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АНАЛИЗ СОСТАВА АТМОСФЕРНОГО ВОЗДУХА И ЕГО АССОЦИАЦИИ С РАЗВИТИЕМ НЕБЛАГОПРИЯТНЫХ СОБЫТИЙ В ЗАВИСИМОСТИ ОТ РАЙОНА ПРОЖИВАНИЯ

Д.П. Цыганкова[1], Е.Д. Баздырев[1], О.В. Нахратова[1], С.В. Кабанова[1], Г.В. Артамонова[1], А.Ю. Просеков[2], О.Л. Барбараш[1]

[1] Федеральное государственное бюджетное научное учреждение «Научно-исследовательский институт комплексных проблем сердечно-сосудистых заболеваний», бульвар имени академика Л.С. Барбараша, 6, Кемерово, Российская Федерация, 650002; [2] Федеральное государственное бюджетное образовательное учреждение высшего образования «Кемеровский государственный университет», ул. Красная, 6, Кемерово, Российская Федерация, 650000

Основные положения

• Загрязнение атмосферного воздуха является одним из ключевых факторов, существенно влияющих на показатели заболеваемости и смертности. В статье представлена оценка загрязнения района проживания и анализ ассоциаций загрязняющих веществ в атмосферном воздухе с развитием неблагоприятных событий.

Цель	Оценить уровень загрязненности районов проживания и выявить ассоциации аэрополлютантов атмосферного воздуха (АВ), с развитием неблагоприятных событий.
Материалы и методы	Уровень загрязняющих веществ АВ анализировались за период 2009–2020 г. Для анализа связи аэрополлютантов с риском развития неблагоприятных событий было включено 2 982 респондента. В качестве неблагоприятных событий оценивали новые случаи дислипидемии, ожирения, сахарного диабета, артериальной гипертензии, инфаркта миокарда, инсульта, нарушения ритма, нестабильную стенокардию, проведение реваскуляризирующих процедур, декомпенсацию и/или верификацию хронической сердечной недостаточности, госпитализацию по поводу кардиальной патологии, смерть.
Результаты	Уровень загрязнения АВ преимущественно расценивается как высокий. К наиболее частым примесям, превышающим ПДК, отнесены бензапирен, диоксид азота, формальдегид и взвешенные вещества. Уровень загрязняющих веществ несколько ниже в сельских районах по сравнению со всеми районами города. Более выраженный уровнем загрязнения был в Заводском и Кировском, в меньшей степени – Ленинском и Центральном районах. На проспективном этапе, несмотря на отсутствие различий по частоте развития инфаркта, инсульта, нарушений ритма, смерти по кардиоваскулярным причинам, были получены статистически значимые различия по объединению вышеуказанных случаев. Выявлен более неблагоприятный профиль у респондентов, проживающих в Ленинском районе. У жителей села, Рудничного района – более благоприятный профиль, в Заводском и Кировском районах – наоборот. При анализе латентных факторов, характеризующие совокупность загрязняющих веществ, оказывающих наибольшее влияние на состояние здоровья выявлены ассоциации между составом примесей атмосферного воздуха и развитием неблагоприятных исходов в проспективном наблюдении.
Заключение	Состояние АВ в районах проживания оценено как неблагоприятное; содержание примесей в атмосферном воздухе ассоциируется с появлением новых случаев гипертонии, дислипидемии, диабета и ожирения у ранее здоровых лиц, а также с риском развития новых случаев всех сердечно-сосудистых событий.
Ключевые слова	Экология • Аэрополлютанты • Загрязнение атмосферного воздуха • Окружающая среда • Качество воздуха • Экологическое воздействие • Неблагоприятные события

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Для корреспонденции: *Дарья Павловна Цыганкова, darjapavlovna2014@mail.ru; адрес: бульвар имени академика Л.С. Барбараша, 6, Кемерово, Российская Федерация, 650002*
Corresponding author: *Darya P. Tsygankova, darjapavlovna2014@mail.ru; address: 6, academician Barbarash blvd., Kemerovo, Russian Federation, 650002*

ANALYSIS OF ATMOSPHERIC AIR COMPOSITION AND ITS ASSOCIATION WITH THE DEVELOPMENT OF ADVERSE EVENTS DEPENDING ON THE AREA OF RESIDENCE

D.P. Tsygankova[1], E.D. Bazdyrev[1], O.V. Nakhratova[1], S.V. Kabanova[1], G.V. Artamonova[1], A.Yu. Prosekov[2], O.L. Barbarash[1]

[1] Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", 6, academician Barbarash blvd., Kemerovo, Russian Federation, 650002; [2] Federal State Budgetary Educational Institution of Higher Education "Kemerovo State University", 6, Krasnaya St., Kemerovo, Russian Federation, 650000

ORIGINAL STUDIES

Highlights

• Atmospheric air pollution is one of the key factors that significantly affect morbidity and mortality rates. The article presents an assessment of the pollution of residential areas and an analysis of the associations of air pollutants with the development of adverse events.

Aim	To assess the level of pollution in residential areas and identify associations between airborne air pollutants and adverse events.
Methods	Airborne air pollutant levels were analyzed for the period 2009–2020. A total of 2,982 respondents were included in the study to analyze the association between airborne pollutants and the risk of adverse events. Adverse events were assessed as new cases of dyslipidemia, obesity, diabetes, hypertension, myocardial infarction, stroke, arrhythmia, unstable angina, revascularisation procedures, decompensation and/or verification of chronic heart failure, hospitalization for cardiac pathology, and death.
Results	Airborne air pollution levels are predominantly considered high. The most common contaminants exceeding the maximum permissible concentrations include benzopyrene, nitrogen dioxide, formaldehyde, and suspended solids. Pollutant levels were somewhat lower in rural areas compared to all city districts. Pollution levels were more pronounced in the Zavodskoy and Kirovsky districts, and to a lesser extent in the Leninsky and Tsentralny districts. At the prospective stage, despite the absence of differences in the incidence of heart attack, stroke, arrhythmia, or cardiovascular death, statistically significant differences were observed when combining the above-mentioned cases. A more unfavorable profile was revealed among respondents living in the Leninsky district. Residents of the village and Rudnichny district had a more favorable profile, while the opposite was true in the Zavodskoy and Kirovsky districts. An analysis of latent factors characterizing the combination of pollutants with the greatest impact on health revealed associations between the composition of atmospheric impurities and the development of adverse outcomes in prospective observation.
Conclusion	The air quality in the districts of residence was assessed as unfavorable; The content of impurities in atmospheric air is associated with the occurrence of new cases of hypertension, dyslipidemia, diabetes and obesity in previously healthy individuals, as well as with the risk of developing new cases of all cardiovascular events.

Keywords	Ecology • Airborne pollutants • Atmospheric air pollution • Environment • Air quality • Environmental impact • Adverse events

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Список сокращений

BaP	– benzopyrene	NO	– nitrogen oxide
CI	– confidence interval	NO2	– nitrogen dioxide
CO	– carbon monoxide	OR	– odds ratio
CVD	– cardiovascular diseases	SO2	– sulfur dioxide
FDH	– ammonia, formaldehyde	SS	– suspended solids
MPC	– maximum permissible concentration		

Introduction

Atmospheric air pollution is one of the key factors that significantly affect morbidity and mortality rates. Despite the fact that air pollution carries a relatively lower risk compared to traditional factors (such as tobacco smoking, high blood lipids, high blood pressure, etc.), it remains a serious issue for public healthcare due to its global spread. Some studies emphasize that the environmental factor surpasses other modifiable risks (insufficient physical activity, unbalanced diet with excessive salt intake and elevated cholesterol) in terms of the degree of impact on human health [1].

Anthropogenic sources of air pollution include vehicles powered by diesel and gasoline, industrial emissions, coal-based energy production, as well as indoor and household pollution (cooking, smoking) [2, 3]. Atmospheric air pollution is a multicomponent mixture of solid particles and gaseous substances. Solid particles, known as aerosols, vary in size and chemical composition, and may contain metals, elemental carbon, organic and inorganic compounds such as nitrates and sulfates, as well as other impurities. There are many studies demonstrating the negative impact of fine particulate matter on cardiovascular health [4–6], but there are fewer studies on the effect of gaseous substances in air on cardiovascular outcomes and they are limited to the analysis of ozone. Even though gaseous pollutants are clearly associated with lung diseases, they can also have adverse effects on the cardiovascular system [7].

Everyday population is being exposed to the air pollutant complex present in the atmospheric air. The formation of this complex is due to the influence of local and regional sources of pollution, meteorological conditions, as well as anthropogenic factors such as urban development and vegetation. According to the results of the Global Burden of Disease study, about 60% of all morbidity and mortality cases associated with air pollution are represented by cardiovascular diseases (CVD). Large-scale epidemiological studies conducted in various regions of the world have established a statistically significant correlation between the level of air pollution and an increased risk of developing diseases such as arterial hypertension, diabetes mellitus and calcification of the coronary arteries. Moreover, an increase in the concentration of pollutants in the atmosphere correlates with an increase in the incidence of coronary artery disease, stroke, chronic heart failure, and an increase in mortality from these pathologies [8–11].

Air pollution is not an isolated event, it is part of a complex system influenced by many other external environmental factors interacting with internal biological factors and predisposition that ultimately determines the cardiovascular and metabolic consequences. It is necessary to develop reliable approaches to minimize negative impact on climate change and limit the harmful effects of air pollution while focusing on the most vulnerable groups of the population [12]. The concept of “One Health” has acquired key importance in public healthcare, emphasizing strong relationship between population health and the environment [13], so its implementation will make it possible to effectively solve large-scale problems in healthcare that go beyond the usual framework and require interdisciplinary approach.

The **aim of this study** was to assess the air pollution in residential areas and analyze the associations between airborne pollutants and the development of adverse events.

Methods

The object of the study was the adult population. The research was conducted in the large industrial center of Western Siberia, a subject of the Russian Federation. The unit of study is a participant of the epidemiological study. The sample consisted of 2.998 participants of the “Epidemiology of cardiovascular diseases and their risk factors in the regions of the Russian Federation” (ESSE-RF) study (n = 1.555) and “Prospective Urban Rural Epidemiology” (PURE) study (n = 1.443), 16 respondents were removed due to missing data. Overall, 2.982 people were included in the final analysis. In accordance with the study design, the baseline (2012–2016) and four prospective follow-ups (2015, 2017, 2019, 2021) were completed according to the research protocols.

During the baseline follow-up, our specialists collected and evaluated clinical and anamnestic data on cardiovascular risk factors, concomitant diseases, air pollution, and the area of residence. During the prospective follow-up, the specialists assessed respondents` cardiovascular risk factors, previously undiagnosed circulatory system diseases, oncological diseases, cardiovascular risk factors (dyslipidemia, obesity), adverse cardiovascular events, in particular new onset of hypertension, myocardial infarction, stroke, atrial fibrillation paroxysm, unstable angina, revascularisation procedures, decompensated and/or verified chronic heart failure, hospitalization for CVD, death.

The environmental factor assessment included an analysis of air pollution from stationary sources for the period 2009–2020. The assessment of air quality was carried out using official reports. The analysis included the average annual concentrations of the following pollutants: suspended solids (SS), sulfur dioxide (SO2), carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO2), phenol, hydrochloride, black carbon (soot), ammonia, formaldehyde (FDH), benzopyrene (BaP). The authors analyzed concentrations of these airborne pollutants using the data of regular measurements of air impurities made by environmental monitoring posts, taking into account the area of residence. Due to the lack of regular monitoring of air pollutants for rural areas, the authors used data obtained by calculation.

The majority of the studied population was made up of urban residents who were three times more numerous compared to residents of rural areas. Respondents were divided into different districts groups based on the residential address. The number of men and women in the analyzed areas was approximately equal.

The average age of 2 982 respondents was 52 years, the predominant gender was female, the characteristics of the respondents are presented in Table 1.

Compliance with ethical standards

Data of the two following epidemiological studies were used for publication: “Epidemiology of cardiovascular diseases and their risk factors in the regions of the Russian Federation” (ESSE-RF) study and “Prospective Urban Rural Epidemiology” (PURE) study. The research protocol received approval by the Institutional Review Boards both for the PURE study (extract from the Protocol of the Institutional Review Board of Research Institute for Complex Issues of Cardiovascular Diseases No. 12 dated July 10, 2015) and for the ESSE-RF study (extract from the Protocol of the National Review Board No. 107-03/12 dated July 03, 2012 of the National Medical Research Center for Therapy and Preventive Medicine). The study was conducted in accordance with the Helsinki Declaration. Prior to being included in the study, all respondents signed an informed consent form.

Statistical data processing

Statistical processing of the results was carried out using the “Statistica 6.0” software dated 31.03.2010 №AXXR003E608729FAN10. The Kolmogorov–Smirnov test was applied to test for a normal distribution. Quantitative variables were represented as medians, percentiles [Me (Q25; Q75)] were used as dispersion measures, and percentages (%) were used to describe qualitative variables. To compare quantitative variables (baseline and prospective indicators) the authors used Mann-Whitney, Kruskal–Wallis, and Wilcoxon tests; to compare qualitative indicators we used Pearson`s chi-squared test (with Yates’ correction for small groups). Factor analysis using the principal component method was used to identify latent factors. The relationship between factors influencing adverse outcomes and air pollutants was assessed using logistic regression analysis. The presence and strength of relationship were assessed by the odds ratio (OR) and the 95% confidence interval (CI). The significance level when testing statistical hypotheses in the study was < 0.05.

Results

The level of pollution in the urban area for the period 2009–2020 is assessed as high, taking into account the total atmospheric pollution index, which is calculated for the five most common pollutants (SS, SO2, CO, NO2 and FDH) and their hazard class, quality standard and average levels of air pollution. It was very high in 2012, and increased even more in 2014.

It is rather difficult to draw a conclusion on the number of impurities in the air in rural areas because the average annual concentrations for the pollutants in these locations were calculated based on a one-time measurement, according to the official data provided. Moreover, some air pollutants were mentioned in the reports at all. However, when comparing the median concentrations of air impurities, the content of NO (0.0369 versus 0.0400 mg/m^3) and NO2 (0.0371 versus 0.0564 mg/m^3), as well as BaP (0.000002 versus 0.000003 mg/m^3) was lower in rural areas compared to urban areas. At the same time, the concentration of SS (0.1882 versus 0.04800 mg/m^3), SO2 (0.017880 versus 0.005050 mg/m^3) and FDH (0.0160 versus 0.0065 mg/m^3) in rural areas exceeded the concentrations of same pollutants in urban areas.

During the analyzed period (2009–2020), BaP, FDH, NO2 and soot were the main pollutants in the urban area that exceeded the maximum permissible

Table 1. Clinical and anamnestic characteristics of the respondents

Clinical and anamnestic characteristics	Number of responders, n = 2 982
Age, years, Me (Q25; Q75)	52.0 (41.5; 59.0)
Male/Female, n (%)	1 074 (36)/1 908 (64)
Smoking, n (%)	1 380 (46.3)
Alcohol consumption, n (%)	1602 (53.7)
Body mass index, kg/m^2, Me (Q25; Q75)	28 (24.0; 31.0)
Stable angina pectoris, n (%)	539 (18.1)
Prior myocardial infarction, n (%)	155 (5.2)
Prior stroke, n (%)	125 (4.2)
Cardiac arrhythmias, n (%)	387 (13)
Arterial hypertension, n (%)	2 056 (68.9)
Chronic heart failure, n (%)	199 (6.7)
Obesity, n (%)	1 151 (38.6)
Overweight, n (%)	893 (29.9)
Type 2 diabetes mellitus, n (%)	199 (6.7)
Carbohydrate metabolism disorders, n (%)	665 (22.3)
Lung diseases (chronic obstructive pulmonary disease, bronchial asthma), n (%)	354 (11.9)
Dyslipidemia, n (%)	1 446 (48.5)
Oncological diseases, n (%)	131 (4.4)

concentrations (MPC), the medians of which exceeded MPC (Table 2).

It should be noted that only BaP exceeded MPC throughout the whole analyzed period, whereas FDH exceeded MPC from 2009 to 2013, NO2 from 2009 to 2015 and in 2019, and soot in the first three years of the analyzed period. Assessing the situation in the urban area as a whole, there was a more than 15-fold decrease in the concentration of soot, 2.3-fold decrease in NO and dioxide, and 2-fold decrease in ammonia and hydrochloride ($p < 0.0001$). There was a slightly lower and statistically significant 1.7 times decrease in NO, and 1.2–1.3 times decrease in phenol, SO2 and BaP ($p = 0.0001$). Moreover, there was a 1.5-fold increase in the concentration of SS and a 1.7-fold increase in FDH ($p < 0.0001$).

FDH reached the maximum one-time concentration exceeding MPC by 1.4 times in 2009 and 2012 in the Leninsky city district. Despite the fact that the average annual concentration of phenol in this urban area in 2014 and 2017 did not exceed MPC, highest one-time concentrations of phenol exceeded MPC by 3.7 and 2.3 times, respectively. Similarly, the concentration of soot exceeded MPC by 2.9 times in 2015. The Leninsky city district had a statistically significant decrease in the concentration of NO by 5.3 times over the entire period ($p < 0.0001$), SS by 2 times ($p < 0.0001$), ammonia by 2.3 times ($p < 0.0001$), BaP by 3 times ($p < 0.0001$), SO2 and phenol by 13 times ($p < 0.0001$), soot by 14 times ($p < 0.0001$), and a decrease in the concentration of hydrochloride from 0.04 to 0.00022 mg/m^3 ($p = 0.0002$). Moreover, there was an increase in the level of pollution via impurities such as NO2 (by 1.3 times, $p < 0.0001$) and FDH (by 1.6 times, $p < 0.0001$).

In the Central city district NO exceeded maximum permissible one-time concentration in 2013 (MPC exceeded by 1.6 times), as well as NO2 (MPC exceeded by 2.3 times) and SS (MPC exceeded by 2.8) in 2015, soot (MPC exceeded by 6.2 times) and NO2 (MPC exceeded by 1.1 times) in 2016. In addition, BaP reached the maximum monthly average concentration, exceeding MPC by 9.7 times in 2014. There was a statistically significant decrease in the concentration of NO by 9 times over the entire period ($p < 0.0001$), hydrochloride by 2.7 times ($p < 0.0001$), phenol and hydrochloride by 1.7 times ($p < 0.0001$), ammonia ($p < 0.0001$), SO2 ($p < 0.0001$) and BaP by 1.3 times ($p < 0.0001$). At the same time, the concentration of NO2 increased by 2 times ($p < 0.0001$), SS by 1.6 times ($p < 0.0001$) and FDH by 1.7 times ($p < 0.0001$).

Table 2. Air pollutants exceeding the maximum permissible concentration in the urban area for the period of 2009–2020

Year	Pollutants (MPC)			
	Benzopyrene	Formaldehyde	Nitrogen dioxide	Black carbon
2009	2.9	1.1	1.8	1.1
2010	3.4	1.1	1.5	1.1
2011	3.3	2.7	1.5	1.2
2012	3.1	3.3	1.6	N
2013	2.4	3.2	1.3	N
2014	1.5	N	1.5	N
2015	2.1	N	1.5	N
2016	2.1	N	N	N
2017	3.1	N	N	N
2018	3.4	N	N	N
2019	2.7	N	1,1	N
2020	2.9	N	N	N

Note: *N – MPC is not exceeded.*

In the Rudnichny city district, despite the fact that the average annual concentration of CO, NO2, and FDH did not exceed MPC in 2017–2019, the following pollutants exceeded the maximum permissible one-time concentrations and MPC repeatedly: CO exceeded MPC by 1.7 times in 2017, NO2 exceeded MPC by 3 times, FDH exceeded MPC by 1.7 times, and CO exceeded MPC by 2.4 times in 2018, NO exceeded MPC by 2 times in 2019. Statistically significant decrease in the concentration of ammonia by 46 times ($p < 0.0001$), soot by 17 times ($p < 0.0001$), BaP by almost four times, hydrochloride, NO and NO2, FDH and CO by more than two times (p from 0.00012 to < 0.0001). There was a slightly lower decrease in phenol (1.5 times) and SO2 (1.3 times). Moreover, there was a negative trend regarding the concentration of SS, the median of which increased more than fourfold (4.2 times, $p < 0.0001$).

In the Zavodsky city district the average annual concentration of NO2 increased with time (MPC exceeded by 2.4 times in 2009, by 2 times in 2010, by 2.2 times in 2011, by 2 times in 2012, by 1.8 times in 2013, by 1.5 times in 2015 and 2016, by 2 times in 2017). Whereas BaP (MPC exceeded by 6.1 times in 2009, by 7.4 times in 2010, by 18 times in 2011, by 11 times in 2012) and FDH (MPC exceeded by 1.3 times in 2013) reached the maximum monthly average concentrations. The maximum one-time concentrations of soot exceeded MPC by 4.7 times in 2009, by 4.5 times in 2011, by 3.8 times in 2012, NO2 exceeded MPC by 2.4 times in 2019, and FDH exceeded MPC by 1.1 times in 2014. The most favorable years from the point of view of lower pollution levels were 2018 and 2020, when there were no MPC excesses. Estimating the concentrations of impurities in the air, we noted an increase in the concentration of SO2 by 2.8 times, FDH by 2.2 times, phenol by 1.4 times and SS by 1.3 times ($p < 0.0001$). However, the level of soot decreased statistically significantly by 10 times, ammonia by more than two times (2.3 times, $p < 0.0001$), NO and NO2, hydrochloride, BaP, and CO by 1.3 to 1.8 times.

The Kirovsky city district had the maximum of all the average monthly concentrations (MPC exceeded by 20.4 times in 2015, by 13.9 times in 2016, by 19.8 times in 2017, by 10 times in 2018, by 14.6 times in 2019), with BaP having the maximum one-time concentration (MPC exceeded by 5.2 times in 2013). In addition, the following pollutants reached the maximum one-time concentrations: NO2 (MPC exceeded by 4.3 times in 2012, by 2.9 times in 2014, by 2.7 times in 2020), soot (MPC exceeded by 3.5 times in 2013), SS (MPC exceeded by 3.0 times in 2017, by 2.4 times in 2019) and NO (MPC exceeded by 1.8 times in 2020). The Kirovsky city district had a decrease in the concentration of NO, NO2, ammonia, and SO2 over the entire period, however, changes in this indicator as a whole were statistically insignificant ($p = 1.00$). On the other hand, a decrease in soot concentration by 13 times ($p < 0.0001$) was statistically significant. At the same time, there was a 3.5-fold increase in SS, 1.7-fold increase in FDH ($p < 0.0001$).

During 2009–2014, the average annual concentrations of BaP decreased by 2.3 times, soot decreased by 1.6 times, whereas NO2 remained within values exceeding MPC by 1.3–1.6 times. The average annual concentrations of FDH over this period varied unevenly: the maximum concentration in 2012 exceeded MPC by 3.3 times, the minimum in 2014 exceeded MPC by 0.8 times. A sharp decrease in the average annual concentration of FDH in 2014 was associated with the introduction of new sanitary and hygienic standards for air impurities. For the period 2015–2020 the average annual concentration of BaP increased by 1.4 times, SS by 1.3 times; NO2 decreased by 1.3 times. Thus, the level of air pollution in the city for the period 2009–2020 is regarded as high. BaP, NO2, FDH and SS has been classified as the most frequent air impurities exceeding MPC during the analyzed period. Among the administrative districts of the city, the Zavodsky and Kirovsky city districts have been deemed as the most unfavorable districts with a pronounced level of air pollutants. The Leninsky and Central city districts turned out to be relatively safe, where rare MPC excesses are associated with certain substances such as FDH and phenol.

Despite the limited official data on the level of pollution in rural areas, the air quality was characterized by lower concentrations of NO, NO2, and BaP compared with the indicators of the urban area as a whole. However, one can note a higher content of SS, SO2 and FDH, which does not allow us to unequivocally assert better air quality in rural areas over urban areas, since there are multidirectional trends in pollution.

Taking into account the selected residential areas, comparative analysis results showed that there were significant differences in concentrations of air pollutants between urban and rural areas. In general, levels of pollutants were slightly lower in rural areas compared to all urban areas. This is due to the lower number of industrial enterprises, traffic flows and other anthropogenic environmental factors in rural areas. In addition, there were differences in changes in concentrations of individual pollutants within urban areas – for example, a significant reduction in the levels of certain toxic components (such as soot, ammonia, BaP) was associated with an increase in the content of other potentially dangerous compounds (FDH, SS).

According to the baseline clinical and anamnestic characteristics of the respondents, taking into account the area of residence, there were no statistically significant differences between them at baseline, with the exception of the frequency of alcohol consumption and overweight or obesity cases. Thus, the largest percentage of people who consume alcohol reside in the Leninsky (34.89%) and Rudnichny (24.78%) city districts, rural areas (24.03%), slightly less in the Central city district (15.11%). The lowest percentage of alcohol drinkers live in the Zavodsky and Kirovsky districts (1% and 0.19%, respectively, $p = 0.0000$). A similar situation can be seen in case with the incidence of overweight and obesity (Leninsky city district 36.89%, Rudnichny city district 24.32%, rural area (25.78%), Central city district 12.18%, Zavodsky city district 0.88%, and Kirovsky city district 0.15%, $p = 0.00000$).

During the prospective follow-up, the development of the analyzed adverse events for individual nosologies did not show statistical differences when taking into account the area of residence, with the exception of new onset of hypertension, angina pectoris, heart failure, diabetes, cancer, and the frequency of hospitalizations due to circulatory system diseases. Despite the absence of differences in the incidence of myocardial infarction, stroke, rhythm disturbances, and death from cardiovascular causes, statistically significant differences were obtained for the composite endpoint combining the above-mentioned cases (Table 3). The authors noticed that by the end of the follow-up there was a negative trend towards a more unfavorable health profile among respondents living in the Leninsky and Rudnichny city district, and rural areas, whereas the Zavodsky and Kirovsky city districts had a more favorable profile in terms of the development of adverse events.

Using principal component method, we identified latent factors that characterize the totality of pollutants that have the greatest impact (increasing or decreasing the risk of adverse events) on the health of the population, depending on the area of residence. It should be noted that it was not possible to identify the association of the identified factors with the analyzed outcomes over the entire 12-year period (Tables 4 and 5).

Thus, SS, ammonia, and NO were classified as risk increasing factors (factor 1), and NO2, SO2, CO, and NO were classified as risk decreasing factors (factor 2) in 2014. It should be noted that both types of risk factors were present in respondents residing in the Central city district. However, the logistic regression analysis did not reveal a statistically significant effect of latent

Table 3. The development of adverse events among respondents according to the data of follow-up, taking into account the area of residence (%)

Adverse events during follow-up	Area of residence							
	Rural area n = 688 (23.1%)	Urban area n = 2 294 (76.9%)	Leninsky city district n = 1 091 (36.6%)	Central city district n = 380 (12.7%)	Rudnichny city district n = 780 (26.2%)	Zavodsky city district n = 38 (1.3%)	Kirovsky city district n = 5 (0.1%)	P
New cases of CVD risk factors (dyslipidemia, obesity, hypertension, diabetes)	29.87	70.13	32.47	20.13	16.88	0.00	0.65	0.00011
New onset of arterial hypertension	25.17	74.83	37.17	12.10	24.44	0.97	0.15	0.00004
New onset of angina pectoris	25.45	74.55	41.82	10.00	22.42	0.30	0.00	0.05262
New onset of heart failure	29.01	70.99	32.10	17.28	21.60	0.00	0.00	0.01415
New onset of diabetes	29.36	70.64	34.30	14.24	20.35	1.74	0.00	0.00137
Hospitalization for cardiovascular diseases	26.50	73.50	35.61	14.81	22.79	0.28	0.00	0.01441
New cases of significant CVD (stroke, myocardial infarction, unstable angina, hospitalization for chronic heart failure and rhythm disorders, death due to heart disease)	24.84	75.16	37.69	12.40	23.84	1.04	0.18	0.00000
New onset of oncological pathology	19.71	80.29	51.09	11.68	15.33	2.19	0.00	0.00900

Note: *CVD – cardiovascular diseases.*

Table 4. The results of a factor analysis characterizing the totality of pollutants that have the greatest impact on public health, depending on the area of residence

Average annual concentration of air pollutant	2014		2015		2017		2018		2019		2020	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Nitrogen dioxide	–0.069201	0.997603	0.016878	0.999858	0.023046	0.988225	–0.693081	0.592516	N/A	N/A	0.001754	0.999997
Ammonia	–0.999975	–0.007141	N/A	N/A	0.023046	0.988225	N/A	N/A	0.943911	0.329816	0.999540	0.000898
Benzopyrene	N/A	N/A	N/A	N/A	0.948945	–0.081542	N/A	N/A	–0.360667	0.932206	0.968102	0.008330
Suspended substances	0.999975	0.007141	0.016878	0.999858	–0.543314	0.142323	0.419011	0.793329	–0.540400	–0.841388	0.999540	0.000898
Hydrochloride	N/A	N/A	0.996397	–0.084817	N/A	N/A	N/A	N/A	N/A	N/A	0.999540	0.000898
Sulfur dioxide	–0.414258	–0.910160	–0.506735	0.862102	–0.516036	0.364071	–0.566992	0.781179	N/A	N/A	0.999540	0.000898
Phenol	N/A	N/A	N/A	N/A	0.008573	0.987809	–0.974898	0.022394	0.861461	0.507730	0.999540	0.000898
Black carbon (soot)	N/A	N/A	N/A	N/A	0.956551	0.030474	0.958936	–0.133266	–0.995760	–0.089150	–0.999540	–0.000898
Carbon monoxide	–0.069201	0.997603	0.971903	–0.235383	0.923782	0.298861	0.063766	–0.335148	0.997415	0.068013	–0.999540	–0.000898
Formaldehyde	N/A	N/A	N/A	N/A	– 0.524122	0.457996	–0.964253	0.027156	0.972143	–0.220068	0.999540	0.000898
Nitric oxide	0.597355	0.801977	0.997715	0.067570	0.037219	0.006034	N/A	N/A	0.720686	0.693259	N/A	N/A

Note: *N/A – not applicable, the pollutant is not included in the model.*

factors over the analyzed year on the outcomes.

In 2015 latent factor 1 was mainly represented by the content of hydrochloride, NO and CO, factor 2 by NO2, SS and SO2. If the risk increasing factor (factor 1) was typical for residents of the Central city district, then the risk decreasing factor (factor 2) was typical for residents of the Leninsky city district (91.76% and 93.45%, respectively). Similarly to 2014, there were no statistically significant associations between the impact of latent factors and the outcomes in 2015.

According to the results of the analysis in 2017, such impurities as CO, soot, and BaP were attributed to latent factor 1, and this factor was found in 99.62% of residents of the Leninsky city district. Phenol, ammonia, and NO2 were attributed to the latent factor 2 and it was found in 95.43% of residents of the Rudnichny and 4.07% of Zavodsky city districts. Logistic regression analysis revealed that factor 1 was associated with the risk of developing all cardiovascular events over the entire follow-up period (OR = 1.5, 95% CI:1.1–2.1, p = 0.010), stroke (OR = 2.6, 95% CI:1.4–4.8, p = 0.003). Factor 2 was associated with a reduced risk of stroke (OR = 0.4, 95% CI: 0.2–0.7, p = 0.003) and all cardiovascular events over the entire follow-up period (OR = 0.6, 95% CI: 0.5–0.9, p = 0.010).

In 2018 the first latent factor was mainly characterized by the content of soot, FDH, and phenol, while the second was characterized by SS and SO2. Factor 1 caused a negative impact on residents of the Rudnichny city district in half of the cases, (51.01%), to a lesser degree it affected the residents of the Leninsky and Central city districts (27.63% and 21.36%, respectively). Factor 2 was predominantly found in residents of the Leninsky (54.36%) and Rudnichny city districts (32.38%). Logistic regression analysis demonstrated that factor 1 was associated with the risk of heart failure (OR = 2.7, 95% CI:1.7–4.3, p = 0.00003), new onset of cardiovascular risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals (OR = 5.2, 95% CI:2.9–9.4, p < 0.0001), whereas factor 2 was associated with a reduced risk of new onset of CVD risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals (OR = 0.2, 95% CI:0.1–0.3, p < 0.0001), heart failure (OR = 0.4, 95% CI: 0.2–0.6, p = 0.00003).

In 2019 factor 1 included a combination of NO, ammonia, FDH, CO, soot, and phenol, and had an impact mainly on residents of the Central city district (90.80%). While factor 2 was represented by NO, BaP and SS, and had an impact mainly on residents of the Rudnichny city district (95.42%). The logistic regression analysis revealed that factor 1 was associated with the risk of developing new cases of significant CVD (including death from CVD, OR = 6.4, 95% CI:1.05–39.3, p = 0.040), new cases of CVD risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals (OR = 2.8, 95% CI:1.2–6.8, p = 0.020), heart failure (OR = 2.5, 95% CI:1.2–5.2, p = 0.015). Factor 2 was associated with a reduced risk of new cases of significant CVD (including death from CVD, OR = 0.1, 95% CI:0.02–0.9, p = 0.043), new onset of CVD risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals (OR = 0.3, 95% CI:0.1–0.8, p = 0.020), heart failure (OR = 0.4, 95% CI:0.2–0.8, p = 0.015).

In 2020 the first latent factor included ammonia, BaP, SS, hydrochloride, SO2, phenol, soot and FDH. It impacted residents of the Rudnichny and Central city districts more frequently (84.45% and 13.96%, respectively). The second latent factor included only NO2, which affected 99.64% of the residents of the Rudnichny city district. At the same time, factor 1 was associated with the risk of heart failure (OR = 5.85, 95% CI:2.1–16.5, p = 0.001), new onset of CVD risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals (OR = 20.9, 95% CI:

Table 5. Distribution of respondents by area of residence, taking into account the impact of latent factors, n (%)

Area of residence	2014		2015		2017		2018		2019		2020	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Rural area	0 (0.0)	2 (2.33)	2 (2.35)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (2.30)	0 (0.0)	2 (0.35)	0 (0.0)
Urban area	15 (5.07)	4 (4.65)	4 (4.71)	371 (93.45)	263 (99.62)	4 (0.51)	260 (27.63)	455 (54.36)	4 (4.60)	4 (0.51)	7 (1.24)	1 (0.36)
Central city district	276 (93.24)	79 (91.86)	78 (91.76)	21 (5.29)	1 (0.38)	0 (0.0)	201 (21.36)	79 (9.44)	79 (90.80)	0 (0.0)	79 (13.96)	0 (0.0)
Rudnichny city district	0 (0.0)	1 (1.16)	1 (1.18)	0 (0.0)	0 (0.0)	751 (95.43)	480 (51.01)	271 (32.38)	2 (2.30)	750 (95.42)	478 (84.45)	274 (99.64)
Zavodsky city district	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	32 (4.07)	0 (0.0)	32 (3.82)	0 (0.0)	32 (4.07)	0 (0.0)	0 (0.0)
Kirovsky city district	5 (1.69)	0 (0.0)	0 (0.0)	5 (1.26)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Note: *N/A – not applicable, the pollutant is not included in the model.*

2.8–154.7, p = 0.003). Whereas factor 2 was associated with a reduced risk of new onset of CVD risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals (OR = 0.05, 95% CI:0.01–0.3, p = 0.003), heart failure (OR = 0.2, 95% CI: 0.1–0.5, p = 0.001).

Discussion

In accordance with the State Report entitled "On the state of sanitary and epidemiological welfare of the population in the Russian Federation in 2020" [14], there has been a steady decline in a number of unsatisfactory atmospheric air samples exceeding MPC in populated areas of the Russian Federation over the ten years (2011–2020). Compared to the level of 2011, this indicator decreased by 1.86 times. During the specified period, the indicator decreased by 1.84 times (from 1.53% to 0.83%) in urban areas, and by 1.6 times (from 0.72% to 0.45%) in rural areas. This has had a positive effect on reducing the number of residents living in unfavorable environmental conditions. Over the past decade, the complex chemical burden on the population has decreased by almost 1.3 times, with an average annual decrease of 3.5%. However, despite the positive dynamics, the region considered in this study is a large industrial center of Western Siberia and is included in the list of subjects of the Russian Federation where air samples regularly exceed level 5 of MPC for various pollutants (airborne pollutants) [14].

The findings revealed that during the twelve-year follow-up, the level of air pollution in the territory is regarded as high due to exceeding MPC. In addition, the average annual concentrations of pollutants vary over different periods: some decrease, others increase. The latent factors we have identified confirm that the environmental component needs to be assessed using an integrated approach. Latent factors have different effects in different areas of the city. The influence of pollutants weakens over time. Latent factors from 2017–2020 were associated with many outcomes and risk factors (heart failure, new cases of cardiovascular risk factors (hypertension, dyslipidemia, diabetes, obesity) in previously healthy individuals. It is noteworthy that MPC excesses take place in two districts of the city, but the frequency of adverse outcomes in residents of these districts is lower compared to the other districts. At the same time residing in the two more environmentally friendly areas of the city is associated with a high risk of adverse events. This feature can be explained by the results of factor analysis, in particular, the impact of an unfavorable latent factor on a larger number of people living in these areas. The same analysis also showed a minimal number of residents affected by airborne pollutants in ecologically unfavorable areas.

The results obtained in the course of this study are consistent with a number of previous studies. Thus, exposure to particulate matter (suspended solids) can exacerbate risk factors (for example, increase blood pressure and glucose levels) and even contribute to the earlier development of chronic cardiometabolic diseases (for example, hypertension and diabetes) in previously healthy people [8, 15]. Dong G.H. and co-authors [16] have found that obesity strengthened the association between prolonged exposure to polluted air and high blood pressure and hypertension. Wu Q.Z. and co-authors [17] have found a similarly strong relationship between the exposure to polluted air and high blood pressure even in young children (up to 11 years old) and especially in overweight or obese children. A cohort study including children and adults in Taiwan has showed that prolonged exposure to pollutants is associated with increased levels of apolipoprotein B, triglycerides, and decreased levels of high-density lipids [28]. In addition, a longitudinal study of 465 mother-child couples in Mexico have found that exposure to particulate matter in the third trimester of pregnancy is associated with increased levels of total cholesterol, low-density lipidic cholesterol, and non-high-density lipidic cholesterol [19].

Potential biological mechanisms by which pollutants negatively affect the cardiovascular system include contact with lung and immune cells (for example, resident macrophages, alveolar cells), neuronal receptors entering the systemic bloodstream, which in turn can lead to disruption or dysfunction of the endothelial barrier, and inflammation of tissues (blood vessels or adipocytes), increased blood clotting and thrombosis, the likelihood of arrhythmias and reactions, caused by autonomic imbalance or activation of the hypothalamic-pituitary-adrenal system (for example, vasoconstriction and increased blood pressure), secondary tissue damage (leading to plaque instability) [2, 16, 20].

Limitations of the study

First of all, the study employed a calculation method for analyzing concentrations of air impurities in rural areas. Secondly, the study included a small number of respondents from the Zavodsky and Kirovsky city districts. Finally, the data regarding the duration of residence in the area is absent, and territorial affiliation is not taken into account (the area of the city may not coincide with the place of residence or work).

Conclusions

The level of atmospheric air pollution in the industrial region of Russian Federation in terms of concentrations of nitrogen oxide and dioxide, benzopyrene in rural areas is lower compared to urban areas, however, concentrations of suspended solids, sulfur dioxide and formaldehyde exceed the same indicators in the city. The results of prospective follow-up of respondents residing in different areas of the city revealed that there are differences in the average annual concentrations of pollutants in different areas of the city, and associations between the composition of atmospheric air impurities and the development of adverse outcomes result in different effects of latent factors. Among the adverse outcomes, the following were significant: new onset of cardiovascular risk factors, significant cardiovascular events, and oncological diseases.

Conflict of interest

D.P. Tsygankova declares no conflict of interest. E.D. Bazdyrev declares no conflict of interest. O.V. Nakhratova declares no conflict of interest. S.V. Kabanova declares no conflict of interest. G.V. Artamonova is the deputy editor-in-chief of the journal "Complex Issues of Cardiovascular Diseases". A.Yu. Prosekov declares that there is no conflict of interest. O.L. Barbarash is the editor-in-chief of the journal "Complex Issues of Cardiovascular Diseases".

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Author Information Form

Tsygankova Darya P., PhD, MD, Leading Researcher, Laboratory of Cardiovascular Epidemiology, Department of Optimization of Medical Care for Cardiovascular Diseases, Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", Kemerovo, Russian Federation; **ORCID** 0000-0001-6136-0518

Bazdyrev Evgeny D., PhD, MD, Head of the Laboratory of Cardiovascular Epidemiology, Department of Optimization of Medical Care for Cardiovascular Diseases, Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", Kemerovo, Russian Federation; **ORCID** 0000-0002-3023-6239

Nakhratova Olga V., Junior Researcher, Laboratory of Cardiovascular Epidemiology, Department of Optimization of Medical Care for Cardiovascular Diseases, Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", Kemerovo, Russian Federation; **ORCID** 0000-0002-2778-6926

Kabanova Svetlana V., Clinical Resident, Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", Kemerovo, Russian Federation; **ORCID** 0009-0000-6121-9370

Artamonova Galina V., PhD, MD, Professor, Deputy Director, Head of the Department of Optimization of Medical Care for Cardiovascular Diseases, Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", Kemerovo, Russian Federation; **ORCID** 0000-0003-2279-3307

Prosekov Alexander Yu., PhD, BD, ED, Professor, Academician of the Russian Academy of Sciences, Rector of the Federal State Educational Institution of Higher Education "Kemerovo State University", Kemerovo, Russian Federation; **ORCID** 0000-0002-5630-3196

Barbarash Olga L., PhD, MD, Professor, Academician of the Russian Academy of Sciences, Director of the Federal State Budgetary Institution "Research Institute for Complex Issues of Cardiovascular Diseases", Kemerovo, Russian Federation; **ORCID** 0000-0002-4642-3610

Author Contribution Statement

TDP – contribution to the concept and design of the study, data collection and interpretation, editing, approval of the final version, fully responsible for the content

BED – contribution to the concept and design of the study, data analysis, manuscript writing, editing, approval of the final version, fully responsible for the content

NOV – contribution to the concept of the study, data analysis, editing, approval of the final version, fully responsible for the content

KSV – contribution to the concept of the study, data analysis, editing, approval of the final version, fully responsible for the content

AGV – contribution to the concept and design of the study, data collection and interpretation, editing, approval of the final version, fully responsible for the content

PAYu – contribution to the concept and design of the study, editing, approval of the final version, fully responsible for the content

BOL – contribution to the concept and design of the study, editing, approval of the final version, fully responsible for the content

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