by low amplitudes (despite increased noise level). Measurements made 750 m and 1,000 m away have very low amplitudes and low sound level values, which proves there are no significant local noise sources.

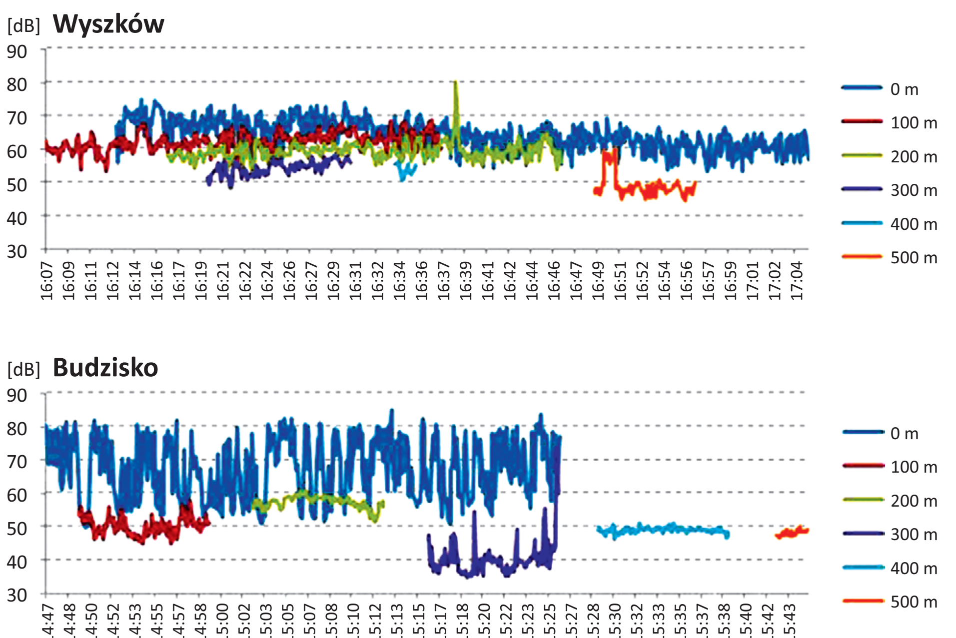

Figure 6. Average equivalent noise level in profiles: Wyszków on 9 October 2013 and Budzisko on 24 July 2012 at various distances from the main road
Source: own study.

Road corridor A1/DK91

In the case of roads A1 and DK 91, noise level studies were aimed at checking which of these had a higher noise level and what was the number and structure of vehicles during the measurements.

At both the selected section of A1 motorway and national road DK 91 two profiles were selected for measurements (Fig. 7). For A1 motorway the noise measurements were made in the vicinity of Pelplin and Kamionka, while at DK 91 in Lignowy Szlacheckie and Pieniążkowo. Each section under analysis had similar landscape features, but different spatial development. On both motorway sections under analysis poorly diversified relief affected acoustic climate to a slight extent. Environment elements such as trees and embankments had greater influence on noise propagation. The acoustic climate was also affected by isolated farms through farm work.

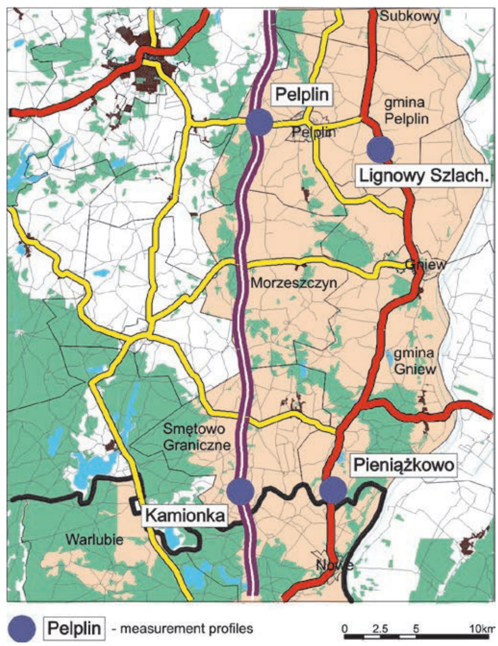

Figure 7. Map of measurement profiles along national road DK91 and motorway A1
Source: own study.

Measurement "Kamionka" profile was situated in an open area with no orographic barriers and that was where the values of equivalent sound level were the highest. At the measuring point next to the motorway the noise level was recorded at 73.1 dB(A), and in "Pelplin" profile it was 71.6 dB(A). At a distance of 100 m from the motorway in "Kamionka" profile equivalent sound level was 56.5 dB(A) and in "Pelplin" profile it was 46 dB(A), because the measurement station was surrounded by trees (Table 6). In general, noise level was decreasing with the growing distance from the noise source. The only modifications of the acoustic climate were introduced by additional sound sources: sounds from households and field work with machines. Direct effect of noise from the motorway was recorded up to 500 m away. Above this distance, local factors were of greater effect. It is worth reiterating that all orographic barriers result in lower noise. As there are no such barriers in "Kamionka" profile, noise had higher values there than in profile "Pelplin". It was the most visible during night measurements when the effect of other noise sources is slight and sound propagation is facilitated due to higher air humidity. Absence of barriers resulted in free propagation of noise and its higher values than during daytime measurements. Equivalent sound level at night next to the motorway in “Kamionka” profile was 70.8 dB(A) and was only 2.3 dB lower than in daytime measurements.

Table 6. Results of noise measurements on profiles: Pelplin, Kamionka, Lignowy Szlacheckie and Pieniążkowo

No.	**Noise level characteristics**	**Equivalent sound level L_{Aeq} [dB]**											
		Day						**Night**					
Pelplin, 26 July 2012, N 53°54’46”, E 18°38’42”													
Distance from the road (m)		*0*	*100*	*200*	*300*	*400*	*500*	*0*	*100*	*200*	*300*	*400*	*500*
1	Average	**71.6**	46	–	44.8	–	43.1	**65.8**	49.7	–	48.6	–	47.6
2	Maximum	**84.8**	55.9	–	57.6	–	54.4	**81.3**	60.3	–	**57.2**	–	55.5
3	Minimum	43	35.9	–	37.3	–	37.8	37.5	39.8	–	35.1	–	36.1
Kamionka, 26 July 2012, N 53º41’29”, E 18º37’42”													
Distance from the road (m)		*0*	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**73.1**	56.4	58.6	49.6	58.6	60.8	**70.8**	**62.2**	**62.4**	**60.8**	**61.1**	**56.8**
2	Maximum	**89.2**	**71.5**	**79.9**	54.6	**80.2**	83	**83.5**	**77.6**	**77.2**	**72.9**	**72.7**	**58.2**
3	Minimum	50.1	45.5	45.2	43.6	43.7	42.6	51.1	49.1	**57.9**	53.1	**58.3**	52.4
Lignowy Szlacheckie, 26 July 2012, N 53° 54’ 39”, E 18° 46’ 46”													
Distance from the road (m)		*0*	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**72.1**	56.7	49	54.5	62.3	43.2	**68.4**	46.7	44.1	50.5	45.9	46.8
2	Maximum	**90.5**	**80.1**	**71.9**	**76.3**	**85.9**	55.5	**90.0**	**57.9**	55.6	55.1	51.7	55.1
3	Minimum	41.0	39.4	36.1	37.5	34.4	32.9	40.0	38.7	41.8	42.0	42.5	34.5
Pieniążkowo, 26 July 2012, N 53° 41’ 43”, E 18° 43’ 18”													
Distance from the road (m)		*0*	*100*	*300*	*500*	*750*	*1,000*	*0*	*100*	*300*	*500*	*750*	*1,000*
1	Average	**73.6**	52.6	58.8	45.8	60.1	41.6	**71.3**	51.1	52.9	46.7	45.8	47.7
2	Maximum	**92.6**	**69.9**	**70.3**	53	**80.5**	49.3	**90.9**	**59.6**	55.3	52.3	51.7	50.6
3	Minimum	41.4	42.3	49.4	38.9	31.6	36.8	39.7	47.1	51.3	42.8	42.4	40.3

Source: own study.

Measurements made for two profiles next to national road DK 91 also prove that the relevant norms have been exceeded. For “Lignowy Szlacheckie” profile right next to the road noise volume was 72.1 dB(A), and in “Pieniążkowo” profile it was 73.6 dB(A): 0.5 dB higher than next to the motorway. “Pieniążkowo” profile, similar to “Kamionka” profile, was more uncovered than “Lignowy Szlacheckie” profile, where in some places vegetation formed an acoustic barrier, but during the day residential buildings were the source of additional municipal noise.

If we compare noise volume next to the motorway and the national road, it turns out that noise is slightly higher next to DK 91. It is surprising as the motorway car traffic was much higher than on the national road. During measurements made for the motorway near Pelplin, traffic intensity was about 1,300 vehicles per hour, and in Kamionka it was 1,200 vehicles. In Pieniążkowo the measurement station next to national road DK91 recorded about 400 vehicles per hour, and in Lignowy Szlacheckie it was 500 (Fig. 8). Thus, the motorway was used by three times more vehicles than national road DK91 at the same time.

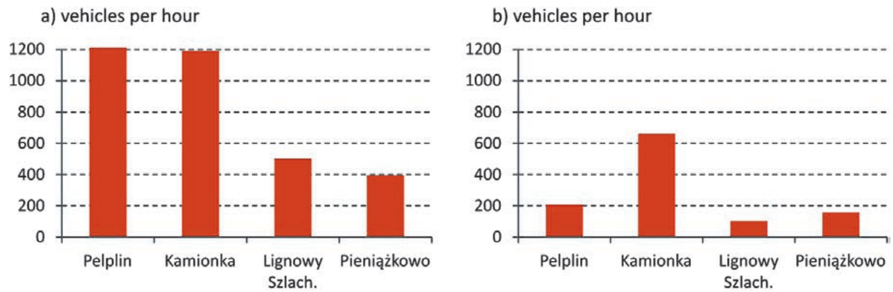

Figure 8. Traffic intensity at traffic noise monitoring stations next to roads A1 and DK91 during the day (a) and at night (b)
Source: own study.

It should be noted that it was not the mere number of vehicles that was of decisive influence on noise volume. In absolute numbers, the cars represented the highest share of vehicles on the motorway as they constituted about 80% of the traffic. There was much less lorries (10–12%) and vans (Fig. 9). On road DK 91 the share of cars was between 55% and 70%, and the share of lorries ranged between 15% in "Lignowy Szlacheckie" profile to 20% in "Pieniążkowo" profile. Also the share of vans was higher there. With such a number and structure of vehicle types, it is impossible for noise at road edge to be lower than the admissible 65 dB(A) as a lorry emits sound at about 70 dB(A) and a car generates nearly 60 dB(A). In addition, newly built motorways near buildings have acoustic screens or other natural acoustic barriers, but there are no such precautions along existing national roads.

Comparing the noise levels at the profiles under analysis, it can be concluded that shifting a considerable portion of car traffic to motorway A1 did not improve the acoustic climate on the parallel section of DK 91. Considerable lorry traffic still generates noise comparable to noise along motorway A1 there. It seems that the situation might improve if payments for use of A1 would be lowered, which would enable more lorry drivers to "leave" national road DK 91.

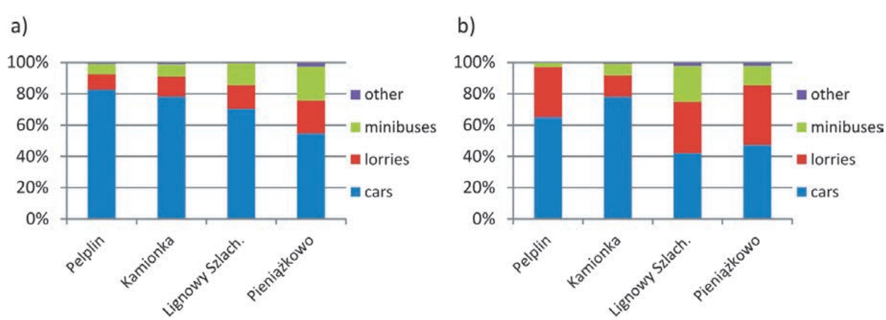

Figure 9. The vehicle type structure at the analysed sections of roads A1 and DK 91 during the day (a) and at night (b)
Source: own study.

Road corridor A4/DK94

Not only motorways and national roads, but also traffic on local roads that connect towns and villages with main roads play an important role in shaping the acoustic climate of a specific area.

In order to examine the degree of effect of the vehicles using high-speed roads compared to other noise sources on the acoustic climate, the effect was measured in profiles along local roads with poor quality pavements that intersect with high-speed roads. A profile perpendicular to motorway A4 and a profile perpendicular to national road DK94 were marked out near Lewin Brzeski.

Next to motorway A4 noise measurements were carried out near Magnuszowice along the road from Lewin Brzeski towards motorway A4. Measurement stations were situated to the north (profile N) and to the south (profile S) of the motorway at 100, 200, 300, 400 and 500 m. On the southern side there was Magnuszowice and the final point was situated in the village. The road runs over the motorway by a viaduct and a short section of the motorway is separated from residential buildings by acoustic screens. The profile next to national road DK94 was marked out between Lewin Brzeski and Buszyce, at distances analogous as in "Magnuszowice" profile, and the initial measurement station was situated among Buszyce buildings.

Each section under analysis had similar topographic conditions and a similar land use: it was mainly farmland.

The results of noise level measurements next to motorway A4 and national road DK94 are very close to the results recorded next to motorway A1 and national road DK 91. The total number of vehicles was also similar, but not the car type structure. At the station next to the motorway the sound level was 73 dB(A) during the day and 77.5 dB(A) at night, while next to national road DK 94 it was 71.4 and 66.3 dB(A), respectively (Table 7).

Table 7. Results of noise measurements on profiles: Magnuszowice and Buszyce

No.	**Noise level characteristics**	**Equivalent sound level L_{Aeq} [dB]**											
		Day						**Night**					
Magnuszowice, 16 May 2012, N 50º42'34", E 17º36'2" – profile N													
Distance from the road (m)		0	*100*	*200*	*300*	*400*	*500*	*0*	*100*	*200*	*300*	*400*	*500*
1	Average	73	63.5	60	72.6	70.8	–	77.5	67.9	65.3	–	61.1	56.2
2	Maximum	87.1	68.9	76.8	91.5	90.3	–	87.7	84.3	80.4	–	80.6	76.3
3	Minimum	52	56.4	49.6	51.3	50.5	–	55	55.3	51.6	–	44.2	46.8
Magnuszowice, 16 May 2012, N 50º42'34", E 17º36'2" – profile S													
Distance from the road (m)		*0*	*100*	*200*	*300*	*400*	*500*	*0*	*100*	*200*	*300*	*400*	*500*
1	Average	73	62	61.2	61.3	55.6	–	77.5	54.2	55.4	63.7	71.5	63.9
2	Maximum	87.1	70.2	73.6	74.5	63.3	–	87.7	60.1	68.0	76.9	93.3	83
3	Minimum	52	54	51.8	50.3	49.8	–	55	44.7	50.3	44.3	48.4	46.8
Buszyce, 16 May 2012, N 50 ° 46'27", E 17°36'36"													
Distance from the road (m)		*0*	*100*	*200*	*300*	*400*	*500*	*0*	*100*	*200*	*300*	*400*	*500*
1	Average	71.4	67.4	69.2	69.3	58.6	72	66.3	54.5	59.7	57.7	54.5	59.6
2	Maximum	92	79.1	85.7	83.4	70.8	87.5	84.7	71.2	80.4	77.0	75.7	77.8
3	Minimum	46	49.4	44.1	45.4	41.8	44.9	31.2	26.8	27.7	34.3	30.7	28.9

Source: own study.

At the measurement station next to national road DK 94 traffic intensity was about 530 vehicles per hour, of which about 35% were lorries. Some of them exited national road DK 94 towards Lewin Brzeski, which additionally increased the noise level on the local road under analysis (Fig. 10). At motorway A4 average traffic intensity was about 1,700 vehicles per hour. Lorries constituted about 40% of the vehicles. Traffic intensity on the motorway was nearly 40% lower than during the day, but the traffic structure was very similar. The share of lorries on the motorway was 43%. During measurements next to national road DK94 at night traffic intensity was 80% lower, with a 30% share of lorries (Fig. 11). It translated directly into the noise level. Equivalent sound level at measurement stations at night was even 10 dB lower than during the day.

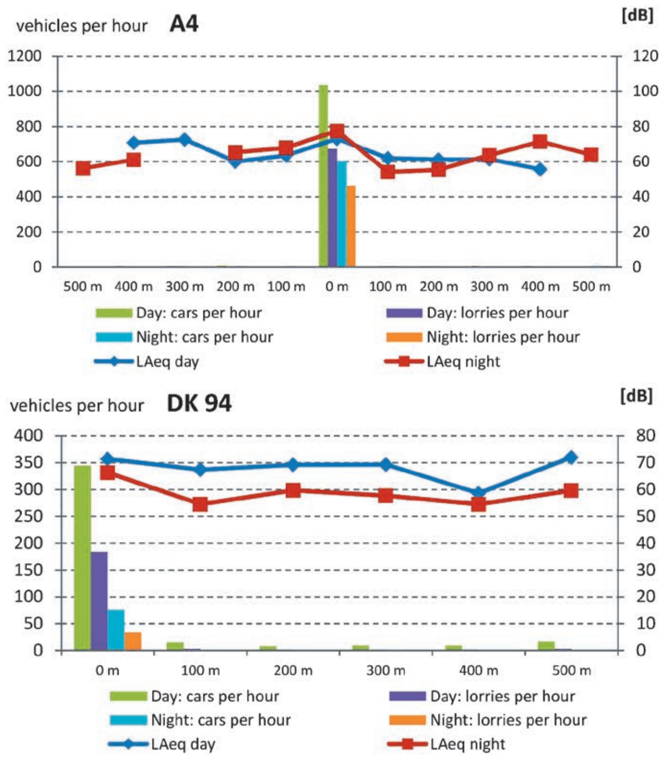

Figure 10. Equivalent noise level and traffic intensity in selected profiles next to motorway A4 and national road DK94

Source: own study.

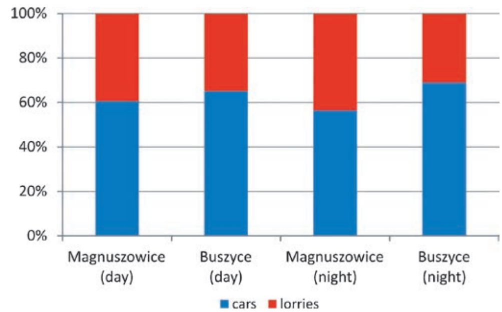

Figure 11. Vehicle type structure in selected profiles next to motorway A4 and national road DK94
Source: own study.

Analysing changes in the acoustic climate along the profile under analysis next to motorway A4, it was discovered that noise volume was different at the same distance on both sides of the motorway. At a distance of 100 m from motorway A4 noise was 9.5 dB on the northern side than next to the roadway, and on the southern side it was 11 dB lower. Lower noise level was the effects of building acoustic screens along this road section on the side of Magnuszowice. The decrease in average noise level in this case is noticeable at a distance of about 200 m on both sides of motorway A4. Further on, the decrease in noise level compared to the values 100 m away from the road decreased considerably, especially on the southern side, and at night it even increased. It could have been caused by the way in which screens were built along motorway A4. Screens were built along a section perpendicular to the road. Right past the screens, the motorway makes a turn, which resulted in unhindered propagation of sound beside the screens. Similar to other road sections under analysis, also near Lewin Brzeski the average noise level decreases until 400 m, unless other sources generate higher volume noise. On the southern side, there was a slow decrease in noise volume until 400 m, while on the southern side there was a production plant at this distance, next to which the average noise level was 70 dB(A). At night, the effect of traffic intensity on noise level is higher due to better sound propagation, which results from higher humidity and lower number of other sounds.

Also in the case of national road DK 94 the average noise level was decreasing with the distance from the road, but the differences were slight. The equivalent sound level at 100 m is lower by only 5 dB, and 400 m away it is lower by 12.8 dB compared to road edge. The reason is the relatively intensive local traffic between Lewin Brzeski and Buszewo. At night, the differences were slightly more pronounced due to lower impact of local traffic.

Conclusions

The studies enabled determining the basic acoustic climate features of selected sections of roads with various transport functions. Field studies covered a number of sections of the same roads (DK 8 and S8) as well as roads of different ranks running close to each other (A1 and DK 91 as well as A4 and DK 94).

The results of earlier studies, according to which noise volume clearly depends on the number of vehicles using a given road, were confirmed. This concerned both the day, in the case of roads with various traffic intensity, and the night. Even on the same road, when the number of vehicles was lower, the equivalent sound level was even 10 dB lower than during the day.

It has also been proven that noise volume results also from other factors:

- The structure of vehicle types: the higher the share of lorries, the higher the noise; thus it is advised to direct lorry traffic outside residential areas; it would be achieved by building by-passes and reducing motorway toll charges, which would encourage a greater number of lorry drivers to "leave" national and local roads;
- Traffic smoothness: on sections where traffic is smooth, noise is lower than in places where vehicles must reduce speed or speed up frequently due to road configuration or traffic organisation;
- Relief: in flat areas sound propagation is of surface nature, while in hill and mountain areas sound waves travel along hollows and reach greater distances with greater volume;
- Land use: all objects, especially avenues of trees and tree clusters, reduce road noise;
- Weather: in places where or at times of the day when humidity is higher sound propagation is easier and the noise level is sometimes increased;
- Local sound sources: increased noise level may come from local traffic, farming machinery, sounds from farms or industrial plants.

Acoustic screens play a vital role in shaping the acoustic climate in the vicinity of roads. Right behind the screen noise is noticeably lower than next to the road, even by a dozen or so decibels. According to Kucharski and Szymański (2011) the efficiency of screens decreases with increasing distance from the road. If the measurement station is situated at 1.2 m above the ground, efficiency of a screen that is 200 m long at the distance of 10 m away from the screen is –7.4 dB and at the distance of 80 m it is only –3.0 dB. The way in which screens are built along the road is important. It has been proven that if the road changes its course abruptly, short screens are ineffective as sound waves pass them by and penetrate at considerable distances.

In general it can be nonetheless claimed that noise is reduced considerably about 500 m away from the road. In excess of this distance, local factors play greater role in shaping the acoustic climate of a given place and traffic noise from the road is heard as relatively monotonous buzz.

The studies lead to one more general conclusion. In direct vicinity of roads, regardless of their category, it is very difficult, if at all, to ensure noise levels lower than 65 dB(A) during the day and 56 dB(A) at night, i.e. levels in compliance with the sanitary norms applicable in Poland. Therefore, to provide the population with adequate conditions during the day and ensure sound rest at night roads should run more than 200–300 m away from residential buildings.

Some general conclusions can also be drawn on the margin of the studies. After Poland's accession to the EU national legislation on protection from noise has been adapted to EU law by implementation of Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002. It stipulates that, "... no one living in the EU should be exposed to noise which poses a threat to their health or quality of life. Exposure of the population to noise in excess of 65 dB(A) should be eliminated and under no circumstances exposures to noise whose level exceeds 85 dB(A) should be allowed..." (*Directive*… 2002). In the framework of the National Environmental Policy by 2016 the exposure of the society to noise in excess of norms was evaluated and steps to be taken to reduce this threat in places where it is the highest have been defined (*National Environmental Policy*… 2008).

Dynamic development of car transport has the greatest impact on acoustic climate in the vicinity of the road sections under analysis. In Podlaskie Voivodeship alone, which was also covered by the studies, the number of registered vehicles (according to data of the Central Statistical Office) doubled between 2000 and 2011.

It should be noted that although we do not always have influence over traffic intensity and the type of vehicles using roads, appropriate actions and regulations can reduce the impact of noise emitted by cars on the environment and humans. Protection from road-induced noise requires comprehensive actions at all stages of building and modernising roads, starting from planning proper routes, to preparing investments, to preparing traffic organisation.

The road run design should take into account landscape and vegetation cover as these elements may significantly reduce or strengthen propagation of sound waves generated by car traffic. In areas with diversified relief noise heard in a given place does not necessarily come from the closest source. It is frequently the case that annoying sounds come from greater distances as they are not hindered by terrain barriers.

Acoustic screens are not the only way to reduce noise levels in the vicinity of roads. Wide and high natural greenery belts along roads can play a significant role in this respect. In high season, greenery can reduce noise by about 0.1–0.35 dB per metre of vegetation screen width. Green belts are useful in places where there is room for wide enough belts to be planted along roads. Narrow green belts in highly urbanised areas serve a decorative purpose rather than having a noise attenuating effect.

Excessive noise levels can be mitigated, where possible, by reducing traffic intensity, changing the type structure of vehicles, reducing their speed and longitudinal profile levelling.

The 2012 increase in admissible noise values was widely opposed by some environmental organisations. They claim it would have a negative effect on the environment and thus on human health and the quality of life and rest opportunities. The negative effect on the environment is also manifested by a reduction or loss of value of protected and recreational areas and resorts. It can also affect the behaviour of birds and some animal species.

It is sometimes the case that the basic problem with shaping the acoustic climate in the vicinity of roads does not lie in financial problems, but in lack of relevant knowledge and awareness of the impact of road noise on humans and the environment and of the ways in which excessive noise can be reduced.

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