Risk Assessment for Public Health from Transportation Noise (on the example of the city of Belgorod)

A Yu Semeykin
Belgorod State Technological University named after V.G. Shukhov, 46, Kostyukova str., Belgorod, 308012, Russia
E-mail: alexsem.m@gmail.com

Abstract. In this paper, an assessment, modelling and calculation of risks for the health of the population of the Southern district of Belgorod was carried out. The study included acoustic calculations carried out on the territory of the assessment within the boundaries of the settlement area of the rectangle with the square 6.72 km², where about 80000 residents live. As a result of computational and instrumental data 4 zones with different levels of potential chronic acoustic impact on the population were allocated. With the use of mathematical models of risk the trend of the formation of moderate and high risk was determined in certain areas within the boundaries of the territory. It is shown that 65% of the residents of the district live in conditions of moderate health risks and about 9% – in conditions of a high risk of developing health disorders from the effects of noise (disorders of the nervous system, hearing and the cardiovascular system).

1. Introduction
At present, the problem of the impact of transportation noise is becoming more acute for many developing urban areas in various countries of the world. It's confirmed by an increase in the number of studies in this area. One of such developing urban territories of the Russian Federation is Belgorod, located in the southern part of the Central Federal District, near the border with Ukraine. The development strategy of the city of Belgorod provides the creation of comfortable and environmentally friendly urban environment through spatial development and improvement of the street-road network [1, 2]. The growth of the territory and population of Belgorod causes an inevitable increase in the intensity of traffic flows, which are the main cause of noise pollution of the urban area and the occurrence of acoustic discomfort. Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing notes an increasing number of complaints from the public about road traffic noise [3].

Noise influences in the urban environment are currently one of the most harmful technogenic factors, along with environmental pollution, and can lead to disorders of the nervous system and cardiovascular diseases, ultimately reducing a person's life by 8 to 10 years. According to studies conducted in Europe and Asia, about 20% of residents suffer from noise, which level exceeds permissible standards and adversely affects health. According to the World Health Organization, about 40% of Europeans are affected by traffic noise, which exceeds 55 dB in daytime and at night [4, 5, 6].

In many cases, the purpose of describing the noise environment (noise regime) is to develop a forecast of the noise situation that arises from the construction of projected industrial enterprises or highways of road, rail and air transport. For quiet residential areas, the problem must be solved using appropriate calculations or by conducting studies on models [7, 8, 9, 10].

The results of full-scale studies and simulation of the noise situation are necessary to identify areas with the greatest acoustic discomfort and, accordingly, a risk to the health of residents. The basis for predicting the risk to public health from different types of noise in the urban environment is to study the dependence of «exposure – response». The studies of W. Babich, E. van Kempen, H. Ising, J. Heinrich, J. M. Fields, Laure-Anne Gille, K. Kryter etc. are devoted to the investigation of the effect of elevated levels of transport noise [5, 6, 7, 8, 12]. In studies of W. Babich, H. Miedema and C. Oudshoorn...
evolutionary mathematical models describing the «dose – effect» and «exposure – response» relationships under the influence of urban traffic noise are developed [5, 11].

The purpose of this work is to predict the magnitude of the population's risk to public health (in the form of hearing impairment, as well as in the cardiovascular and nervous systems) using the example of certain areas of the city of Belgorod (Russia). The location of the city and the study area are shown in figures 1 and 2.

Figure 1. Location of Belgorod, Russian Federation

Figure 2. Belgorod city map and measurement site

2. Methods

2.1. Noise measurement and modelling

Investigation of the noise situation in some areas of Belgorod was carried out in accordance with the requirements of state standards GOST 20444-2014 and GOST R 53187-2008 [13, 14]. As the main noise characteristics of traffic flows, the equivalent $L_{\text{Aeq}}$ and maximum $L_{\text{Amax}}$ sound levels, dBA, measured in daytime (from 7.00 to 23.00) and night time (from 23.00 to 7.00) are selected for the periods of maximum traffic intensity. For full-scale measurements, the integrating sound level meter Ecophysics-110, which meets the requirements of GOST 17187-2010, was used.

The results of field measurements of noise levels were used to simulate the noise environment and build noise maps of the territory with the help of the «Acoustics» software package. The software complex «Acoustics» allows the user to create a spatial plan of the surveyed area, taking into account the building and operating sources of noise (linear and point sources), and calculate the levels of acoustic impact anywhere in the space, build color fields and isolines of sound levels in the horizontal and vertical planes with user defined parameters [15, 16, 17, 18]. The spatial scheme of the location of objects in the investigated area was constructed on the basis of the 3D model of the city district obtained using the geographic information system 2GIS [19].

As a basic indicator of operating noise levels, the $L_{\text{den}}$ (the A-weighted average level of sound pressure for the sum of day time periods over a year being used for the assessment of discomfort during daytime) was adopted. Indicator $L_{\text{den}}$ can be determined according to the equation (1):

$$L_{\text{den}} = 10 \log_{10} \left( \frac{1}{24} \left( \frac{L_{\text{day}}}{10^16} + \frac{L_{\text{night}}}{10^8} \right) \right)$$

where $L_{\text{day}}$, $L_{\text{night}}$ – A-weighted average levels of sound pressure for the sum of periods of 16-hour day time and 8-hour night time respectively.
2.2. Risk assessment
Calculation of the predicted value of the risk of health disorders was carried out on the basis of the methodology of guidelines MR 2.1.10.0059-12 «Assessment of the health risk of the population from the effects of traffic noise». As the initial data for calculation and forecasting of the risk, noise measurements in the streets of the city and simulation of the noise situation were used. Based on the received data, noise maps were constructed, and areas of the urban territory in which the sound pressure levels exceed sanitary and hygienic standards were identified.

The calculation of risk values and the assessment of the aggregated risk of cardiovascular, nervous and hearing disorders were conducted using evolutionary mathematical models for the development of adverse effects under the influence of noise. Applied models take into account domestic and foreign data on the dynamics of these effects against the background of natural aging of the organism. Calculation of risk values was carried out by solving a system of recurrent equations [5, 11, 12, 20].

3. Results and discussion
3.1. Modelling of noise situation
An analysis of the noise situation and the assessment of the magnitude of the health risk were carried out for the urban area in the Southern District of Belgorod, as the most densely populated part of the city with a large number of streets with high traffic intensity. About 80000 people live in the district. In order to assess the level of noise pollution in the territories, we measured noise levels at various points in the districts between the streets of Shchors, Gubkin, Oktyabrskaya, Budyonny, Sportivnaya, Yesenin. The main source of noise in the territory of these districts is road transport, so to assess the noise level, we considered the complex sources of noise – traffic flows. Noise map of the Southern district of Belgorod is shown in figure 3.

![Figure 3. Noise map of the Southern district of Belgorod](image-url)
Acoustic calculations were carried out for an area of 6.72 km$^2$ at nodal points with a grid spacing of 100×100 m. In addition, the noise level was calculated at points located on the territory of residential buildings, medical and educational institutions. It was revealed that in some areas of the city territory with a traffic intensity of more than 1000 cars per hour, the estimated sound pressure levels reached 78 dBA in the morning and evening hours. This is confirmed by the data of field measurements.

The analysis of the obtained noise map makes it possible to determine the most problematic zones of the Southern district of Belgorod by the noise factor. These include the crossroads of Gubkin and Shchors streets (exceeding 8 dBA), Gubkin and Budyonny streets (exceeding 4 dBA). All residential buildings located near the streets under study are in the zone of acoustic discomfort, which increases the risk of specific functional deviations in health due to the impact of traffic noise, which can be determined by special methods.

3.2. Results of risk assessment

The studies allowed to identify 4 zones of urban area, with average daily noise levels, respectively: zone 1 – $L_{\text{den}} = 38$ dB; zone 2 – $L_{\text{den}} = 49$ dB; zone 3 – $L_{\text{den}} = 62$ dB; zone 4 – $L_{\text{den}} = 74$ dB. Thus, about a third of the study area falls into the zone of acoustic discomfort with an increased risk of health problems.

The results of calculating the population risk to the public health under exposure of daytime average level of sound pressure 74 dBA in the Southern district of Belgorod are presented in Table 1.

| Age, years | Aggregated risk of hearing disorders $R_{1}^{\text{Ahd}}$ | Aggregated risk of cardiovascular disorders $R_{1}^{\text{Acd}}$ | Aggregated risk of developing disorders of the nervous system $R_{1}^{\text{Ans}}$ |
|------------|----------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 1          | 0.023717                                                 | 0.010902                                                     | 0.041491                                                     |
| 5          | 0.024442                                                 | 0.014979                                                     | 0.055423                                                     |
| 6          | 0.025174                                                 | 0.019255                                                     | 0.070366                                                     |
| 7          | 0.025914                                                 | 0.023739                                                     | 0.086394                                                     |
| 9          | 0.026662                                                 | 0.028442                                                     | 0.103588                                                     |
| 10         | 0.027417                                                 | 0.033375                                                     | 0.122034                                                     |
| 15         | 0.02818                                                  | 0.03855                                                      | 0.141823                                                     |
| 20         | 0.028951                                                 | 0.04398                                                      | 0.163056                                                     |
| 25         | 0.029729                                                 | 0.049677                                                     | 0.185838                                                     |
| 30         | 0.030516                                                 | 0.055656                                                     | 0.210285                                                     |
| 35         | 0.031311                                                 | 0.06193                                                      | 0.236519                                                     |
| 40         | 0.032114                                                 | 0.068515                                                     | 0.264672                                                     |
| 45         | 0.032926                                                 | 0.075428                                                     | 0.294886                                                     |
| 50         | 0.033745                                                 | 0.082684                                                     | 0.327313                                                     |
| 55         | 0.034574                                                 | 0.090302                                                     | 0.362117                                                     |
| 60         | 0.035341                                                 | 0.0983                                                       | 0.399474                                                     |
| 70         | 0.036256                                                 | 0.106698                                                     | 0.439572                                                     |

In accordance with the recommendations of MR 2.1.10.0059-12, the value of risk (R) less than 0.05 is estimated as a low risk, weakly affecting the level of health status in the study area. Measures are recommended to organize selective monitoring of noise load, planning activities that can be implemented in the long term (5 years or more). The value of R in the range 0.05 – 0.35 is estimated as moderate risk. Measures are recommended for the organization of continuous monitoring of the noise load. Measures to reduce the noise load are recommended to be developed taking into account the medium and short term (1 to 3 years). The planned revision is recommended at a frequency not less than...
once every three years. Measures to reduce the noise load are recommended to be developed taking into account the medium and short term (1 to 3 years). The value of $R$ in the range 0.35 – 0.6 is estimated as a high risk. Measures are recommended for the organization of an extended noise load monitoring program with additional studies in places and / or periods of maximum noise levels. It is necessary to develop measures to reduce the noise load for the short term within a year. It is recommended that the risk level be reviewed every year.

The calculation data show that when exposure to elevated noise levels to 74 dBA, the aggregate risk of developing nervous system disorders (nervous tension, sleep disorder, cognitive impairment, and vascular dystonia) is characterized as moderate, from the age of 7 to 50 years. Since age 55, the risk of developing disorders of the nervous system has reached a high level. The risk of hearing disorders (tinnitus, conductive sensor neural hearing loss, hearing loss caused by noise) is estimated to be insignificant up to the age of 50 years and moderate for a population aged 50 years. The aggregated risk of developing cardiovascular disease is estimated as moderate.

Table 2. The results of the calculation of the cumulative risk to public health under the exposure to transportation noise

| Age, years | Cumulative risk of health disorders $R_{1}^{Sum}$ | Zones under chronic exposure of noise level of sound pressure, dBA |
|------------|-------------------------------------------------|---------------------------------------------------------------|
|            |                                                 | 38                                    | 49                                    | 62                                    | 74                                    |
| 1          | 0.0052571                                       | 0.05927833                           | 0.067172                              | 0.074426                              |
| 5          | 0.0047394                                       | 0.06124523                           | 0.077472                              | 0.092314                              |
| 6          | 0.0041945                                       | 0.06341676                           | 0.088439                              | 0.111219                              |
| 7          | 0.0036208                                       | 0.06580626                           | 0.100119                              | 0.131196                              |
| 9          | 0.003017                                        | 0.06843539                           | 0.112559                              | 0.152304                              |
| 10         | 0.0023813                                       | 0.07132796                           | 0.125812                              | 0.174604                              |
| 15         | 0.001712                                        | 0.07451009                           | 0.139934                              | 0.198157                              |
| 20         | 0.0010075                                       | 0.07801046                           | 0.154983                              | 0.223029                              |
| 25         | 0.002657                                        | 0.08186058                           | 0.171023                              | 0.249286                              |
| 30         | 0.00515                                         | 0.08609507                           | 0.18812                               | 0.276995                              |
| 35         | 0.01337                                         | 0.09075194                           | 0.206347                              | 0.306226                              |
| 40         | 0.02203                                         | 0.09587301                           | 0.225778                              | 0.33705                               |
| 45         | 0.03115                                         | 0.10150422                           | 0.246497                              | 0.369536                              |
| 50         | 0.04074                                         | 0.10769613                           | 0.268588                              | 0.403757                              |
| 55         | 0.05085                                         | 0.11450432                           | 0.292143                              | 0.439782                              |
| 60         | 0.06149                                         | 0.12199001                           | 0.317261                              | 0.47768                               |
| 70         | 0.0727                                          | 0.13022055                           | 0.344045                              | 0.517519                              |

A space-time analysis of the magnitude of the cumulative health risk to public health under chronic exposure to noise is shown in Table 2. The results of the calculations showed that the risk of health disorders for zones with noise exposure level $L_{den} = 38$ is low and becomes moderate after the age of 55 years; in the zone with the value $L_{den} = 49$ dBA and $L_{den} = 62$ dBA the risk is moderate; in the zone with a value of $L_{den} = 74$ dBA, the risk of developing health disorders becomes high for the population aged 45 years.

The total population living in these zones of noise exposure is correspondingly: low risk for health 20800 (26%), moderate risk 52000 (65%), high risk of 7200 (9%).

4. Conclusion
The most probable consequences of the impact of traffic noise in the Southern district of Belgorod are the aggregated risk of developing disorders of the nervous system (nervous tension, sleep disorder,
cognitive impairment and vascular dystonia), starting from the age of 5 years. The risk of hearing disorders (tinnitus, conductive sensor neural hearing loss, hearing loss caused by noise) is estimated as moderate for the population over the age of 50 years. The aggregated risk of developing cardiovascular disease is estimated as moderate. A space-time analysis of the magnitude of the cumulative health risk to public health under chronic exposure to noise shows that total population living in these zones of noise exposure is correspondingly: low risk for health 20800 (26%), moderate risk 52000 (65%), high risk of 7200 (9%). Thus, it requires mandatory implementation of a set of measures to reduce noise pollution in the city, as envisaged by the Concept «Comprehensive scheme of urban transport development for 2009 – 2025», which sets the task of developing a system of measures to reduce noise pollution of the urban environment by road transport in order to reduce the population, living in conditions of noise discomfort by 10%.

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