UDC 613.15, 614.71
DOI: 10.21668/health.risk/2024.3.01.eng

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Research article

AMBIENT AIR QUALITY AND RISK OF CIRCULATORY DISEASES FOR POPULATION OF A LARGE CITY IN THE EUROPEAN NORTH OF RUSSIA

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Cardiovascular diseases are the most frequent causes of premature mortality associated with ambient air quality. In the Arkhangelsk region, population mortality caused by diseases of the circulatory system is higher than the national average. The aim of this study was to assess ambient air quality in Arkhangelsk and associated health harm in adult population.

The study relied on using data of ambient air monitoring in Arkhangelsk collected over 2011–2022. We analyzed average annual levels of 23 pollutants and primary incidence of diseases of the circulatory system (CVD) and calculated hazard quotients under chronic inhalation exposure (HQ), hazard index (HI) for the cardiovascular system, and the number of attributable deaths associated with exposure to PM_{10} and $PM_{2.5}$.

Over the analyzed period, the average long-term concentrations of most pollutants met hygienic standards. Average levels of formaldehyde, chromium, copper and benzene were found to exceed the MPL by 1.5–2.3 times. Hazard coefficients for formaldehyde (HQ = 2.3), copper (HQ = 1.8) and $PM_{2.5}$ (HQ = 1.7) were established to be above their permissible value. The risk of developing general toxic effects is determined to be high (HI = 6.6) for the cardiovascular system. The main contribution to the risk level is made by copper and $PM_{2.5}$. Attributable outcomes of primary cardiovascular incidence among the adult population of Arkhangelsk associated with exposure to PM_{10} and $PM_{2.5}$ equaled 10.7 and 2.9 ‰ cases per year. The greatest harm under exposure to $PM_{2.5}$ is due to the development of coronary artery disease and amounts to 1.9 ‰ cases per year.

Keywords: *ambient air, pollutants, diseases of the circulatory system, primary incidence, health risk assessment, hazard quotient, hazard index, health harm.*

At present, ambient air pollution remains a global threat for human health. Relying on considerable pool of research data on health harm caused by ambient air pollution, the WHO issued new global air quality guidelines in 2021. The document outlines analytical data according to which approximately 80 % of deaths caused by $PM_{2.5}$ exposure can be prevented by reducing concentrations of this harmful admixture down to their safe levels[1].

In 2022, 40 cities in the Russian Federation with their total population reaching 10.4 million people had very high levels of ambient air pollution with API (air pollution index) ≥ 14; in 2021, only 33 cities were included in this list. Overall, 49 % of the urban population in Russia lives in cities with high and very high ambient air pollution. In 2022, the total pollutant emissions in Russia amounted to 17.174 million tons from station-

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[1] WHO global air quality guidelines: Particulate matter ($PM_{2,5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva, World Health Organization, 2021, 300 p.

nary sources and 4.8 million tons from motor transport[2].

Cardiovascular diseases, in particular, coronary heart disease (CHD) and stroke are the most frequent causes of premature death attributable to ambient air pollution. According to the WHO data, 24 % of CHD burden and 25 % of stroke burden are attributable to ambient air pollution [1]. The number of additional deaths among population due to diseases of the circulatory system (CVDs) associated with ambient air pollution amounted to 0.7 per 100 thousand people in 2022 in Russia; the number of CVD cases attributable to ambient air pollution reached 42.9 per 100 thousand people, which corresponds to 1.4 % of the actual incidence[3].

CVDs hold the second rank place in the structure of incidence in the Arkhangelsk region. According to Rosstat, cardiovascular incidence in the Arkhangelsk region is at the same level with the national average (23.7 per 1000 against 26.29 per 1000). Cardiovascular mortality in the Arkhangelsk region (714.5 per 100 thousand) is 20.7 % higher than the national average.

In 2022 in the Arkhangelsk region, the total pollutant emissions were equal to 117 thousand tons (81.1 %) from stationary sources and 27.33 thousand tons (18.9 %) from mobile sources. In Arkhangelsk, ambient air pollution is mostly created by enterprises dealing with production and distribution of electrical power, water and gas, waste treatment and disposal; by automobile, river and railways transport. Most pollutants enter ambient air with automobile exhausts as their contributions to the total emissions amount to 70.5 %[4].

The aim of this study was to assess ambient air quality in Arkhangelsk and associated health harm in adult population.

Materials and methods. We used data on pollutant levels to assess ambient air quality in Arkhangelsk. They were provided by the Northern Office for Hydrometeorology and Environmental Monitoring and the Center for Use of Natural Resources and Environmental Protection. We analyzed average annual levels of total solid particles (TSP), sulfur dioxide, carbon oxide, nitrogen dioxide, nitrogen oxide, hydrogen sulfide, formaldehyde, methyl mercaptan, benzo(a)pyrene, benzene, toluene, ethyl benzene, xylene, and metals (chromium, manganese, iron, nickel, copper, zinc, and lead) over 2011–2022; ozone, PM_{10} and $PM_{2.5}$ over 2021–2022. We calculated the total number of samples that did not conform to safety standards, average long-term levels of the analyzed pollutants and their levels at the upper exposure limit (P_{90}).

Non-carcinogenic health risks upon exposure to pollutants were assessed according to the Guide R 2.1.10.1920-04 Human Health Risk Assessment from Environmental Chemicals[5]. We calculated hazard quotients (HQ) for chronic inhalation exposure to the analyzed pollutants and hazard index (HI) of general toxic effects caused by unidirectional impacts exerted by adverse chemicals on the cardiovascular system as well as contributions made by specific chemicals into the hazard index.

Cardiovascular incidence among the Arkhangelsk population was analyzed using data from the Form No. 12 the Number of

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[2] Sostoyanie zagryazneniya atmosfery v gorodakh na territorii Rossii za 2022 god: ezhegodnik [Ambient air pollution in Russian cities in 2022: annual bulletin]. Saint Petersburg, Rosgidromet GGO, 2023, 256 p. (in Russian).

[3] O sostoyanii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya v Rossiiskoi Federatsii v 2022 godu: Gosudarstvennyi doklad [On sanitary-epidemiological welfare of the population in 2022: State report]. Moscow, the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 2023, 368 p. (in Russian).

[4] Sostoyanie i okhrana okruzhayushchei sredy Arkhangel'skoi oblasti za 2022 god: doklad [The state and protection of the environment in the Arkhangelsk region in 2022: report]. In: O.V. Perkhurova ed.; The Center for Use of Natural Resources and Environmental Protection. Arkhangelsk, SAFU, 2023, 529 p. (in Russian).

[5] Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals. In: Yu.A. Rakhmanin, S.M. Novikov, T.A. Shashina, S.I. Ivanov, S.L. Avaliani, K.A. Bushtueva, E.N. Belyaev, M.V. Fokin [et al.] eds. Moscow, Rospotrebnadzor, 2004, 143 p. (in Russian).

Diseases Registered in Patients Living in an Area Served by a Healthcare Organization over 2011–2022. We analyzed primary incidence of Diseases of the Circulatory System class (ICD-10: I00–I99) per 4 items and 10 nosologies among population aged 18 years and older and calculated extensive rates and chain growth / decline rates of primary cardiovascular incidence.

To establish attributable disease cases, a level – response function was used given by the relative risk rate per 10 μg/m^3 as well as frequency of diseases per 1000 people. Additional numbers of adverse health outcomes associated with exposure to pollutants were calculated using average daily PM_{10} and $PM_{2.5}$ levels at the upper exposure limit (P_{90}) per 1000 adult people (‰). Primary incidence of diseases associated with elevated blood pressure, myocardial infarction, stroke, chronic CHD and cardiovascular mortality among the adult Arkhangelsk population were estimated as adverse health outcomes in this study. An additional number of cardiovascular events was calculated using relative risk levels under exposure to $PM_{2.5}$ [2–8] and PM_{10} [9–12] (Table 1). The obtained data were statistically analyzed with STATA software, version 18.

Results and discussion. Levels of most chemical pollutants in ambient air, both average and at $P_{90,}$ conformed to safety standards in Arkhangelsk in 2011–2022 (Table 2). Formaldehyde levels were 2.3 and 3.3 times higher than average annual MPL at the average and P_{90} level respectively. Average benzene levels were 1.5 times higher than average annual MPL and 1.6 times higher than P_{90} over the analyzed period. We also detected chromium and copper levels that exceeded their MPLs and were 1.8 times higher at the average level and 2.8–3.3 times higher than MPLs at the upper exposure limit. Average TSP, PM_{10} and $PM_{2.5}$ levels conformed to safety standards but their levels at the upper exposure limit were 1.2, 1.1 and 1.6 times higher than average annual MPL respectively. Average benzo(a)pyrene and ozone levels were within safety ranges in ambient air in Arkhangelsk; at the upper exposure limit, their levels exceeded average annual MPLS 1.3 and 1.2 times respectively.

Essential (primary) hypertension accounts for the biggest proportion in cardiovascular incidence (23.9 %); it is followed by CHD, (the second place with 22.1 %) and cerebrovascular diseases (21.1 %). Over the 12-year analyzed period, primary cardiovascular incidence was established to decline in Arkhangelsk with its chain decline rate being -3.0 % (Table 3). Primary incidence went down for most items: average chain decline rates starting from -5.0 % identified for diseases of veins, lymphatic vessels and lymph nodes to -2.3 % identified for CHD. Essential primary hypertension was the only exclusion for which an average chain growth of 1.7 % was identified.

Table 1

A growth in effect on adult population per one-unit change in pollutant level (10 μg/m^3)

A growth in effect per one-unit change in level	ICD-10 code	$PM_{2.5}$	PM_{10}	Source ($PM_{2.5}$ / PM_{10})
Diseases of the circulatory system	I00–I99	1.36	1.10	[3] / [10]
– Ischemic heart diseases (coronary heart disease)	I20–I25	1.27	-	[2] / -
– Acute myocardial infarction	I21	1.28	1.03	[2] / [9]
– Cerebral infarction	I63	1.21	-	[6] / -
– Essential (primary) hypertension	I10	1.11	1.12	[7] / [12]
Cardiovascular mortality	I00–I99	1.12	1.10	[5] / [10]
Death due to cerebral infarction	I63	1.11	-	[4] / -
Death due to coronary heart disease	I20–I25	1.18	-	[8] / -
Death due to myocardial infarction	I21	-	1.05	- / [11]

Table 2

Ambient air quality in Arkhangelsk over 2011–2022

Chemical	The number of samples, total	Level				Average annual MPL, mg/m^3
		Average annual		At P_{90}		
		mg/m^3	Proprotion of average annual MPL	mg/m^3	Proprotion of average annual MPL	
Total solid particles	28,753	0.049	0.6	0.087	1.2	0.075
Sulfur dioxide	20,378	0.002	< 0.1[b]	0.003	0.1[b]	0.05[b]
Carbon oxide	22,240	1.26	0.4	1.685	0.6	3.000
Nitrogen dioxide	31,428	0.025	0.6	0.033	0.8	0.040
Nitrogen oxide	10,452	0.024	0.4	0.054	0.9	0.060
Hydrogen sulfide	30,555	0.001	0.4	0.001	0.5	0.002
Formaldehyde	31,429	0.007	2.3	0.010	3.3	0.003
Methyl mercaptan	5253	0.0001	–	0.0001	–	–
Benzo(a)pyrene	5606	0.875[c]	0.9	1.29[c]	1.3	1.00[c]
Benzene	5793	0.007	1.5	0.008	1.6	0.005
Toluene	5791	0.006	< 0.1	0.010	< 0.1	0.4
Ethyl benzene	5792	0.001	< 0.1	0.002	0.1	0.04
Xylenes	5792	0.010	0.1	0.012	0.1	0.1
Chromium	283	0.000014	1.7	0.000023	2.8	0.000008
Manganese	283	0.000014	0.3	0.000021	0.4	0.00005
Iron	283	0.000549	< 0.1	0.000718	< 0.1	0.04
Nickel	283	0.000010	0.2	0.000015	0.3	0.00005
Copper	283	0.000036	1.8	0.000066	3.3	0.00002
Zinc	283	0.000031	< 0.1	0.000045	< 0.1	0.035
Lead	283	0.000005	< 0.1	0.000010	0.1	0.00015
$PM_{2.5}$[a]	594	0.025	0.8	0.039	1.6	0.025
PM_{10}[a]	594	0.028	0.7	0.044	1.1	0.04
Ozone[a]	401	0.021	0.8	0.037	1.2	0.03

Note: [a] means data collected in 2021–2022; [b] means average daily MPL; [c] means ($\times 10^{-6}$).

Table 3

Primary cardiovascular incidence among adult population in Arkhangelsk in 2011–2022 (average frequency per 1000 people aged 18 years and older)

Diseases of the circulatory system	ICD-10 code	Proportion, %	Frequency per 1000 people	Chain growth / decline rate, %
Diseases of the circulatory system	I00–I99	100.00	29.70	-3.00
Essential (primary) hypertension	I10–I13	23.91	7.11	1.67
Ischemic heart diseases (coronary heart disease)	I20–I25	22.13	6.58	-2.58
– Angina pectoris	I20	5.44	1.61	-4.13
– Myocardial infraction	I21	4.20	1.25	-2.12
– Chronic ischaemic heart disease	I25	10.66	3.17	5.67
Cerebrovascular diseases	I60–I69	21.09	6.27	-2.32
– Subarachnoid haemorrhage	I60	0.29	0.09	2.18
– Intracerebral haemorrhage and other nontraumatic intracranial haemorrhage	I61, I62	1.46	0.43	-6.75
– Cerebral infarction	I63	9.53	2.83	-2.58
Atherosclerosis of arteries of extremities, thromboangiitis obliterans	I70.2,I73.1	1.86	0.55	-8.67
Diseases of veins, lymphatic vessels and lymph nodes	I80–I89	14.58	4.33	-5.00
– Phlebitis and thrombophlebitis	I80	2.59	0.77	-8.51
– Varicose veins of lower extremities	I83	8.17	2.43	-0.57

Average hazard quotients taken over 2011–2022 were higher than their permissible levels for formaldehyde (HQ = 2.3), copper (HQ = 1.8) and $PM_{2.5}$ (HQ = 1.7) and conformed to them for the remaining analyzed chemicals (Figure 1). HQ at the upper exposure limits equaled 3.3 for copper and formaldehyde, which corresponds to high risk of general toxic effects (Figure 2). HQ at the P_{90} level corresponded to alerting risk levels for $PM_{2.5}$, benzo(a)pyrene, ozone, and total solid particles.

HI for the cardiovascular system amounted to 6.6 over the analyzed period in Arkhangelsk, which corresponds to high risk of general toxic effects caused by exposure to ambient air pollutants. HI for the cardiovascular system was 10.8 at the upper exposure limit. Major contributions to the identified risk levels were made by copper (27 %), $PM_{2.5}$ (26 %), ozone (11 %), total solid particles, and PM_{10} (9 % both).

Adverse health outcomes associated with primary cardiovascular incidence among adult population in Arkhangelsk caused by $PM_{2.5}$ and PM_{10} exposure amounted to 10.69 and 2.96 ‰ respectively. Attributable cardiovascular incidence rates caused by $PM_{2.5}$ exposure

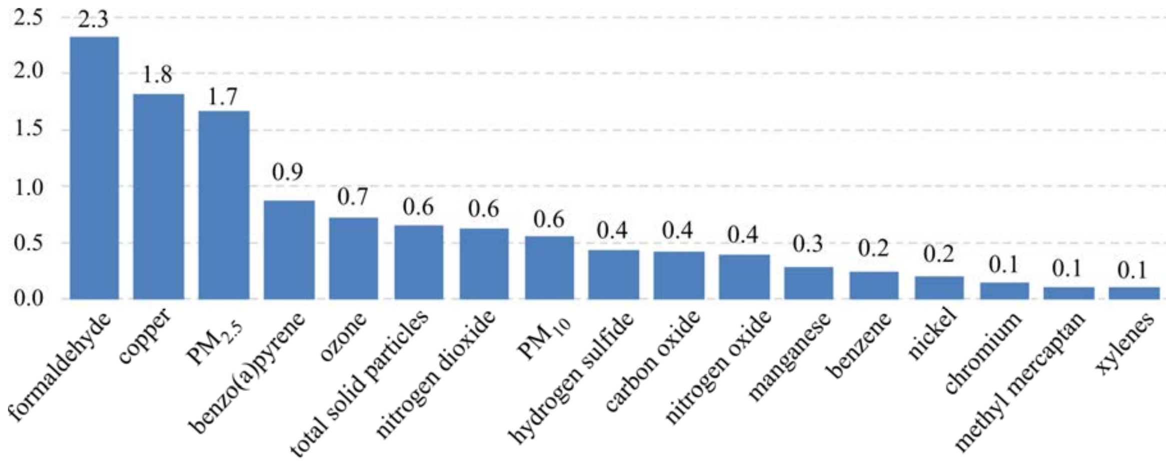

Figure 1. Hazard quotients of pollutants identified in ambient air in Arkhangelsk in 2011–2022 (taken as per average levels)

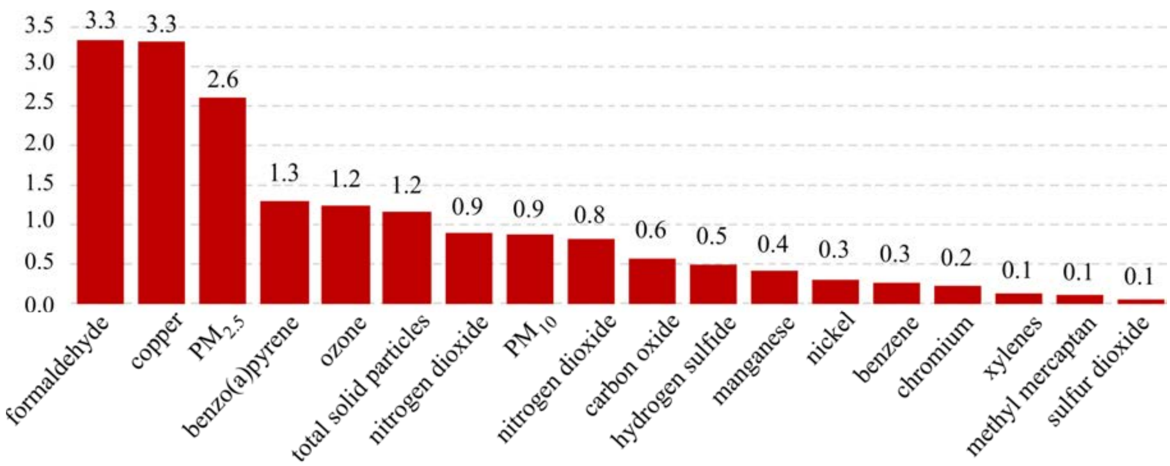

Figure 2. Hazard quotients of pollutants identified in ambient air in Arkhangelsk in 2011–2022 (taken as per average levels) (taken as per P_{90})

were established to be equal to 1.85 ‰; myocardial infarction. 0.48 ‰; cerebral infarction, 0.59 ‰. Likely additional numbers of first diagnosed essential hypertension upon $PM_{2.5}$ and PM_{10} exposure amounted to 0.78 and 0.85 ‰ respectively. Cardiovascular mortality caused by $PM_{2.5}$ exposure equaled 2.28 ‰ cases; PM_{10} exposure, 1.89 ‰ cases. Attributable deaths due to coronary heart disease and myocardial infarction upon $PM_{2.5}$ exposure amounted to 2.04 and 0.27 ‰ respectively.

Analysis of ambient air quality in Arkhangelsk established that levels of most pollutants were within their safe ranges; however, long-term average annual concentrations of formaldehyde, benzene, chromium and copper did not conform to safety standards. HQ for formaldehyde, copper and $PM_{2.5}$ was established to be higher than its permissible level. Hazard index for the cardiovascular system corresponded to high risk of general toxic effects. Major contributions to toxic effects were made by copper, $PM_{2.5}$, ozone, total soli particles, and PM_{10}. Primary cardiovascular incidence attributable to $PM_{2.5}$ exposure amounted 10.69 ‰; PM_{10} exposure, 2.96 ‰ cases.

Diversity of chemicals in ambient air, their structure and pollution intensity depend on pollution sources present on a given territory. Motor transport is a major source of ambient air pollution (more than 70 %) in many cities in Russia, for example, Kazan, Samara, Saint Petersburg, Tyumen, and Vladikavkaz. Our study findings are consistent with data obtained for Tyumen [13] and Vladikavkaz [14] where HI values were higher than 6 for the cardiovascular system, which corresponds to high risk of general toxic effects (23.2 and 6.7 respectively). Major contributions to pollution in these cities are made by carbon oxide and nitrogen dioxide.

In Kazan [15], Samara [16] and Saint Petersburg [17], where motor transport is a major source of ambient air pollution, HI established for the cardiovascular system is not higher than its permissible level (1.9; 0.74; 1.4 respectively). In Kazan, the greatest contributions to HI value are made by PM_{10} (79 %) and carbon oxide (21 %); in Samara, carbon oxide (55 %) and phenol (45 %); in Saint Petersburg, carbon oxide and $PM_{2.5}$.

Differences in HI values established for the cardiovascular system in different cities with similar major sources of ambient air pollution might be due to different chemicals included into monitoring programs, different methods for identifying chemicals in ambient air, or different approaches to selecting priority chemicals for health risk assessment.

Stationary sources make the main contribution to ambient air pollution in the Perm region [18], Novokuznetsk [19], Tula [20], Donetsk region [21], Orenburg region [22], and Irkutsk region [23]. High risk of general toxic effects for the cardiovascular system has been established in Makeevka (Donetsk region), a city with developed metallurgic production (HI = 9.33), where the greatest contributions are made by total solid particles (45 %) and ammonia (30 %) [21]. In Novokuznetsk, HI for the cardiovascular system was 4.6, which corresponded to alerting risk [19]. According to research data, areas with permissible risks of general toxic effects include Perm [18], Berezniki (Perm region) [18], Tula [20], Orenburg region [22], and Irkutsk region [23], where HI values established for the cardiovascular system equaled 0.76, 1.9, 0.48, 2.1 and 2.23 respectively. Major contributions to HI in these areas are made by benzene, phenol, carbon oxide, ammonia, and total solid particles.

Additional number of deaths due to CVDs per year caused by $PM_{2.5}$ exposure is higher in Arkhangelsk (11.9 %) than in Ust-Kamenogorsk (3.9 %), a city with developed metallurgic industry [24]. According to some foreign research, additional number of deaths due to CVDs under $PM_{2.5}$ exposure amounts to 0.072 ‰ in one of the most polluted Iranian cities with developed metallurgic and petrochemical industry [25]. This is considerably lower against Arkhangelsk (2.28 ‰). A study accomplished in an industrially developed area in Northern Italy with intense motor traffic established that cardiovascular mortality caused by $PM_{2.5}$ exposure amounted to 4.33 ‰ [26], which is higher than in Arkhangelsk. In Tallinn, health losses due to cardiovascular incidence caused by $PM_{2.5}$ exposure amounted to 3.38 ‰ [27] additional diseases per year, which was lower than In Arkhangelsk (10.69 ‰).

Conclusion. Ambient air quality in Arkhangelsk conforms to safety standards as per levels of most pollutants. Long-term average annual concentrations of formaldehyde, benzene, chromium and copper did not conform to safety standards; additionally, non-conformity was also established at the upper exposure limit for total solid particles, PM_{10} and $PM_{2.5}$, ozone and benzo(a)pyrene. Risk of general toxic effects was determined as high for the cardiovascular system under exposure to ambient air pollution. Attributable levels of primary cardiovascular incidence caused by PM_{10} and $PM_{2.5}$ exposure amounted to 10.7 and 2.9 ‰ cases per year respectively among adult population in Arkhangelsk. It is necessary to expand lists of chemicals that are subject to monitoring in Arkhangelsk at stationary posts of the Northern Office for Hydrometeorology and Environmental Monitoring so that monitoring programs cover fine-dispersed fractions of solid particles.

Funding. The research was not granted any sponsor support.

Competing interests. The authors declare no competing interests.

References

1. Prüss-Üstün A., Wolf J., Corvalán C., Bos R., Neira M. Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. Geneva, World Health Organization, 2016, pp. 56–60.

2. Li J., Liu F., Liang F., Huang K., Yang X., Xiao Q., Chen J., Liu X. [et al.]. Long-Term Effects of High Exposure to Ambient Fine Particulate Matter on Coronary Heart Disease Incidence: A Population-Based Chinese Cohort Study. *Environ. Sci. Technol.*, 2020. vol. 54, no. 11, pp. 6812–6821. DOI: 10.1021/acs.est.9b06663

3. Kim H., Kim J., Kim S., Kang S.-H., Kim H.-J., Kim H., Heo J., Yi S.-M. [et al.]. Cardiovascular Effects of Long-Term Exposure to Air Pollution: A Population-Based Study With 900 845 Person-Years of Follow-up. *J. Am. Heart Assoc.*, 2017, vol. 6, no. 11, pp. e007170. DOI: 10.1161/JAHA.117.007170

4. Liang R., Chen R., Yin P., van Donkelaar A., Martin R.V., Burnett R., Cohen A.J., Brauer M. [et al.]. Associations of long-term exposure to fine particulate matter and its constituents with cardiovascular mortality: A prospective cohort study in China. *Environ. Int.*, 2022, vol. 162, pp. 107156. DOI: 10.1016/j.envint.2022.107156

5. Xia Y., Liu Z., Hu B., Rangarajan S., Tse L.A., Li Y., Wang J., Hu L. [et al.]. Associations of outdoor fine particulate air pollution and cardiovascular disease: Results from the Prospective Urban and Rural Epidemiology Study in China. *Environ. Int.*, 2023, vol. 174, pp. 107829. DOI: 10.1016/j.envint.2023.107829

6. Qiu H., Sun S., Tsang H., Wong C.-M., Lee R.S.-Y., Schooling C.M., Tian L. Fine particulate matter exposure and incidence of stroke: A cohort study in Hong Kong. *Neurology*, 2017, vol. 88, no. 18, pp. 1709–1717. DOI: 10.1212/WNL.0000000000003903

7. Liu C., Chen R., Zhao Y., Ma Z., Bi J., Liu Y., Meng X., Wang Y. [et al.]. Associations between ambient fine particulate air pollution and hypertension: A nationwide cross-sectional study in China. *Sci. Total Environ.*, 2017, vol. 584–585, pp. 869–874. DOI: 10.1016/j.scitotenv.2017.01.133

8. Pope C.A. 3rd, Burnett R.T., Thurston G.D., Thun M.J., Calle E.E., Krewski D., Godleski J.J. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation*, 2004, vol. 109, no. 1, pp. 71–77. DOI: 10.1161/01.CIR.0000108927.80044.7F

9. Zou L., Zong Q., Fu W., Zhang Z., Xu H., Yan S., Mao J., Zhang Y. [et al.]. Long-Term Exposure to Ambient Air Pollution and Myocardial Infarction: A Systematic Review and Meta-Analysis. *Front. Med. (Lausanne)*, 2021, vol. 8, pp. 616355. DOI: 10.3389/fmed.2021.616355

10. Lv S., Li Z., Li H., Hu Y., Hu M., Li S., Xie W., Li Y. [et al.]. Long-term effects of particulate matter on incident cardiovascular diseases in middle-aged and elder adults: The CHARLS cohort study. *Ecotoxicol. Environ. Saf.*, 2023, vol. 262, pp. 115181. DOI: 10.1016/j.ecoenv.2023.115181

11. Zhang Y., Wang Y., Du Z., Chen S., Qu Y., Hao C., Ju X., Lin Z. [et al.]. Potential causal links between long-term ambient particulate matter exposure and cardiovascular mortality: New evidence from a large community-based cohort in South China. *Ecotoxicol. Environ. Saf.*, 2023, vol. 254, pp. 114730. DOI: 10.1016/j.ecoenv.2023.114730

12. Dong G.-H., Qian Z.M., Xaverius P.K., Trevathan E., Maalouf S., Parker J., Yang L., Liu M.-M. [et al.]. Association between long-term air pollution and increased blood pressure and hypertension in China. *Hypertension*, 2013, vol. 61, no. 3, pp. 578–584. DOI: 10.1161/HYPERTENSIONAHA.111.00003

13. Litvinova N.A., Molotilova S.A. The influence of motor transport emissions on morbidity and health risk of the population of Tyumen city. *Ekologiya cheloveka*, 2018, vol. 25, no. 8, pp. 11–16. DOI: 10.33396/1728-0869-2018-8-11-16 (in Russian).

14. Tsallagova R.B., Kopytenkova O.I., Makoeva F.K. Health risk assessment of population under chronic inhalation exposure of automotive transport emissions. *Profilakticheskaya i klinicheskaya meditsina*, 2021, no. 2 (79), pp. 15–21. DOI: 10.47843/2074-9120_2021_2_15 (in Russian).

15. Tafeeva E.A., Ivanov A.V., Titova A.A. Akhmetzyanova I.F. Air pollutions as a risk factor for the population health in Kazan city. *Gigiena i sanitariya*, 2015, vol. 94, no. 3, pp. 37–40 (in Russian).

16. Suchkov V.V., Semaeva E.A. Air pollution risk to health of the population of the cities Samara and Novokuibyshevsk. *Gigiena i sanitariya*, 2017, vol. 96, no. 8, pp. 729–733. DOI: 10.47470/0016-9900-2017-96-8-729-733 (in Russian).

17. Movchan V., Zubkova P.S., Kalinina I.K., Kuznetsova M.A., Sheinerman N.A. Assessment and forecast of the ecological situation in St. Petersburg in terms of air pollution and public health indicators. *Vestnik Sankt-Peterburgskogo universiteta. Nauki o Zemle*, 2018, vol. 63, no. 2, pp. 178–193. DOI: 10.21638/11701/spbu07.2018.204 (in Russian).

18. Chetverkina K.V. Assessing risks of circulatory disorders among adults exposed to ambient air chemical contamination when living in the Perm region. *Gigiena i sanitariya*, 2020, vol. 99, no. 8, pp. 861–865. DOI: 10.47470/0016-9900-2020-99-8-861-865 (in Russian).

19. Kuzmin S.V., Avaliani S.L., Dodina N.S., Shashina T.A., Kislitsin V.A., Sinitsyna O.O. The practice of applying health risk assessment in the Federal Project “Clean Air” in the participating cities (Cherepovets, Lipetsk, Omsk, Novokuznetsk): problems and prospects. *Gigiena i sanitariya*, 2021, vol. 100, no. 9, pp. 890–896. DOI: 10.47470/0016-9900-2021-100-9-890-896 (in Russian).

20. Grigoriev Yu.I., Lyapina N.V. Hygienic evaluation of air quality and health of the child population of Tula. *ZNiSO*, 2013, no. 8 (245), pp. 29–31 (in Russian).

21. Kulyas V.M. Hygienic assessment of non-carcinogenic and carcinogenic risks to the health of the population of the industrial center from aerogenic pollutants. *Arkhiv klinicheskoi i eksperimental'noi meditsiny*, 2021, vol. 30, no. 1, pp. 55–60 (in Russian).

22. Boev V.M., Kryazheva E.A., Kudusova L.Kh., Kryazhev D.A., Perepelkin S.V. Hygienic assessment of ambient air and non-carcinogenic risk for public health living on border territories. *ZNiSO*, 2019, no. 3 (312), pp. 29–35 (in Russian).

23. Vekovshinina S.A., Kleyn S.V., Zhdanova-Zaplesvichko I.G., Chetverkina K.V. The quality of environment and risk to health of the population residing under the exposure to emissions from colored metallurgy enterprises and wood processing industry. *Gigiena i sanitariya*, 2018, vol. 97, no. 1, pp. 16–20. DOI: 10.18821/0016-9900-2018-97-1-16-20 (in Russian).

24. Tokbergenov E.T., Dosmukhametov A.T., Askarov K.A., Amrin M.K., Askarov D.M., Beisenbinova Z.B. Assessment of aero-genic risks for people living in close proximity to Ulba metallurgical plant. *Health Risk Analysis*, 2022, no. 4, pp. 45–55. DOI: 10.21668/health.risk/2022.4.04.eng

25. Abdolahnejad A., Jafari N., Mohammadi A., Miri M., Hajizadeh Y., Nikoonahad A. Cardiovascular, respiratory, and total mortality ascribed to PM10 and PM2.5 exposure in Isfahan, Iran. *J. Educ. Health Promot.*, 2017, vol. 6, pp. 109. DOI: 10.4103/jehp.jehp_166_16

26. Fattore E., Paiano V., Borgini A., Tittarelli A., Bertoldi M., Crosignani P., Fanelli R. Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy. *Environ. Res.*, 2011, vol. 111, no. 8, pp. 1321–1327. DOI: 10.1016/j.envres.2011.06.012

27. Orru H., Maasikmets M., Lai T., Tamm T., Kaasik M., Kimmel V., Orru K., Merisalu E., Forsberg B. Health impacts of particulate matter in five major Estonian towns: Main sources of exposure and local differences. *Air Qual. Atmos. Health*, 2011, vol. 4, pp. 247–258. DOI: 10.1007/ s11869-010-0075-6

Rastokina T.N., Peshkova A.A., Unguryanu T.N. Ambient air quality and risk of circulatory diseases for population of a large city in the european north of Russia. Health Risk Analysis, 2024, no. 3, pp. 4–12. DOI: 10.21668/health.risk/2024.3.01.eng

Received: 12.04.2024
Approved: 23.09.2024
Accepted for publication: 27.09.2024