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ASSESSING THE RISKS OF CIRCULATORY DISEASES DUE TO NOISE EXPOSURE IN URBAN AREAS

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Abstract. This paper describes the basic sources of noise exposure as significant negative physical factors for human health in an urban environment. We present the share of the industrial enterprises and vehicles not meeting hygienic standards of noise impacts for 2012–2021. Noise pollution levels are measured for six districts of Krasnoyarsk, and the territories with the highest levels are identified. The spatial distribution of noise levels is shown for Krasnoyarsk in the evening. The equivalent levels of weighted average daily noise exposure in the Tsentralny and Oktyabrsky districts of Krasnoyarsk are determined. Health risks are assessed by calculating the relative risk of circulatory diseases due to noise exposure. As noted, ensuring noise safety depends largely on determining load levels and obtaining characteristics of noise distribution in various functional areas promptly considering the multiplicity, diversity, and complexity of noise exposure sources. The obtained results can be used to study the impact of environmental factors on human health, perform hygienic diagnosis, elaborate and implement exposure reduction measures, and obtain reliable information about different exposures for human health.

Keywords: noise safety, health risk, urban territory, noise level measurement, spatial distribution, traffic noise, equivalent noise level, relative risk, risk of circulatory diseases, traffic noise protection.

INTRODUCTION

Currently, a wide range of technogenic and anthropogenic factors demonstrate a significantly increasing negative impact on public health. Among them, the factors of physical nature lead by the exposure intensity in urban areas. Anthropogenic noise as one of the physical factors has risen considerably in recent years [1–3] due to the growth of technological infrastructure, the intensified use of urban areas, and the development of the transport network. Undoubtedly, noise safety in urban areas is an extremely urgent problem.

The character of noise depends on its source. In urban areas, the most significant sources of noise are as follows:

– transport (motor vehicles, rail cars, aircraft, etc.),
– companies (industrial enterprises, service and trade firms, etc.),
– construction and repair work,
– sports and cultural and entertainment facilities, including sound-amplifying advertising devices,
– ventilation and air conditioning systems,
– food facilities,
– interblock sources (courtyards, etc.),
– loading and unloading work.

According to the State report [3], 12.6% of objects do not meet the hygienic standards for the noise level. Table 1 shows the shares of industrial enterprises and examined motor vehicles not meeting these standards.

There is a general trend towards reducing the level of long-term, systematic, and complex noise exposures, but they are still high. In residential construction territories, the share of noise measurements not meeting the hygienic standards constituted 17% in 2021; for details, see [3]. Noise exposure in restrained urban conditions is one of the most significant physical fac-

tors affecting the human environment and, consequently, population health.

According to different researchers, acoustic pollution from traffic lines forms about 80% of all external noises in cities [1–3], causing irritation and affecting the psychological state, including anxiety [4], fatigue, and tension [5, 6].

The noise exposure duration is 15–18 h/day [1, 2]. The long-lasting noise exposure disturbs the normal activity of the cardiovascular and nervous systems and digestive and hematopoietic organs. Also, occupational deafness develops up to a complete loss of hearing. Urban noise shortens life expectancy. Excessive noise can cause nervous exhaustion, mental depression, vegetative neurosis, ulcer disease, and upsets of the endocrine and cardiovascular systems [7]. Nocturnal noise disturbs sleep, possibly causing particular anxiety. Disturbed sleep may negatively affect many aspects of health and well-being by deteriorating attention, memory consolidation, neuroendocrine and metabolic functions, mood, and overall quality of life. Moreover, nocturnal noise influences autonomic functions: as shown by epidemiological studies [8], prolonged exposure to nocturnal environmental noise may increase the risk of cardiovascular diseases.

Circulatory diseases (CD) occupy the second place in the population morbidity structure of Krasnoyarskii krai; for details, see [9, 10]. Table 2 presents the CD incidence data, including the number of first-time diagnosed cases. The increase in the general morbidity rate was observed until 2019; in 2020–2021, it was reduced.

The main share (54.3%) in the CD incidence structure falls on diseases characterized by high blood pressure. The primary morbidity in this group is also increasing. The share of other CD is much smaller. According to the experimental evidence [7], exposure to high-level noises increases the blood pressure of humans.

The total CD morbidity among the adult population in Krasnoyarskii krai has decreased by 3.3% over the last five years; the primary morbidity, by 16.7%. CD are much more common in old age, when irreversible changes significantly limit the adaptive capacity of blood vessels.

This paper investigates the levels of noise exposure from motor vehicles on the population health of Krasnoyarsk. We map noise pollution and assess the CD risks due to acoustic impacts based on noise level measurements for different districts of Krasnoyarsk.

Table 1

The share of industrial enterprises and examined vehicles not meeting the hygienic standards for the noise level

Years	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
The share of industrial enterprises not meeting the hygienic standards for the noise level, %	35.9	33.9	33.1	31.5	32.7	32.4	31	26.8	23.6	26.1
The share of examined vehicles not meeting the hygienic standards for the noise level, %	24.9	23.8	21.8	19.3	20.5	15.8	10.8	88.8	66.6	77.6

Table 2

CD morbidity and mortality data for Krasnoyarskii krai [3, 10]

Indicator	Year				
	2017	2018	2019	2020	2021
Regional population, thousand people	2876	2877	2874	2866	2856
The regional number of CD cases, thousand people	716	719	725	679	675
The regional number of first-time diagnosed CD cases, thousand people	106	108	96	84	83
Mortality rate per 100 000 residents due to CD	574.2	587.6	589.4	657.2	688.0

1. DATA AND METHODS

Noise levels were measured from April to May 2021 using CEM DT-815, a noise meter with the following technical specifications: range 30–130 dB; dynamic range 50 dB; four measurement modes: Low (30–80 dB), Med (50–100 dB), High (80–130 dB), and Auto (30–130 dB); frequency range 31.5–8000 Hz; measurement speed 2 samples per second. The measurements were taken in the Tsentralny, Oktyabrsky, Kirovsky, Zheleznodorozhny, and Sverdlovsky districts and the Vzletka residential community of the Sovetsky district of Krasnoyarsk at a height of 1.5 ± 0.1 m from the roadway surface, on the shoulder at a distance of 7.5 ± 0.2 m from the axis of the road lane nearest to the measuring point or the path of motor vehicles.

Six points (intersections with heavy vehicular traffic, parks, residential areas, social and cultural facilities, bridges, etc.) were selected in each district. Measurements were taken in the daytime and evening hours during one week, 504 ones in total.

According to the WHO recommendations [11], the noise produced by motor vehicles should be reduced to an equivalent daily noise level L_{den} below 53 dBA: the road traffic noise above this level negatively affects human health. At night, the noise level should not exceed 45 dBA: the road traffic noise above this level deteriorates normal sleep.

In the Russian Federation, population health risks due to noise exposure are commonly assessed using evolutionary models. They are also widely used for assessing risks due to environmental factors (air pollution, electromagnetic radiation, etc.) [12]. The risk value calculated by a recurrent relationship is expressed through the relative risk indicator. This indicator is a non-probabilistic characteristic demonstrating how many times the risk of disease development in the presence of a given exposure factor exceeds that in its absence [13]. In international practice, the Cox regression, or the proportional risk model, is often used.

Within this model, the risk level is a time-varying function that exponentially depends on the exposure factor and can exceed unity [14–16]. A common relative risk assessment approach is calculating the ratio of the chances of negative effects to the background value of a health indicator (morbidity or mortality) with evaluating the statistical significance of the differences. This approach is also used to assess the negative effects on population health from both physical and chemical exposures [17, 18].

Population health risks were assessed in accordance with Guidelines MR 2.1.10.0059-12 [19] considering exposure estimation based on instrumental noise measurements. The exposure estimation procedure includes determining normative noise parameters at a given time and the exposure duration as well as estimating the daily weighted noise as a measure of population contact with a harmful factor. This procedure yields more accurate values. The points for acoustic calculations were chosen by the locations of permanent residential areas, recreation zones, indoor territories, etc.

2. NOISE POLLUTION MEASUREMENTS IN KRASNOYARSK

The noise pollution measurements are combined in Fig. 1. During the periods of the maximum-intensity exposures (evening time), the highest noise levels were observed in the Tsentralny and Oktyabrsky districts of the city. A significant scatter of the measurement results in the Zheleznodorozhny and Sverdlovsky districts is explained by appreciably decreased noise levels in these territories far from roads (inside residential areas neighborhoods and parks).

The average noise pollution levels for the Tsentralny and Oktyabrsky districts of Krasnoyarsk were compared with the maximum permissible levels (MPL) of non-permanent noise sources, according to the Code of Practice SP 51.13330.2011 [20]. Clearly, the measured values at seven examined sites exceed the established standard (Table 3).

The spatial distribution of noise levels in the evening clearly demonstrates the presence of several areas with values exceeding the established standards. The isolines characterize the variations of noise levels along the surface: they are located farther from each other (closer to each other) where the noise levels vary insignificantly (increase or decrease rapidly, respectively). The highest density of the isolines was obtained for the Tsentralny district. This result is explained by a high concentration of traffic flows, especially in the evening.

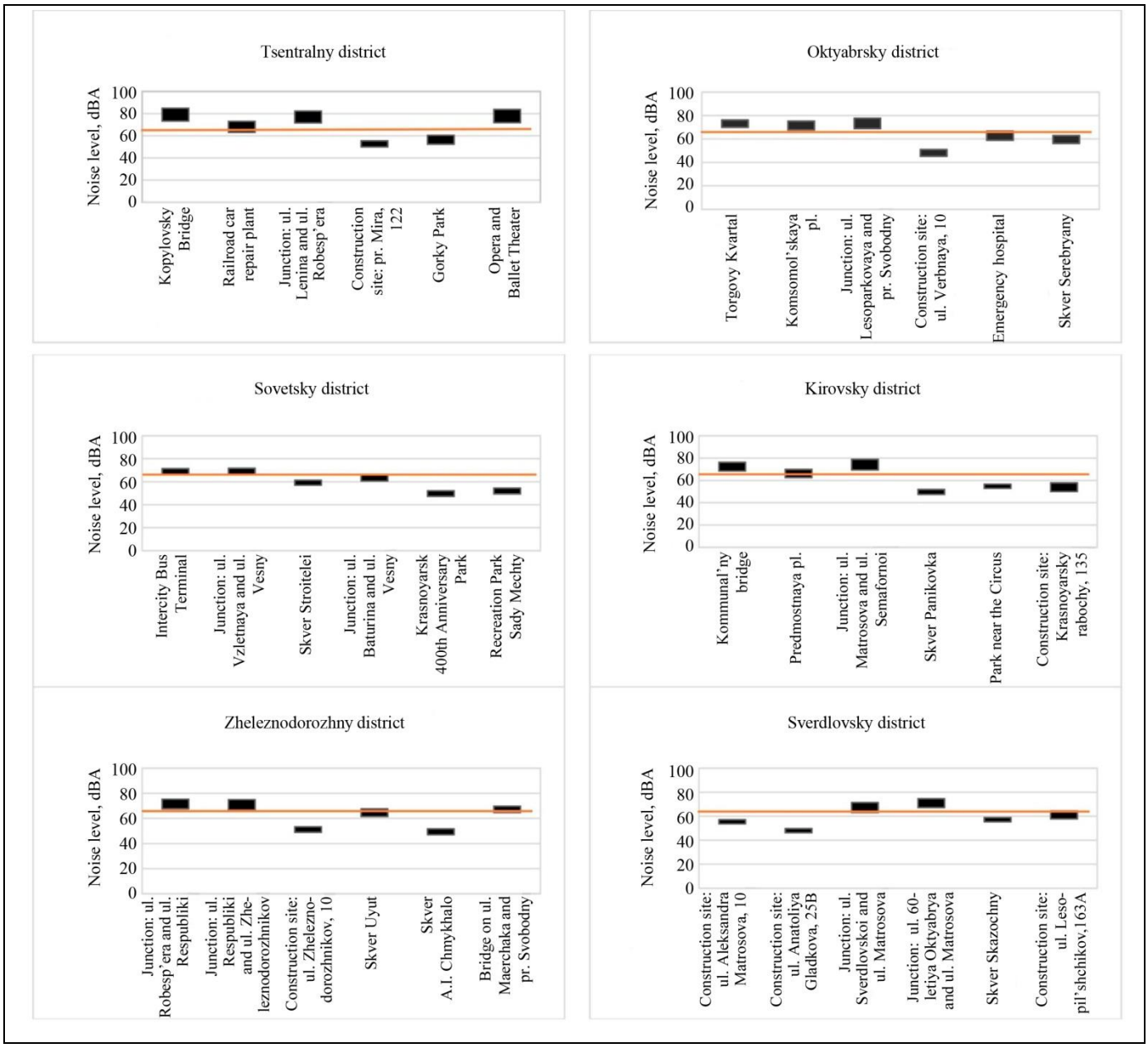

Fig. 1. The spatial dynamics of noise levels in Krasnoyarsk districts in the evening (the orange line shows the maximum permissible noise level).

Table 3

Average noise levels in the Tsentralny and Oktyabrsky districts of Krasnoyarsk, April 2021.

Tsentralny district	Average noise level, dBA	MPL_{max} for non-permanent noise sources, dBA	Oktyabrsky district	Average noise level, dBA	MPL_{max} for non-permanent noise sources, dBA
Kopylovsky Bridge	**78.2**	70	Shopping mall on pr. Svobodny	**73.7**	70
Railroad car repair plant	65.1	70	Komsomol'skaya pl.	**71.4**	60
Junction: ul. Lenina and ul. Robesp'era	**74.8**	70	Junction: ul. Lesoparkovaya and pr. Svobodny	**74.1**	70
Construction site: pr. Mira, 122	50.0	70	Construction site: ul. Verbnaya, 10	47.4	70
Gorky Park	55.2	60	Emergency hospital	**62.6**	60
Bridge near the Opera and Ballet Theater bus stop	**75.0**	70	Skver Serebryany	58.9	60

Figure 2 shows the noise pollution map of Krasnoyarsk based on QGIS measurement data.

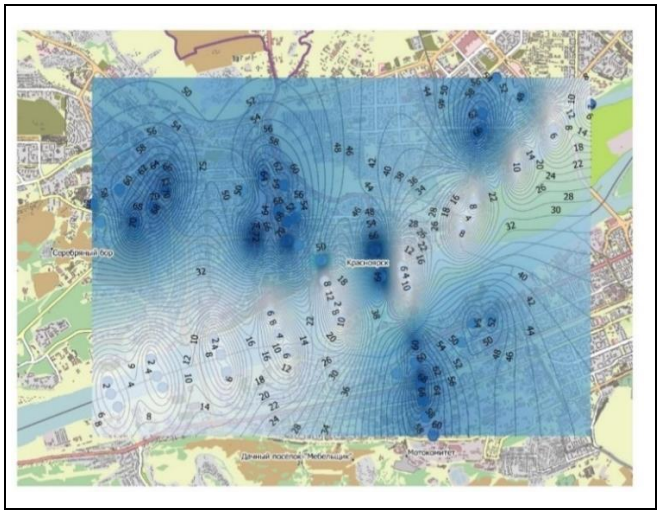

Fig. 2. The spatial distribution of noise levels in Krasnoyarsk in the evening.

3. HEALTH RISK ASSESSMENT

In accordance with GOST R 53187–2008 [21] and Guidelines MR 2.1.10.0059-12 [19], we assessed the health risk using the equivalent level of weighted average daily noise exposure, L_{den}, with the measured values of the daytime and evening levels:

$$L_{den} = 10 \lg \frac{1}{24}(16 \cdot 10^{(L_{day}/10)} + 8 \cdot 10^{((L_{night}+10)/10)}),$$

where L_{day} and L_{night} denote the equivalent levels of the weighted average daytime (16-h period) and evening (8-h period) noise exposure in dBA.

Based on the calculations, the equivalent weighted average noise levels range from 55 to 85 dBA for all districts of Krasnoyarsk. Table 4 shows the calculation results for the Tsentralny and Oktyabrsky districts. Obviously, the recommended levels are exceeded at all sites examined.

Noise is a general biological irritant. It affects not only the auditory analyzer but also many vital systems (the cardiovascular, nervous, digestive, and circulatory ones).

Following Guidelines MR 2.1.10.0059-12 [19], we calculated the relative risk of circulatory diseases due to noise exposure using the available measurements:

$$OR = 1.63 - 6.13 \cdot 10^{-4} L^2_{day,16} + 7.36 \cdot 10^{-6} L^3_{day,16},$$

where $L_{day,16}$ is the equivalent daytime noise level in dBA.

The relation between the factor and the outcome depends on the values of the relative risk indicator: for $OR \leq 1$, the noise level has no effect on the likelihood of circulatory diseases; for $OR > 1$, the noise level increases the morbidity of circulatory diseases.

Thus, the average values of the relative risks of circulatory diseases due to noise exposure for the six districts of Krasnoyarsk range from 1.05 to 1.16 (Table 5). The limits of the confidence intervals for the risk indicator *OR* were calculated by Student's criterion with the significance level $\alpha = 0.01$.

Table 4

The equivalent levels of weighted average daily exposure in the Tsentralny and Oktyabrsky districts of Krasnoyarsk, April 2021.

Tsentralny district	L_{day}, dBA	L_{night}, dBA	L_{den}, dBA	Oktyabrsky district	L_{day}, dBA	L_{night}, dBA	L_{den}, dBA
Kopylovsky Bridge	77.4	79.1	84.5	Shopping mall on pr. Svobodny	74.3	73.1	79.4
Railroad car repair plant	62.1	68.1	73.5	Komsomol'skaya pl.	71.5	71.5	77.5
Junction: ul. Lenina and ul. Robesp'era	72.6	77.0	82.5	Junction: ul. Lesoparkovaya and pr. Svobodny	75.0	73.3	79.6
Construction site: pr. Mira, 122	47.2	52.8	58.3	Construction site: ul. Verbnaya, 10	46.6	48.1	53.9
Gorky Park	54.0	56.4	62.1	Emergency hospital	62.4	62.9	68.8
Bridge near the Opera and Ballet Theater bus stop	72.3	77.8	83.3	Skver Serebryany	58.1	59.6	64.4

Table 5

The relative risk of circulatory diseases due to noise exposure by the districts of Krasnoyarsk, April 2021

District	*OR*, average value	Confidence interval	*OR*, corrected by the equivalent value
Tsentralny	1.16	[1.09, 1.23]	1.17
Oktyabrsky	1.14	[1.06, 1.22]	1.16
Sovetsky	1.05	[1.03, 1.06]	1.05
Kirovsky	1.11	[1.06, 1.16]	1.11
Zheleznodorozhny	1.06	[1.04, 1.08]	1.06
Sverdlovsky	1.05	[1.01, 1.08]	1.05

The average relative risk for Krasnoyarsk is insignificant, amounting to 1.09. The difference from the risk level by the equivalent noise level corrected for daytime exposure is slight.

4. DISCUSSION

The reasonable choice of noise protection measures requires acoustic load monitoring to obtain reliable data on its distribution in urban areas [22]. When protecting against traffic noise, important organizational measures include traffic flow redistribution, cargo traffic restriction, speed limitation, etc. There is no general concept of ecological safety regarding the noise factor. This often leads to casual decisions with local and expensive constructive protection methods. Passive noise regulation methods should be replaced by active ones to form an environment with predetermined properties with the necessary ecological safety level. Note that the ecological validity of the applied decisions affects the qualitative condition of the environment and, moreover, the future cost of eliminating potential negative consequences [23].

Thus, an appropriate environment management strategy as well as justified investments and the rational use of urban areas largely depend on a comprehensive ecological assessment of anthropogenic loads, including noise pollution. Within health risk management, each subject of the Russian Federation will have individual tasks since the subjects and even large cities considerably differ by the population health due to heterogeneous living conditions and quality of the environment [3].

Despite the decrease in the total CD morbidity among the adult population of Krasnoyarskii krai over the past five years, its level is still high and requires attention both from researchers and environmental protection authorities.

The combined effect of noise and other physical factors (electromagnetic fields, lighting, air temperature, vibration) may amplify the negative impact and cause multidirectional reactions from all functional systems of humans.

CONCLUSIONS

This paper has presented noise level measurements for six districts of Krasnoyarsk. According to the data, there is an excess of the maximum noise levels for non-permanent sources in each district. The noise pollution map has been constructed to study the spatial distribution of noise exposure in the city. The risks of circulatory diseases in the considered conditions have been calculated. As discovered, the produced noise level increases the morbidity of circulatory diseases.

The obtained results can be used to study the impact of environmental factors on human health, perform hygienic diagnosis, elaborate and implement exposure reduction measures, and obtain reliable information about different exposures for human health. Ensuring noise safety depends largely on determining load levels and obtaining characteristics of noise distribution in various functional areas promptly considering the multiplicity, diversity, and complexity of noise exposure sources. Obviously, the real levels of noise impacts and associated population health risks for all vital systems of an organism should be investigated further.

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