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Changes of the acoustic conditions connected with the development of traffic presented on the example of the A2 highway

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Abstract. The article will present a change in parameters of the acoustic climate around the Poznań section of the A2 motorway Komorniki - Krzesiny resulting from the increasing traffic volume due to opening of subsequent sections of this motorway. The acoustic conditions are a significant factor affecting peoples' lives in big urban agglomerations. It is connected with providing appropriate conditions for living and relaxation for the inhabitants in residential areas. This work includes the data concerning present acoustic conditions of the Greater Poland Voivodeship and Poznań. On the example of the Komorniki–Krzesiny section of the A2 highway, the authors proposed changes related to the monitoring studies of the acoustic conditions. For the study, the southern ring road of Poznań, which is a section of the A2 highway, has been chosen. This section of the highway has been chosen because it is located in a lowered area and mostly runs through residential areas with various types of urbanisation. In the considered section, noise has been measured in four measuring stages. These stages consisted in including subsequent sections of the A2 highway to the traffic and measuring the acoustic background (without vehicles). The study considered different locations of the highway in relation to the ground level as well as different distances of noise measuring points from the edge of the roadway. The study was a basis for the evaluation of the highway's influence on the surrounding areas and people living nearby. Moreover, the article presents also the analysis of changes of traffic intensity in Poland.

1. Introduction

The acoustic conditions, according Kucharski et. al [1], are the collection of phenomena occurring in a given area, regardless of their causes. Usually, the acoustic conditions are evaluated quantitatively on the basis of the sound pressure level. In Poland, all issues related to the noise protection and protection from other factors which can affect people and their environment are indicated in the Environmental Protection Act. The rules of realization of this act are determined by the ordinances of the Minister of Environment. In large urban agglomerations, where many people and goods are transported and many services are provided, means of transport are one of the main sources of pollution. This is due to the high emissions of toxic fumes and high sound pressure levels. The World Health Organization (WHO) estimates that environmental stressors account for 15–20% of all deaths in Europe. By contrast, according to the OECD, by 2050 levels of urban air pollution are expected to be the leading cause of deaths in the world. Data on long-term average noise exposure show that 65% of Europeans living in large urban areas are exposed to high levels of sound and over 20% of Europeans are exposed to nighttime noise, which is associated with frequent adverse health effects [2]. The European Union, in order to counteract the negative impacts of transport in the environment, implements its directives. In terms of noise, this is Directive 2002/49/EC of 25 June 2002 on the assessment and management of environmental noise. Regarding toxic substances in vehicle emissions, the EU sets limits, which apply to all types of vehicles. Emissions from individual sources of pollution can be determined by laboratory measurements [3] (on motor and chassis dynamometers) as well as under actual operating conditions [4, 5]. In the case of noise exposure, two types of environmental studies are carried out: long-term studies which are used to develop noise maps [6-9] or short-term studies for the assessment of unitary noise per day for a specific location [10-13].

This article presents the results of measurement of noise and traffic intensity. Roads located in Greater Poland Voivodeship were selected for the research. The analysis of exposing the inhabitants of Poznan to noise was carried out, basing on the example of noise maps that had been made. In addition, noise monitoring studies were conducted on the A2 highway section Komorniki–Krzesiny. On the basis of noise measurements in four measurement stages, the authors evaluated the impact of this section on the areas in the immediate vicinity of the highway.

2. Monitoring noise and traffic changes in Greater Poland

Traffic noise, in particular road noise, is the most common factor that causes disruption in the acoustic environment – both because of the territorial coverage and the number of people exposed. The number and category of vehicles on the road, the speed with which they move, the type of traffic (uniform or non-uniform) and the technical condition of the infrastructure have all a significant impact on noise levels. Information on the quantity and structure of traffic in Poland is provided by traffic measurements carried out every five years by the General Directorate for National Roads and Motorways. The last such measurement took place in 2015. Traffic surveys carried out during this measurement showed that on national roads in Poland the average daily traffic was 11,178 vehicles per day. Figure 1 shows changes in road traffic intensity in Poland in the period between 2000 and 2015 for individual technical grades of roads [14-17].

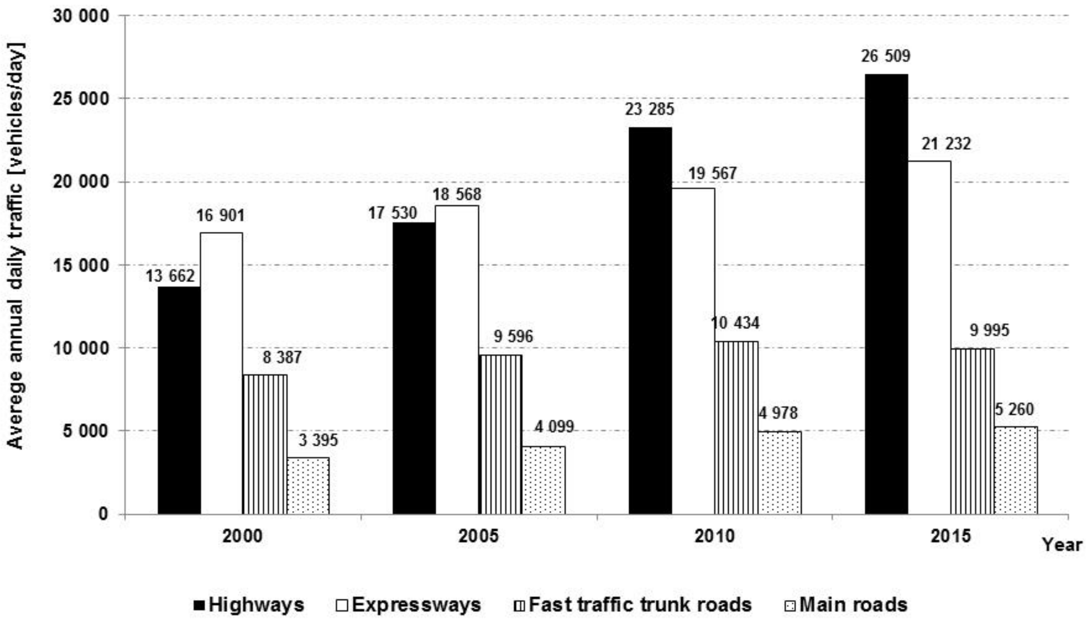

Figure 1. Changes in average daily traffic in Poland in the period 2000–2015 [14-17].

Road traffic studies conducted in Poland since 2000 show a dynamic increase in annual average daily traffic on highways and expressways. Compared to 2000, traffic on highways has increased by more than 50% in 2015 and by 79% on expressways. These data also correlate with the number of kilometres of new sections of highways and expressways made available. In Poland, since the last measurement, which was made in 2015, there was an increase in the length of highways by 700 km and expressways by over 900 km. In the case of the A2 highway, the average daily traffic in 2015 was 24 031 vehicles per day and it was by 68% higher than the results of measurements made in 2010 [14-17]. The traffic measurements in Poland allow to determine the change of traffic intensity and consequently the change of the noise level.

Currently, the source of information about the environmental acoustic conditions are noise maps made mostly for large urban agglomerations over 250 000 inhabitants. They are created every five years since 2007 on the basis of long-term indicators, i.e.: the day-evening-night level (L_{DWN}) and the night level (L_N). Noise maps indicate the current state of the acoustic environment and the number of people exposed to noise. They also indirectly present the pressure of individual sources on the environment. Regarding the road and railroad noise, the current obligatory values of long-term indicators are within the ranges of 50 – 70 dB for day-evening-night level (L_{DWN}) and 45 – 65 dB for night level (L_N) [18]. Figure 2 presents a comparison of the number of Poznan residents exposed to road noise in the ranges of values of the L_{DWN} level for noise maps made in 2007 and 2012.

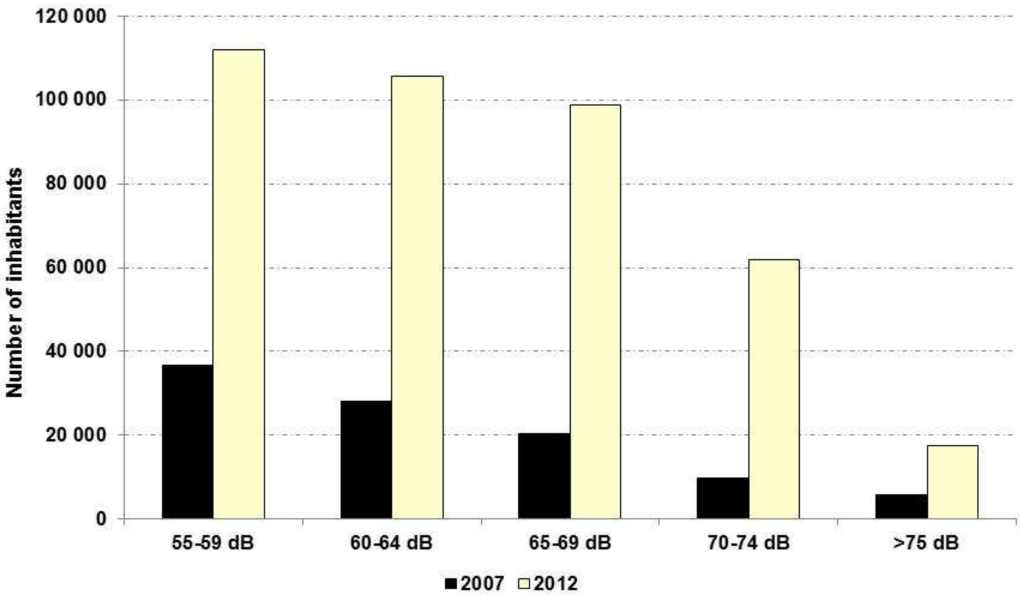

Figure 2. Number of inhabitants of Poznań exposed to road noise during the day-evening-night time L_{DWN} [7].

The Poznan acoustic map, made in 2012, showed a very high increase in the number of Poznan residents exposed to noise in individual ranges of the L_{DWN} values. The highest increase was recorded in the range of 55 to 69 dB: on average by 77 000 inhabitants, in the range of 70 – 74 dB by 52 000 inhabitants and in the range > 75 dB by 12 000 [6].

Apart from acoustic maps made for large urban agglomerations with above 250 000 inhabitants, other studies based on long-term noise indicators are also made. These include the work done for the General Directorate for National Roads and Motorways – acoustic maps for national roads with traffic exceeding 3 000 000 vehicles per year. This study included developing acoustic maps and determining the number of people exposed to each noise range for roads in each of the voivodeships. In Greater Poland, the distribution is as follows: table 1 contains exceedances of permissible values of sound level in the environment for the L_{DWN} indicator [7].

Table 1. Exceeding the permissible sound levels of the L_{DWN} indicator in Greater Poland [7].

	Exceeding permissible values of the L_{DWN} indicator				
	< 5 dB	5 – 10 dB	10 – 15 dB	15 – 20 dB	> 20 dB
The exposed area [km^2]	29.867	17.090	9.463	5.681	4.471
The number of exposed premises [thousands]	20.397	10.038	5.252	3.614	1.682
The number of exposed inhabitants [thousands]	79.871	39.204	20.496	14.343	6.724
The number of buildings of schools and kindergartens	166	73	59	39	21
The number of health care and social care facilities	23	16	9	3	5

According to the analysis, most people are exposed to exceeding the L_{DWN} limit values at the lowest sound levels to 10 dB. A similar situation also exists in the case of school buildings and health care facilities. Nevertheless, it was determined that in Greater Poland about 41 000 people live in bad and very bad acoustic environment. The study is also confirmed by the assessment of traffic intensity. In Greater Poland, in 2015, traffic intensity surveys showed that the average daily traffic on the roads was more than 12 000 vehicles per day and was higher than in the measurements made in 2010 by 1200 per day [7, 14].

3. Monitoring of acoustic environment changes on the Poznan highway ring road

The Poznan highway ring road was also the subject of research. It is a 13,3 km long section lying within the A2 highway Świecko – Kukuryki, which is in construction. Poznan ring road, although it is part of the toll highway A2, is accessible to users via Komorniki, Dębina and Krzesiny interchanges without payment. Its location is calculated from 158+300 km (junction "Komorniki") to 171+300 km (junction "Krzesiny"). Poznan section of the A2 highway runs through the southern part of the agglomeration of the city of Poznan, the areas of the municipality of Komorniki and the city of Luboń. The section of the motorway under investigation passes for the most part in a deep cutting (western and central part) – along garden plots and areas of single-family and multi-family housing, as well as on an embankment and at ground level – by drinking water intake at Dębina and along agricultural areas (middle and eastern part).

The highway A2 (Świecko – Poznan – Warsaw – Siedlce – Kukuryki) is one of the three toll highways to be built in Poland. The planned length of A2 is over 650 km. The A2 highway is located in the Pan-European Transport Corridor II connecting Warsaw, Łódź and Poznan urban agglomerations with road transport system of the European Union (by linking with the German highway No 12 in Świecko) and Belarus (via the connection to the Belarusian main road M1 in Kukuryki). Figure 3 shows a map of the part of the A2 highway with the marked measuring section Komorniki – Krzesiny.

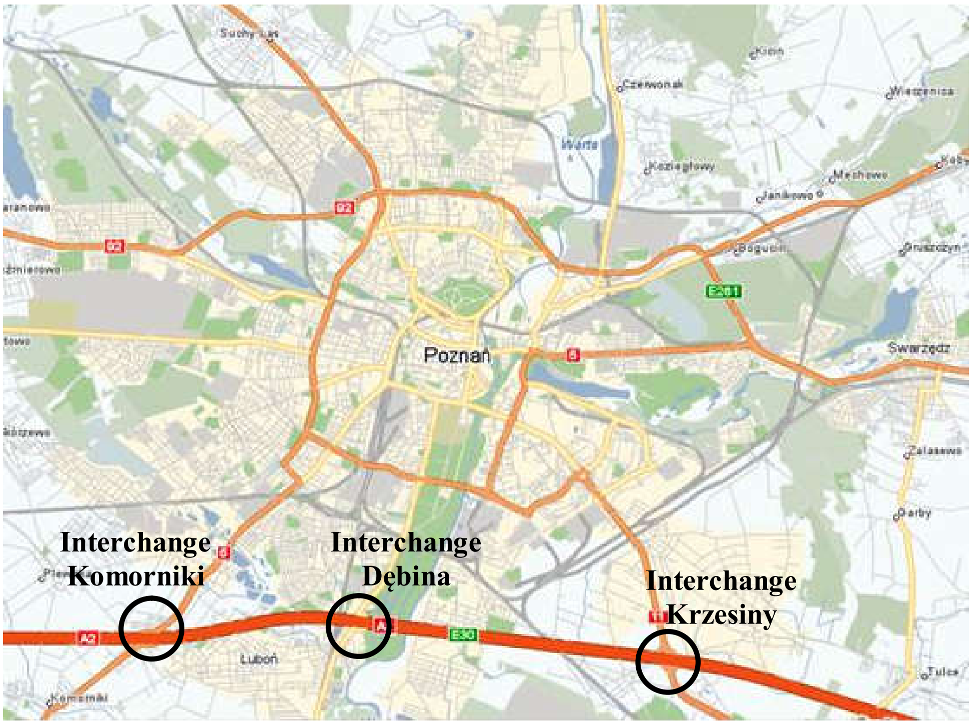

Figure 3. The location of the highway rind road of Poznan Komorniki – Krzesiny [19, 20].

During the realization of the work, the authors used four stages of the research on the state of operation of the highway, concerning noise measurement around the Poznan section of the A2 highway:

- The first stage was connected with noise measurements before putting the highway into service – without vehicle traffic (acoustic background measurement). This stage was completed in 2003.
- The second stage concerned the noise measurement after putting the highway into service and after the inclusion of the new section Września – Krzesiny. This stage was completed in 2004.
- The third stage concerned the noise measurement after enabling the new A2 highway section Nowy Tomyśl – Komorniki. This stage was completed in 2005.
- The fourth stage concerned the noise measurement after enabling the new A2 highway section Konin – Stryków. This stage was completed in 2011.

In each of the assumed stages, measurements were made at the same measuring points. A total of 23 measuring points were selected for the 13 km section Komorniki – Krzesiny of the A2 highway. They were located in different places in the highway surroundings:

- 16 points in the settlements near which the motorway runs, of which 11 measuring points were located next to a two-storey building (single-family houses) at a distance of 55-300 m from the edge of the motorway embankment, two measuring points were located at four- and five-storey buildings at a distance of about 200 m from the edge of the embankment, two measuring points were located at the so-called recreational areas (garden plots) at a distance of about 120 m from the edge of the embankment and one measuring point was located at the Primary School building, approximately 120 m from the edge of the embankment,
- 3 points at the highway interchanges,
- 4 points, which correspond to different depths of the lowered area (2.50 m, 4.30 m and 7.15 m).

All measurements in four stages of the study were done during daylight hours between 8 AM and 22 PM on weekdays from July to September, in the absence of precipitation, with dry surface and wind speeds of less than 5 m/s. Measurements in neighbourhoods and highway junctions were made with integrating Brüel & Kjær's 2238 Mediator ™ sound level meter. At points corresponding to various depths of the lowered area, simultaneous sound measurements were taken. Measurements were made using five pressure measuring microphones and the LAN-XI NOTARTM 3050 measuring cassette from Brüel & Kjær. Within a single 10 minute measurement session, all sound pressure levels were recorded at all measuring points and then the appropriate acoustic parameters were determined using the PULSE Reflex Data Viewer software. In addition, each measurement session, apart from measuring acoustic parameters, contained also vehicle traffic volume registrations with division into passenger cars and lorries. This data was used to develop a predictive model of sound level estimation depending on the volume of vehicle traffic.

Generally, the measurement points in neighbourhoods in the vicinity of the highway were located in accordance with the Polish Standard PN-ISO 1996-1: 1 m away from the fence of the property or the external wall of the building at the height of 1.2÷1.5 m above the ground. In order to determine the impact of the highway on the acoustic environment of the nearby areas, where the highway carriageway runs in a lowered area, the noise measurements were made for different depths of the lowered area: 2.50 m, 4.30 m and 7.15 m. Measurements were carried out according to the following algorithm: the first measurement at 1 m from the roadway, the second measurement 1 m from the edge of the escarpment, the next measuring points were located farther and farther from the middle of the highway (separation lane between the roadways) and their distance ranged from 10 m to 100 m.

Highway noise measurements were carried out using direct noise measurement with sampling. This method consists in determining the equivalent sound level of $L_{Aeq,T}$ based on measurements in representative periods of study. These periods are determined on the basis of the analysis of changes in the distribution of intensity and structure of traffic on the studied section of the road. To determine representative measurement periods, researchers used the data recorded by the so-called "highway" counter that automatically counts the vehicles that pass through a given section of the highway.

Measurements are conducted in both directions of travel, divided into CAT 1 vehicles − with a wheelbase of less than 5 m and CAT 2 − with a wheelbase greater than 5 m. A separate analysis of the traffic volume was made for the section Komorniki-Dębina and Dębina-Krzesiny. Traffic volume analyses were not carried out in the first stage of research. This was due to the fact that the motorway was not yet put into operation. In the second measurement stage, the average daily traffic on the motorway was around 11,500 vehicles per day, of which 15% were vehicles of the CAT 2 category. During the day (16 hours), the average traffic volume of all vehicles on the motorway section in question did not exceed 700 vehicles per hour, while the percentage of CAT 2 vehicles did not exceed 20%. During the night hours (from 22.00 to 06.00) traffic volume did not exceed 200 vehicles per hour, of which 40% were CAT 2 vehicles. In the third stage of research, the average daily traffic volume (covering five days of the week) was around 19,000 vehicles per day, of which approximately 30% were vehicles of the CAT 2 category. Therefore, the traffic volume was higher by 7,500 vehicles compared to the volume in the first measurement stage. Within 16 hours corresponding to the day time, an average of 1,000 vehicles per hour passed through this section of the motorway. During the night time traffic volume was at the level of about 300 vehicles per hour, of which about 50% were CAT 2 vehicles. In the fourth measurement stage, the traffic volume on the section Komorniki-Krzesiny increased to 27,000 vehicles per day in relation to the third measurement stage and 35,000 vehicles per day in relation to the second measurement stage. It was around 46,000 vehicles a day. During the day, more than 2,500 vehicles per hour passed through this section of the motorway, while during the night the traffic decreased to about 700 vehicles per hour. The intensity of traffic of CAT 2 vehicles was 38% of all vehicles passing through the motorway during the day and 65% during the night.

On the basis of all noise measurements made at the four stages (in interchanges, neibourhoods along the highway, various depths of the lowered area), the average equivalent sound level was calculated to obtain a global assessment and to answer the question of how the opening of the Komorniki – Krzesiny highway section affected the acoustic environment. Figure 4 shows the effect of the distance from the roadway on the decrease in measured equivalent sound pressure level in four measurement steps. Figure 4 also contains the calculated measurement uncertainty estimated at the confidence level of 95%.

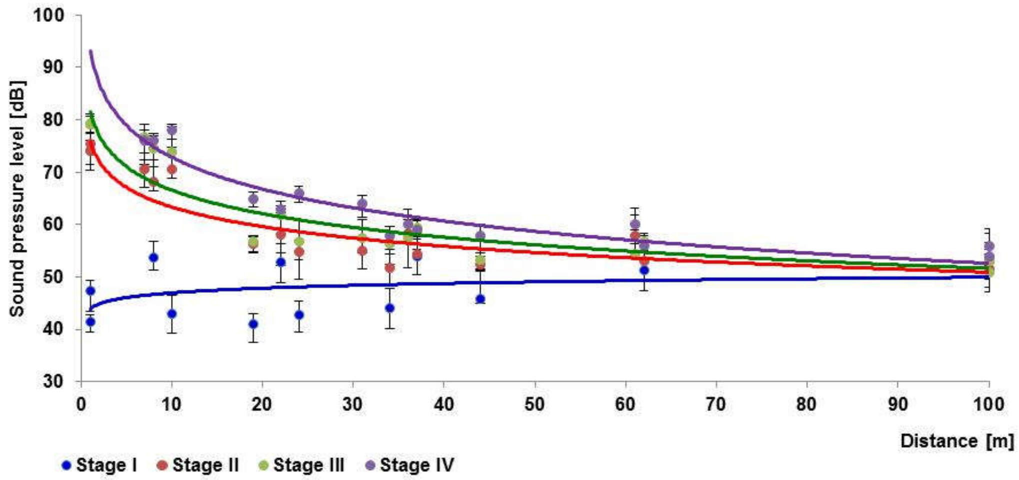

Figure 4. The correlation between distance and decrease in the equivalent sound pressure level on the Komorniki – Krzesiny section of the A2 highway in four measurement stages.

The average equivalent sound pressure level calculated from all results of the first measurement stage was 51 dB. This value was adopted as the so-called "acoustic background level" for the entire discussed section of the highway. By thoroughly analysing the changes of equivalent sound pressure levels measured in the four stages of the study in relation to measurements made at different distances from the highway, it was found that the opening of the highway resulted in an increase in the equivalent sound pressure level by the roadway by approximately 30 dB in the second measurement step. By the edge of the lowered area the increase amounted to 20 dB compared to the measurements of noise made in the first measuring stage. At the second measurement stage, the equivalent sound pressure level at the roadway was 74 dB and at the edge of the lowered area the measured equivalent sound pressure levels were around 68 dB. As the distance increased 19÷100 m from the highway, measured equivalent sound pressure levels ranged from 49÷60 dB. At a distance of 100 m from the roadway, the measured equivalent sound pressure levels were 51 dB and were equal to the results obtained for this distance in the first measurement stage. Based on the studies conducted in the first and second stage, it was found that there is no impact of noise generated by vehicles moving on the highway at a distance of about 100 m from the roadway. Noise studies conducted in the third measurement stage confirmed the conclusion drawn on the basis of the first two measurement steps. The equivalent sound pressure levels measured then at 100 m from the roadway did not exceed 53 dB.

The noise measurements made in the third measurement stage showed a further increase in the equivalent sound pressure level on the roadway by 5 dB, while at the edge of the lowered area, an increase in equivalent sound pressure level by 9 dB at an average was observed relative to the noise measured at the second measurement stage. The measurements made at the edge of the roadway were 79 dB in the third measurement stage and 77 dB at the edge of the lowered area. As the distance increased 19÷100 m from the motorway track, measured equivalent sound pressure levels ranged 52÷62 dB and were higher than those measured in the second measurement stage by an average of 2÷7 dB. At a distance of 100 m or more from the highway, the measured equivalent sound pressure level was 52 dB. This proves that 100 m from the highway the dominating sound is the noise of the environment rather than the highway.

A re-examination made seven years after the opening of the highway (fourth measurement stage) showed an increase in the equivalent sound pressure level at different distances from the roadway averagely by 5 dB compared to measurements taken in the third measurement stage. The test results recorded in this measurement stage ranged 53÷76 dB. In the case of measurements taken 1 m from the edge of the highway slopes, the measured equivalent sound pressure levels were similar to the third stage of measurement and amounted to approximately 76 dB. The increase in distance from the roadway resulted in a decrease in measured values in the range 53÷65 dB. At 100 m from the roadway, the measured equivalent sound pressure levels were 55 dB and were 4 dB above the overall highway acoustic background. Considering the impact of the A2 highway on the acoustic environment of the settlements along the Komorniki – Krzesiny section, it was found that the measured sound pressure levels in the estates did not exceed the 60 dB, which was the level measured during the day. In the first measurement stage, the measured equivalent sound pressure level in the neighbourhoods along the highway was 51 dB, while the equivalent sound levels measured in the remaining stages of the test were around 61 dB [19, 20].

4. Conclusions

Noise as an environmental factor does not directly damage the environment. Its effect on people is indirect and often cumulative with other factors. Depending on its level in the vicinity of places of residence it can cause various health effects such as fatigue, irritability, concentration problems and, in extreme cases, pain. The studies identified levels of noise immission in the environment and do not indicate directly places where noise could cause pain in people living nearby major transport routes. The analyses show that in recent years, traffic on national roads in the Greater Poland Voivodeship has increased by an average of 18%. This also corresponds to the recorded sound pressure levels. Noise maps made for the city of Poznan show that the majority of inhabitants are exposed to noise from 55 to 69 dB. On the other hand, on the roads in Greater Poland, where the traffic exceeds 3 000 000 vehicles per year, the permissible levels were exceeded by the average of 10 dB. The opening of the A2 highway section Komorniki–Krzesiny significantly affected the acoustic environment of the areas lying in its immediate vicinity. The level of sound background measured in the first stage – 51 dB – was exceeded by 28 dB on average at the roadway and 26 dB at the edges of slopes. Considering the impact of the A2 highway on the acoustic environment of the settlements along the Komorniki – Krzesiny section, it was found that the measured sound pressure levels in the estates did not exceed the 61 dB, which was the level measured during the day.

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