ZONING OF URBAN AREAS TO HIGHLIGHT THE RISK LEVELS OF HEALTH VIOLATIONS INDUCED BY ENVIRONMENTAL MAN-CAUSED NOISE

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ABSTRACT

This study proposes and tests the approach to zoning of the urban area on the level of risk of the possible health disorders among population exposed to anthropogenic ambient noise. The method is based on the coupling of instrumental and calculated data about the level of acoustic exposure. The zoning was made in the account of the identification of the negative effects' sources, acoustic calculations and the results of instrumental measurements. The coupling of the calculated and field data with establishing the coefficients of correspondence between the calculated and actual average daily noise levels at each point of the field measurements was implemented.

The procedure of accuracy triangulation with the following procedure of points' interpolation lying inside the triangle, and the extrapolation procedure for the points, lying outside the triangle, was performed. Taking into account the obtained widely distributed accuracies, the noise levels on grid points on the map of the study area were calculated.

A map of the spatial distribution of verified noise levels was generated. Zoning of the selected area due to the risk of possible health disorders with the use of a certain scale of the risk was conducted. It was established that the proposed method of spatial quantification of noise level increases the accuracy of the acoustic exposure assessment, as evidenced by the change in of accuracy from 0.88 - 1.35 (before coupling) to 0.96 - 1.17 (after coupling), t. e. significantly increased the convergence of the field and calculated and instrumental data obtained as a result the coupling.

The territory was divided into 4 zones in consideration of the level of exposure and generated health risk. For each of the selected areas the program of organizational, technological and sanitary measures was proposed.

Keywords: *acoustic calculations, instrumental noise measurements, conjugation, interpolation, extrapolation, exposure, public health risk, territory zoning.*

INTRODUCTION

Modern approaches to assessing and analyzing the acoustic situation in large cities and settlements are extremely diverse, starting from the complex acoustic mapping and finishing by the local instrumental evaluation of the noise levels for specific tasks (investigation, research, examination). Noise exposure establishment is a phasing stage during analysis and interpretation of the results of acoustic assessments in the form of risks of risk of the possible health disorders among the population affected by technogenic noise.

The structure and methodology for assessing the risk of public health disorders are outlined in several of normative documents [1], [2], that assume the computing and instrumental assessment of the levels being formed on the health status of the exposed population. Nevertheless, different types of assessment have their advantages and disadvantages, which characterize certain research methods.

Calculated acoustic evaluation allows performing large-scale acoustic calculations with minimal expenditure of forces and means. However, the accuracy of the results may not correspond to the actual noise parameters because of insufficient completeness and reliability of the initial data on sources of noise interference, non-observance of all noise propagation conditions on the ground and other factors [3], [4], [5]. The instrumental method is the most accurate according to quality of the acoustic evaluation. This method is based on the results of instrumental measurements that take into account the entire existing picture of noise pollution. However, this method is expensive and does not allow performing a spatially distributed acoustic evaluation, all other things being equal, in comparison with the estimated evaluation.

Therefore, for a long time, there is a problem of obtaining reliable spatially-distributed results of acoustic exposure for the tasks of correct acoustic evaluation and acoustic zoning of territories [6].

Within this study, we have proposed one of the most optimal options for obtaining real information on the acoustic effect of anthropogenic origin, followed by zoning of the study area, including for assessing the emerging risks of disrupting the health of the exposed population.

THE AIM OF THE STUDY

The study object became the central part of the territory of a large urban settlement with a population of more than 1 million people. The study area is characterized by the presence of a heavy traffic networks, railways, regular flights of aircraft and the availability of industrial production close to residential buildings. So the residents of such areas, living in the zone of acoustic discomfort around the sources of external anthropogenic noise, are exposed to the noise levels that exceed the permissible hygienic standards.

In particular, we have investigated the central part of the urban settlement with a total area of about 10 square kilometers, which includes more than 100 thousand people among whom there are more than 15 thousand people of the child population.

METHODS OF THE STUDY

The initial stage of the study comprised the identification and collection of source information on technogenic environmental noise origins. The main origins are stationary and mobile noise sources. The architectural and planning peculiarities of the territory were also taken into account as shielding objects (capital construction objects, green plantations, natural barriers, etc.), transport parameters (actual traffic load on roads, width of the roadway, traffic flow speed, the longitudinal slope of the roadway and etc.) [6].

Further, the relevant information on noise parameters was collected, which contained the following data: the name of the noise source, the noise source number, type, height of placement, location coordinates (x and y), width (for an area source), equivalent and maximum noise, as well as levels in octave frequency bands.

Locations of identified sources of environmental anthropogenic noise were charted on the electronic map of the settlement and acoustic calculations were executed with consideration of the spatial characteristics of the location of the noise sources using a database of noise sources, standard mathematical models and software implementing current regulatory documents on noise propagation on the ground [5], [7], [8].

Together with performing of acoustic calculations, instrumental measurements of the levels of technogenic noise in the external environment were made in the selected area at 130 nodal points, where the calculated average daily levels were established. Apart this, the results of measurements of noise level performed within the framework of socio-hygienic monitoring (20 points) were taken into account. Instrumental measurements of noise levels in more than 150 control points were carried out during the period of 2012-2015 years with fixation of the date, the time of noise measurement, and the characteristic of meteorological conditions at the time of measurement.

At each set point, four full-time one-off measurements of the level of technogenic noise per day for 20 days with coverage of all seasons of the year were conducted. They, firstly, took into account the changes in the noise load during the day, changes in noise characteristics for the seasons of the year, leveling of the error on-site measurements on certain days due to the number of measurements (20 days per year, i.e. 5 days per season). Secondly, they allowed calculating the actual average daily noise level from sources of the external environment. As a result, an information base was formed with spatially differentiated characteristics of the level of technogenic noise at each node, including in regular grid cells.

For the first time, for the zoning of the territory, it was proposed to perform the calculation of the correspondence coefficient (K) between the calculated and actual average daily noise levels at the points of instrumental measurements, in accordance with the technogenic noise of the external environment, which allowed to determine the level of differences in the actual and calculated data (1):

$$K_i = \frac{C_i^p}{C_i^y}, \tag{1}$$

where

i – point number of field measurements;

C_i^y – estimated average daily noise levels at the i-th measuring point;

C_i^p – the actual average daily noise level at the i-th measuring point.

Next, the procedure of triangulation was carried out, which consisted on the allocation of a set of triangular objects on the plane by joining all points of field measurements with disjoint segments, so that new segments could no longer be added without intersecting with existing ones, forming a system of triangles with vertices at points of full-scale measurements. For each triangle, the equation of the plane with the establishment of the coefficients of the equation was solved, depending on the coordinates x and y of the vertices of the triangle - the points of actual measurements, and the values of the coefficients of the correspondence K (x; y) in them by the formula (2):

$$K(x, y) = a_0 + a_1 x + a_2 y, \tag{2}$$

where a_0, a_1, a_2, – constant coefficients.

Then, each node of the computational grid with the coordinates (xi; yi) was assigned to any triangle of the formed system of triangles, or it was established that it lies inside or outside the indicated system of triangles. This was necessary in order to determine which method (interpolation or extrapolation) needed to be used to calculate the coefficient of correspondence for a particular point with coordinates (xi; yi).

For points with coordinates (xi; yi) lying inside the system of triangles, the interpolation procedure was performed by the formula (3):

$$k_i = K(x_i, y_i) = a_0 + a_1 x_i + a_2 y_i, i = \overline{1,3}, \tag{3}$$

where

k_i – coefficient of correspondence for all points within a certain triangle;

a_0, a_1, a_2 – constant coefficients established in the previous stage.

For points with coordinates (xi; yi) lying outside the system of triangles, an extrapolation procedure was performed, for which the value of the coefficient of correspondence at the node was taken to be equal to the correspondence coefficient at the nearest point lying on the outer boundary of the system of triangles.

As a result of these interpolation and extrapolation procedures, a spatial distribution of the coefficients of correspondence was obtained at all nodal points on the map of the selected territory, i.e. allowed to obtain an estimate of the scalar field characterizing the spatial distribution of the correspondence coefficient in the selected territory.

Taking into account the spatial coefficients of correspondence that were spatially distributed on the map, the calculated levels of technogenic noise at the nodal points on the map of the selected territory were calculated by the formula (4):

$$C^r(x_i, y_i) = K(x_i, y_i) \cdot C^y(x_i, y_i), \tag{4}$$

where

$C^r(x_i, y_i)$ – adjusted noise levels at the node (x, y);

$K(x_i, y_i)$ – coefficient of correspondence at the node (x, y);

$C^y(x_i, y_i)$ – total levels of calculated technogenic noise from all sources of noise at the node (xi, yi).

Next, a map of the spatial distribution of refined levels of technogenic noise in the external environment was constructed in the selected territory.

The zoning of the selected territory for the risk of possible disruption of the health of the population under the influence of the received refined level of environmental anthropogenic noise was carried out using a risk scale based on the threshold values of noise levels causing a public health impairment with regard to the nervous system, cardiovascular system and hearing, critical systems of the body with respect to noise exposure:

– at a noise level of less than 43 dB - there is no risk of health impairment;

– at a noise level of 43 to 50 dB - the risk of a disturbance of the nervous system;

– at a noise level of 50 - 58.5 dB - the risk of disorders of the nervous and cardiovascular systems;

– at a noise level of more than 58.5 dB - the risk of disorders of the nervous, cardiovascular and hearing systems.

These threshold values were obtained using a set of scientifically based mathematical and statistical methods of research and analysis of international scientific literature with the results of scientific research. As sources of information, international works in the field of epidemiological studies on establishing links of acoustic effects on human health were used [9], [10], [11].

At the next stage, each node on the map, in accordance with the verified level of technogenic noise in it, was assigned to a certain gradation of the risk of health disorders on the above scale. At the final stage of the study, a set of points assigned to the same gradation was merged, isolines, thus obtaining a map of the selected territory with four zones of risk of possible disruption of public health under the influence of technogenic noise of the external environment.

As an indirect proof of the correctness of the results of noise exposure in different zones, the incidence of the population was studied because of the analysis of a continuous sample of data on the treatment of the child population for medical care. The children's population is selected as a representative group, as children are the most sensitive to the quality of their habitat, do not have bad habits, and the factor of influence of hazardous working conditions is excluded. The analysis was subject to depersonified data of the mandatory medical insurance fund with targeted binding of insurance policies, which allowed each child to be clearly identified and, accordingly, each case of the disease according to the researched answers to this or that zone of acoustic impact.

RESULTS OF THE STUDY

In the framework of approbation of the proposed method of zoning using the example of a large urban settlement, the following results were obtained.

At the initial stage of the acoustic assessment, the map of the investigated area was covered with a regular grid with a step of 100 x 100 m (Fig. 1). The size of the calculated rectangle (regular grid) was 5 km by 2 km and consisted of 1505 nodal points and 150 points of instrumental measurements.

On the territory of the assessment, all sources of noise impact were identified, namely, the central part of the urban settlement was characterized by the presence of an intensive transport load in almost all kinds of transport: road transport (more than 300,000 transport units were included in the assessment), railways capacity of 20-30 trains per day), air transport (civil aircraft of the airport of the urban settlement and state aircraft of the troops hand side - spans 20 a day). As a source of traffic noise, more than 1,200 linear sections of the road network, transit and local branches of the railway mains, routes of approach of aircraft in the airport location area were taken into account.

Calculation of the coefficients of correspondence of the measured (actual) noise level to the calculated level at 150 points of instrumental measurements showed that the variation of the conformity coefficients lies in the range 0.88 - 1.35.

In the next stage, based on the results of the triangulation, a polygon consisting of 260 triangles with vertices at the points of instrumental measurements was obtained (Fig. 1).

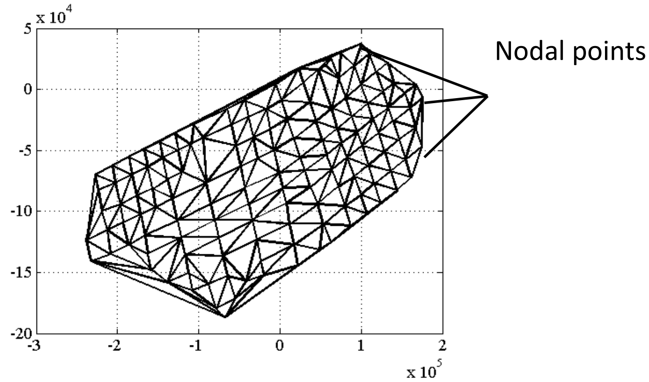


Figure 1 – The result of triangulation in the study area

Based on the results of applying this method, the regular grid was divided into points lying inside the polygon and outside it. With the use of the obtained coefficients of correspondence, the calculated noise levels at each node of the computed grid in the study area were calculated. Their range was 42.5 - 79.6 dB. The results obtained represent the noise levels at the points of a regular grid covering the whole of the investigated territory systemically.

Fig. 2 shows a three-dimensional map-scheme of the spatial distribution of the calculated noise levels in the study area before the approximation procedure is carried out.

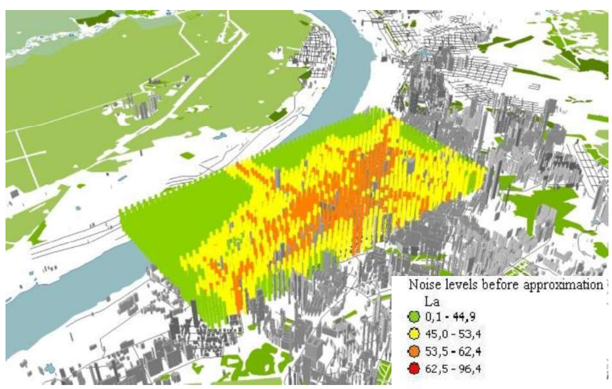


Figure 2 – Three-dimensional map-scheme of results of acoustic calculations to approximation

Fig. 3 shows a three-dimensional map-scheme of the spatial distribution of calculated noise levels in the study area after approximation (interpolation and extrapolation).

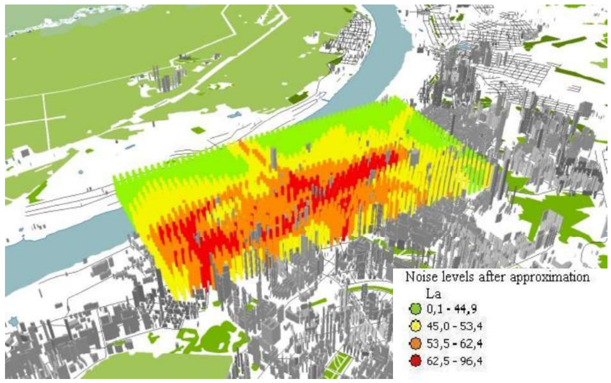
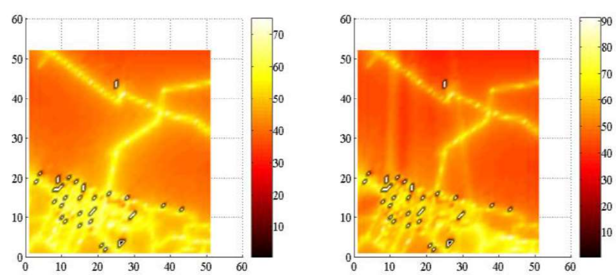


Figure 3 – Three-dimensional map-scheme of results of acoustic calculations after approximation

After carrying out the procedure of approximation, as shown in Fig. 3, the pattern of propagation of noise influence has changed, while at the points of instrumental measurements the coefficients of correspondence are 1, and in a number of points of full-scale studies (20 verification points) that were selected in the study area to confirm the reliability of the received the convergence of calculated and full-scale data increased to 72-96% with the previously noted 7-53% (Fig. 2, 3).

Fig. 4 shows the levels of noise exposure at the nodes of the grid and in 150 control points of field studies (chosen to confirm the accuracy and reliability of the proposed approach) before and after the procedure of approximation, respectively.



a) b)

Figure 4 – Distribution of noise exposure levels to approximation (a) and after approximation (b)

A confirmation that the proposed method of spatial quantification of noise levels is accurate and reliable is the fact that after the entire step-by-step procedure of approximation, the results of full-scale and approximated data at 20 verifying points became close in value, and the coefficients of correspondence from 0.88 to 1, 35 (before approximation) reached the values of 0.96 – 1.17 (after approximation), i.e. The convergence of the actual and the data obtained as a result of the approximation has grown. Consequently, verifying measurements at 20 points confirmed the correctness of the estimation of noise levels at the grid points.

The results of zoning of the study area, taking into account the refined results of noise impact and using the proposed risk scale [2] for possible disruption of public health under the influence of technogenic noise of the external environment, are shown in Fig. 5.

According to the results of combining the set of points, four main zones of acoustic impact on the urban population were identified (Fig. 5):

– zone 1, in which the risk of health damage from the impact of technogenic noise is absent, covers an area of 4,370,000 m2 of the study area;

– zone 2, in which the risk of occurrence of disorders of the nervous system in the population is possible, covers an area of 3,200,000 m2 of the study area;

– zone 3, in which the risk of occurrence of disorders of the nervous and cardiovascular systems in the population is possible, occupies an area of 3,880,000 m2 of the study area;

– zone 4, in which the risk of occurrence in the population of disorders of the nervous, cardiovascular and hearing systems, occupies an area of 2,860,000 m2 of the study area.

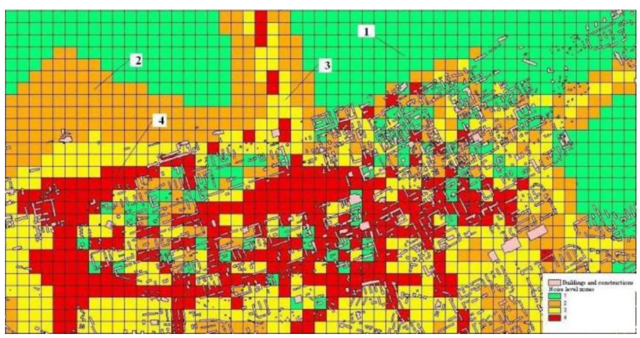


Figure 5 – The results of zoning of the study area on the risk of possible disruption of the health of the population under the influence of technogenic noise of the environment

The results of the assessment of the incidence of childhood diseases of the nervous system, cardiovascular system and hearing organs are presented in the table. As a result of the comparison of prevalence rates for the investigated disease classes, in most cases, data were obtained on the presence of statistically significant differences ($p < 0.05$) for the prevalence of diseases of the nervous system, cardiovascular system and hearing organs in children from zones with different levels of noise exposure and "kind" of the formed risk to health of the population (tab.).

Table – The prevalence of the incidence of the nervous system, cardiovascular system and hearing organs in children by risk zones (according to the request for medical care)

The risk zone determined by the proposed method	The presence of morbidity in children, in% of the total number of people living in the study area			
	Children without pathology of the nervous system, cardiovascular system, hearing organs	Of the nervous system	Of cardiovascular system	Of hearing organs
Zone 1	99,54	0,38	0,02	0,06
Zone 2	98,93	0,92	0,02	0,13
Zone 3	98,89	0,93	0,04	0,14
Zone 4	98,62	1,13	0,06	0,19

Thus, the proposed method of acoustic assessment with subsequent zoning of the territory based on hygienic criteria or risk to the health of the population [12] can be used for a comprehensive acoustic assessment of large settlements, noise mapping of the territory, justification of sanitary measures, and other tasks in order to ensure the correctness of the results and economic feasibility of evaluation.

According to the results of the study, a program of organizational, technological and sanitary-epidemiological measures is proposed for each zone in full accordance with their characteristics, namely:

– zone 1: in this area no additional noise reduction measures are required, the noise level is subject to periodic monitoring;

– zone 2: noise-protective measures of an organizational nature that form the systemic nature of the acoustic impact (the mode of operation of infrastructure facilities, the organization of uniform motion, etc.). The control of the effectiveness of the proposed activities is proposed to be carried out under the full program 4 times a day (morning, afternoon, evening and night), 20 days a year, covering all seasons of the year;

– zone 3: specialized noise protection measures, isolating the population from sources of technogenic noise (acoustic screens, barriers, etc.). The control of the effectiveness of the proposed activities is proposed to be carried out under the full program 4 times a day (morning, afternoon, evening and night), 20 days a year, covering all seasons of the year;

– zone 4: a complex of noise protection measures, both local and complex, with maximum isolation of the exposed population from sources of anthropogenic noise and the area of their impact (acoustic screens, landscaping, noise-proof glazing). The control of the effectiveness of the proposed activities is proposed to be carried out under the full program 4 times a day (morning, afternoon, evening and night), 20 days a year, covering all seasons of the year.

CONCLUSION

Thus, the proposed approach to verification of acoustic impact on the territory of a large urban settlement allows:

- taking into account the joint (additive) effect of several sources of technogenic noise on public health, since the total noise at each node of the map of the selected territory is determined;

- minimizing the uncertainties of each method (only the method of full-scale measurements or only the calculation method) separately and obtain the most accurate and reliable results of exposure levels provided that the data are correctly approximated when the proposed and tested method is implemented;

- zoning of the territory according to the level of possible risk to public health in the environment impact of anthropogenic noise of the external environment of varying intensity;

- using the results obtained to identify problems and develop technological, architectural and planning and other measures to minimize the levels of technogenic impact of the noise factor on public health and to plan medico-prophylactic measures in order to minimize the negative effects on the part of the health of the population.

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