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Research article

METHODICAL APPROACHES TO ASSESSING PUBLIC HEALTH RISKS UNDER COMBINED EXPOSURE TO CLIMATIC FACTORS AND CHEMICAL AIR POLLUTION CAUSED BY THEM

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The ongoing climate change makes its contribution to public health risks. These risks can be caused both due to direct impacts of the process and modifying influence exerted by climatic factors on chemical levels in ambient air. Given that, it is advisable to develop methodical approaches that give an opportunity to quantify public health risks under combined influence of climatic factors and chemical air pollution caused by them.

In this study, we suggest methodical approaches eligible for calculating, assigning a category and assessing acceptability of public health risks under climatic exposures considering their influence on chemical air pollution. We outline approaches to establishing priority climatic factors, calculating exposure levels and associated responses; making up a list of chemicals levels of which are influenced by climatic factors and probable health outcomes caused by exposure to them; identifying levels of chemicals associated with climatic influence; calculating and assigning a category for public health risks associated with combined exposure to climatic and chemical factors using a multiple logistic regression model.

We tested the approaches using data collected in Perm in 2020. As a result, we established an unacceptable health risk for working age population ($1.11 \cdot 10^{-4}$) due to cerebrovascular diseases (I60–I69). This risk was associated with combined exposure to climatic factors (heat waves) and associated chemical air pollution (high levels of carbon oxide). Risk levels for working age population and older age groups due to diseases of the circulatory system (ischaemic heart diseases (I20–I25) and other cardiac arrhythmias (I49)) were rated as permissible (acceptable), $7.68 \cdot 10^{-5}$ and $4.07 \cdot 10^{-5}$ accordingly. The contribution made by the analyzed climatic factor (heat waves) varied between 76.24 and 92.44 %; the analyzed chemical factor (carbon oxide), between 7.56 and 23.76 %.

Keywords: *climate, climatic factors, chemical air pollution, public health risk assessment, quantitative indicators, heat wave, carbon oxide, multifactorial models.*

Climate and climatic factors are among leading environmental influences that largely determine availability of comfortable living conditions for population and people's lifestyles. They produce direct effects on people's activities, their work capacity and social activity [1, 2]. Climate change is one of the most significant global issues in the 21st century [3]. A lot of changes observed at the moment have been going on for decades; over the recent years they have accelerated considerably and this raises a lot of concern on the global scale and undoubtedly influences people's lives worldwide [4, 5].

According to the Report on Climatic Peculiarities in the Russian Federation in 2021, air temperatures higher than the climate normals were observed practically all over the country. These average annual temperature conditions occurred due to extremely hot summer and cold winter [6, 7].

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Climate change is diverse and becomes apparent, in particular, through changing frequency and intensity of climatic anomalies and extreme weather events directly caused by the overall temperature growth[1]. Among them, we can mention heat waves and peatland combustion in the Central European Part of Russia in 2003; extreme heat and large-scale forest fires in 2010; draughts in the agricultural areas of the country in 2010 and 2012 and some others [8].

According to the RF President Order issued on December 17, 2009 No. 861-rp On the Climate Doctrine of the Russian Federation, an elevated public health risk (growing incidence and mortality rates) is a negative outcome of expected climate change[2]. This is due to climatic factors being able to influence changes in disease prevalence and character, including non-communicable diseases. Thus, for example, an extremely high air temperature (heat waves) can exacerbate cardiovascular diseases, respiratory diseases, kidney diseases, diseases of the nervous system; it can also induce an increase in mortality caused by diseases of the cardiovascular and respiratory systems, especially among elderly people [5, 9–11].

Outcomes of climate change can create a wide range of risks for human health. Together with direct effects produced by climatic factors, the latter can influence the composition and levels of chemicals in ambient air [12]. Probable mechanisms of such influences can include impacts exerted by air temperatures on rates of chemical reactions; air humidity, on formation and destruction of chemical compounds; cloudiness, on ambient air composition; near-ground temperatures and precipitations, on chemical emissions and deposition; changes in ground wind intensity over a continent, on mobility of dust particles in droughty areas and, consequently, aerosol burden in the troposphere, etc. [13–15]. For example, heat waves not only influence public health directly but also can cause short-term changes in ambient air pollution with nitrogen dioxide, carbon oxide, particulate matter, sulfur dioxide, etc. [5, 16–19].

Climatic parameters are considerably changeable both over time and space; this facilitates more intense transportation, transformation, accumulation, and dispersal of pollutants [20].

According to the WHO, events involving ambient air pollution might become more frequent and acute under future climate change [21].

Global climate change creates a peculiar situation for the Russian Federation considering its huge territory, geographical position, extreme diversity of climatic conditions etc. This situation necessitates advanced development of a comprehensive and well-thought approach to climate issues adopted by the state. This approach should rely on complex scientific analysis of certain factors and consider global climate change both on its national and international scale a top priority of the state policy pursued in the Russian Federation [22][3].

Therefore, ongoing climate change is able to influence public health due to both direct effects produced by climatic factors and modified chemical pollution in ambient air. To create conditions for proper public health protection, it is necessary to assess health risks in such a way so that these risks are quantified under combined exposure to climate change and associated chemical pollution in ambient air.

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[1] Dmitry Medvedev signed an order approving the Russian Federation Climate Doctrine. *President of Russia: official website*. Available at: http://en.kremlin.ru/events/president/news/6365 (March 03, 2023).

[2] O klimaticheskoi doktrine Rossiiskoi Federatsii: Rasporyazhenie Prezidenta Rossiiskoi Federatsii ot 17.12.2009 g. № 861-rp [On the Climate Doctrine of the Russian Federation: the RF President Order issued on December 17, 2009 No. 861-rp]. *The Russian Government*. Available at: http://government.ru/docs/all/70631/ (March 03, 2023) (in Russian).

[3] Ibid.

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In this study, our aim was to develop methodical approaches to assessing public health risks under combined exposure to climatic factors considering their influence on chemical pollution in ambient air.

Materials and methods. We applied the fundamentals stipulated in the Methodical Guidelines MR 2.1.10.0057-12 Assessment of Risks and Damage due to Climate Change Influencing an Increase in Incidence and Mortality in Population Groups with Elevated Risks[4] and the Guide R 2.1.10.1920-04 Human Health Risk Assessment from Environmental Chemicals[5] as the methodical basis for developing approaches to assessing public health risks under combined exposure to climatic factors and chemical air pollution caused by them.

The suggested methodical approaches were tested within assessing public health risks created by exposure to climatic factors and chemical ambient air pollution caused by them in Perm in 2020.

Air temperature (heat waves) was chosen as a climatic factor to be analyzed. Data on average daily air temperatures (°C) collected in Perm over 2010–2020 were taken as initial information about the analyzed climatic parameter. These data were provided by the Unified State Fund of the Russian Federal Service for Hydrometeorology and Environmental Monitoring[6].

To achieve our aim, we calculated periods of heat waves in accordance with the procedure described in the Methodical Guidelines 2.1.10.0057-12[4]. Heat wave criteria were applied as a threshold of action for this factor.

Our initial data on population incidence were provided by a territorial fund for mandatory medical insurance after removing all the patients' personal data from them. We took data on daily numbers of applications for medical aid in Perm over 2010–2020 as per age groups (working age population, people older than working age) and as per the nosology category 'Diseases of the circulatory system' as well as specified diseases within this category.

We established what climatic factors would be able to induce a growth in chemical levels in ambient air and drew up a list of chemicals with their levels prone to change under climatic influence by analyzing relevant literature sources. Overall, we analyzed approximately 50 such sources including those found in WoS and Scopus.

Initial data on average daily levels of chemicals in ambient air in Perm over 2010–2020 were provided by the Perm Regional Office of the Federal Service for Surveillance over Consumer Right Protection and Human Wellbeing.

To calculate risk levels associated with effects of heat waves and carbon oxide, we cal-

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[4] MR 2.1.10.0057-12. Otsenka riska i ushcherba ot klimaticheskikh izmenenii, vliyayushchikh na povyshenie urovnya zabolevaemosti i smertnosti v gruppakh naseleniya povyshennogo riska (utv. i vved. v deistvie Rukovoditelem Federal'noi sluzhby po nadzoru v sfere zashchity prav potrebitelei i blagopoluchiya cheloveka, Glavnym gosudarstvennym sanitarnym vrachom Rossiiskoi Federatsii G.G. Onishchenko 17 yanvarya 2012 g.) [Assessment of Risks and Damage due to Climate Change Influencing an Increase in Incidence and Mortality in Population Groups with Elevated Risks (approved and put into effect by G.G. Onishchenko, the Head of the Federal Service for Surveillance over Consumer Right Protection and Human Wellbeing, the RF Chief Sanitary Inspector on January 17, 2012)]. Moscow, Rospotrebnadzor's Federal Center for Hygiene and Epidemiology, 2012, 48 p. (in Russian).

[5] R 2.1.10.1920-04. Rukovodstvo po otsenke riska dlya zdorov'ya naseleniya pri vozdeistvii khimicheskikh veshchestv, zagryaznyayushchikh okruzhayushchuyu sredu (utv. i vved. v deistvie Pervym zamestitelem Ministra zdravookhraneniya Rossiiskoi Federatsii, Glavnym gosudarstvennym sanitarnym vrachom Rossiiskoi Federatsii G.G. Onishchenko 5 marta 2004 g.) [Human Health Risk Assessment from Environmental Chemicals (approved and put into effect by G.G. Onishchenko, the Head of the Federal Service for Surveillance over Consumer Right Protection and Human Wellbeing, the RF Chief Sanitary Inspector on March 05, 2004)]. Moscow, The Federal Center for State Sanitary and Epidemiological Surveillance of the RF Ministry of Health, 2004, 143 p. (in Russian).

[6] Spetsializirovannye massivy dlya klimaticheskikh issledovanii [Specialized data arrays for climatic research]. *Russian Scientific Research Institute for Hydrometeorological Information-World Data Center.* Available at: http://meteo.ru/it/178-aisori (October 15, 2022) (in Russian).

culated additional likelihood of incidence among working age population and population older than working age. The calculation relied on a multiple logistic regression model that described a relationship between daily incidence of circulatory diseases caused by combined exposure to heat waves and elevated carbon oxide levels associated with these waves (Formula). An additional daily carbon oxide level caused by heat waves is used as X_1 whereas X_2 is the difference in air temperatures on days with heat waves and days without them.

Risk levels were calculated as additional likelihood of incidence associated with exposure to heat waves (the number of days included into a wave over 2020) multiplied by average weighted severity of diseases used as health outcomes in this study. Severity of diseases was established in conformity with the WHO document entitled 'WHO methods and data sources for global burden of disease estimates 2000–2019' [23].

Results and discussion. We have developed approaches to assessing public health risks under combined influence of climatic factors and chemical air pollution caused by them. These approaches include the following stages:

1. Establishing priority climatic factors that can create a public health risk and associated health outcomes.
2. Calculating exposure to climatic factors.
3. Identifying a list of chemicals with their levels being influenced by climatic factors and probable health outcomes caused by exposure to them.
4. Establishing chemical levels associated with influence of climatic factors.
5. Calculating levels of public health risks and assigning their category under combined influence of climatic factors and chemical air pollution caused by them using a multiple logistic regression model.

1. Establishing priority climatic factors that can create a public health risk and associated health outcomes. A factor can be considered a priority for an analyzed territory in case values of indictors that describe it are authentically different from average values typical for this territory over an analyzed period or are beyond the established comfort ranges or threshold levels.

A threshold level / a boundary of a comfort range is a value that characterizes such an exposure to a climatic factor that is not likely to produce harmful effects on public health associated with influence of this factor. It is identified based on quantitative parameters of a relationship between exposures to climatic factors and prevalence of associated diseases. These parameters can be established either by analyzing relevant literature sources or by using mathematical modeling methods.

We analyzed research literature to identify health outcomes caused by influence of the selected climatic factors; namely, we searched for valid cause-effect relations that characterized a potential threat for human health posed by exposure to the analyzed climatic indicators. Various indicators can be eligible, for example, those describing influence of specific meteorological elements or indicators that describe complex effects produced by several climatic factors (for example, bioclimatic indicators such as equivalent–effective temperature (EET), physiological equivalent-effective temperature (PEET), radiation equivalent-effective temperature (REET), biologically active temperature (BAT), etc.)

2. Calculating exposure to climatic factors. Calculation of exposure to climatic factors has a peculiarity, that is, an exposure level does not cover the whole duration of exposure but only those periods when values of indictors describing climatic factors were beyond threshold levels or ranges within which negative health outcomes were unlikely. Besides, in some cases it is necessary to identify the excess level of an indicator over its threshold level or deviation from an established range (in °C, mm Hg, units used to measure an index, etc.).

3. Identifying a list of chemicals with their levels being influenced by climatic factors and probable health outcomes caused by exposure to them. Initially, it is necessary to establish climatic factors typical for an analyzed territory, which would potentially be able to raise chemical levels in ambient air, and to make a list of such chemicals. In addition, ranges / thresholds of data effects are established for such factors. The latter do not produce any effects beyond these ranges / threshold, according to data available in literature.

If actual values of an analyzed climatic factor differ authentically from average values typical for a given territory over an analyzed period or are beyond established ranges / thresholds of effect, then they are able to have potential influence on levels of chemicals in ambient air on this territory. Given that, the ultimate list should include only those chemicals, levels of which change under influence exerted by climatic factors; we consider only factors with their values being beyond the ranges / thresholds established for indictors that describe them.

Health outcomes caused by exposure to the selected chemicals can be established both based on the Guide R 2.1.10.1920-04[7] and the results of literature analysis.

4. Establishing chemical levels associated with influence of climatic factors. First, it is necessary to establish an analyzed period, which will include those days / weeks / months when changes appeared in climatic factors and their indicators able to raise chemical levels in ambient air ('unfavorable periods'). Next, periods are established during which any influence on chemical levels in ambient air is unlikely ('favorable periods'). For each day in both 'unfavorable' and 'favorable' periods, actual levels of chemicals included in the list at the previous stage, are identified. The difference between chemical levels in days within 'unfavorable' and 'favorable' periods is considered a level caused by influence of climatic factors.

5. Calculating levels of public health risks and assigning their category under combined influence of climatic factors and chemical air pollution caused by them using a multiple logistic regression model. Risks of incidence are calculated as additional likelihood of incidence associated with influence exerted by climatic factors and chemical pollution in ambient air caused by them multiplied by average weighted severity of diseases as per disease classes used as health outcomes.

Additional likelihood of disease associated with combined exposure to unfavorable climatic factors and chemical pollution is calculated based on modeling cause-effect relations using multiple regression analysis.

In general, we can use the following multiple logistic regression model:

$$\Delta p = \frac{1}{1+e^{-(b_0+b_1x_1+b_2x_2)}},$$

where

Δp is additional likelihood of disease associated with combined exposure to the factors X_1 and X_2;

X_1, X_2 are the indicators describing levels of exposure to climatic and chemical factors;

b_0, b_1, b_2 are the parameters of the mathematical model.

All the models should be tested to identify the statistical significance of all the established relations ($p < 0.05$) and estimated by experts to check their conformity with biomedical concepts.

Exposure to climatic factors, chemical levels caused by influence of climatic factors and population incidence are taken as initial parameters. Applied data should have homogenous spatial and time level of detail.

[7] R 2.1.10.1920-04. Rukovodstvo po otsenke riska dlya zdorov'ya naseleniya pri vozdeistvii khimicheskikh veshchestv, zagryaznyayushchikh okruzhayushchuyu sredu (utv. i vved. v deistvie Pervym zamestitelem Ministra zdravookhraneniya Rossiiskoi Federatsii, Glavnym gosudarstvennym sanitarnym vrachom Rossiiskoi Federatsii G.G. Onishchenko 5 marta 2004 g.) [Human Health Risk Assessment from Environmental Chemicals (approved and put into effect by G.G. Onishchenko, the Head of the Federal Service for Surveillance over Consumer Right Protection and Human Wellbeing, the RF Chief Sanitary Inspector on March 05, 2004)]. Moscow, The Federal Center for State Sanitary and Epidemiological Surveillance of the RF Ministry of Health, 2004, 143 p. (in Russian).

Mathematical models are created using data on incidence as per disease classes or specific nosologies influenced by both climatic factors and chemicals with their level prone to change under effects produced by these climatic factors.

We suggest the following classification to assign calculated risks into a specific category: $1.0 \cdot 10^{-6}$ or lower is a minimal risk; $1.1 \cdot 10^{-6}$–$1.0 \cdot 10^{-4}$, a permissible (acceptable) risk; $1.1 \cdot 10^{-4}$–$1.0 \cdot 10^{-3}$, an alerting risk; $> 10^{-3}$, a high risk. Alerting and high risks are considered unacceptable; in case such risk levels are established, it is advisable to develop certain measures aimed at preventing health disorders and creating favorable conditions for health protection. These measures should be aimed at protecting those organs and systems for which unacceptable risk levels were identified [24].

Also this stage might involve identifying specific contributions made by chemical and climatic factors to public health risks caused by them.

Therefore, the suggested methodical approaches make it possible to quantify public health risks and assign them into a specific risk category under combined exposure to climatic factors and chemical air pollution caused by them.

Air temperature is considered a leading climatic factor able to influence human health. According to the Report on Climatic Peculiarities in the Russian Federation in 2021, air temperatures higher than the climate normals were observed practically all over the country [7]. Growing frequency and intensity of climatic anomalies and extreme weather events, heat waves included, are a direct outcome of the overall growth in air temperature [16, 17, 21, 25][8].

An average temperature that could be considered a heat wave in Perm equals 27.5 °C. This value can be used as a level of exposure which is unlikely to produce any harmful effects on public health caused by heat waves. Nine heat waves were established to occur on the analyzed territory over the period between 2010 and 2020 indicating the relevance of the climatic factor for this territory.

Diseases of the circulatory system were used as health outcomes under exposure to heat waves according to data available in literature. To be more exact, we used hypertensive diseases (I10–I15), ischemic heart disease (I20–I25), other forms of heart diseases (I49–I50), and cerebrovascular diseases (I60–I64) [11, 26–30]. Working age population and population older than working age were established to be the most sensitive population groups under the analyzed combined exposure [11, 28].

Two heat waves were established to occur in Perm in 2020 at the stage involving calculation of exposure to climatic factors. The first one was between July 08 and 12 (5 days); the second, between July 14 and 16 (3 days). Daily air temperatures higher than their threshold level that identified a heat wave boundary on the analyzed territory (27.5 °C) ranged between 1.0 and 3.6 °C.

Heat waves in Perm can lead to a growth in levels of nitrogen dioxide, carbon oxide, particulate matter, and sulfur dioxide[9] [5, 18, 19].

In accordance with the Guide R 2.1.10.1920-04, the respiratory organs are used as target ones where health outcomes occur

[8] Dmitry Medvedev signed an order approving the Russian Federation Climate Doctrine. *President of Russia: official website*. Available at: http://en.kremlin.ru/events/president/news/6365 (March 03, 2023).

[9] MR 2.1.10.0057-12. Otsenka riska i ushcherba ot klimaticheskikh izmenenii, vliyayushchikh na povyshenie urovnya zabolevaemosti i smertnosti v gruppakh naseleniya povyshennogo riska (utv. i vved. v deistvie Rukovoditelem Federal'noi sluzhby po nadzoru v sfere zashchity prav potrebitelei i blagopoluchiya cheloveka, Glavnym gosudarstvennym sanitarnym vrachom Rossiiskoi Federatsii G.G. Onishchenko 17 yanvarya 2012 g.) [Assessment of Risks and Damage due to Climate Change Influencing an Increase in Incidence and Mortality in Population Groups with Elevated Risks (approved and put into effect by G.G. Onishchenko, the Head of the Federal Service for Surveillance over Consumer Right Protection and Human Wellbeing, the RF Chief Sanitary Inspector on January 17, 2012)]. Moscow, Rospotrebnadzor's Federal Center for Hygiene and Epidemiology, 2012, 48 p. (in Russian).

under exposure to nitrogen dioxide, particulate matter, and sulfur dioxide; the cardiovascular system and development, carbon oxide.

We performed the relevant calculations using the actual levels of the analyzed chemicals. As a result, it was established that high air temperatures on the analyzed territory during heat waves created elevated average daily levels of nitrogen dioxide (the level was 0.03 mg/m^3 under normal conditions and 0.04 mg/m^3 under heat waves); carbon oxide (1.11 mg/m^3 and 1.83 mg/m^3 accordingly); and particulate matter (0.13 mg/m^3 and 0.16 mg/m^3 accordingly). Sulfur dioxide levels did not change. Chemical levels were higher than their average daily permissible ones (average daily MPL) only for particulate matter, being 0.1 average daily MPL higher. Additional growth in chemical levels caused by heat waves equaled 0.01 mg/m^3 (0.1 average daily MPL) for nitrogen dioxide; 0.72 mg/m^3 (0.2 average daily MPL) for carbon oxide; 0.03 mg/m^3 (0.2 average daily MPL) for particulate matter[10].

Diseases of the circulatory system associated with effects of heat waves and carbon oxide were used as health outcomes caused by combined exposure to climatic factors and chemical air pollution occurring due to their influence in Perm.

Table 1 provides the results of correlation-regression analysis (b_0, b_1 and b_2 are the model parameters, R^2 is the determination coefficient). We selected only statistically significant relations ($p < 0.05$).

We established authentic relationships between combined exposure to heat waves and carbon oxide and development of diseases from the following categories: ‘ischemic heart disease’ (I20–I25) and ‘cerebrovascular diseases’ (I60–I69) for working age population and additionally ‘other cardiac arrhythmias’ (I49) for population older than working age.

Biological plausibility of the created models is confirmed by specific mechanisms of influence exerted by heat waves and carbon oxide on the cardiovascular system. Due to effects of heat waves, hyperthermia usually stimulates hypotonia caused by vasodilation. Lower blood pressure makes for compensatory tachycardia; as a result, circulation becomes hyperdynamic and the cardiovascular system gets overstrained due to it [11]. Failure of hemoglobin oxygen-transportation function and associated developing hemic and tissue hypoxia are the leading components in pathogenesis of acute effects produced by carbon oxide. These hypoxias are further aggravated by hyperdynamic circulation caused by heat waves. Cerebral and cardiac tissues are the most susceptible to these effects and this is evidenced by the modeling results [31].

Additional likelihood of incidence caused by combined exposure to heat waves and carbon oxide was quantified for working age population in Perm as per several nosologies; it equaled $1.66 \cdot 10^{-5}$ for ‘ischemic heart disease’ (I20–I25) and $2.40 \cdot 10^{-5}$ for ‘cerebrovascular diseases’ (I60–I69). The calculated risk was $8.81 \cdot 10^{-6}$ for people older than working age as per ‘other cardiac arrhythmias’ (I49) (Table 2).

Table 1

The parameters of statistically significant multiple logistic regression models ($p < 0.05$)

Age group	Disease category as per ICD-10	b_0	b_1	b_2	R^2
Adult working age population	Ischemic heart disease (I20–I25)	-13.78	0.19	0.22	0.2
	Cerebrovascular diseases (I60–I69)	-11.84	0.01	0.11	0.1
Adults older than working age	Other cardiac arrhythmias (I49)	-15.66	0.48	0.3	0.2

[10] SanPiN 1.2.3685-21. Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya (utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha RF ot 28 yanvarya 2021 g. № 2; vved. v deistvie 01.03.2021) [Hygienic standards and requirements to providing safety and (or) harmlessness of environmental factors for people (approved by the Order of RF Chief Sanitary Inspector dated January 28, 2021 No. 2; became valid on March 01, 2021)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/573500115 (February 15, 2023) (in Russian).

Table 2

Public health risks in Perm associated with combined exposure to heat waves and chemical pollution with carbon oxide in ambient air

Age group	Health outcome	Additional incidence (per day under a heat wave)	Risk level (over 1 day under a heat wave)	Health risks for population in Perm caused by heat waves in 2020	Factor contribution, %	
					Heat waves	Carbon oxide
Working age adults	Ischemic heart disease (I20–I25)	$1.66 \cdot 10^{-5}$	$9.59 \cdot 10^{-6}$	$7.68 \cdot 10^{-5}$	88.35	11.65
	Cerebrovascular diseases (I60–I69)	$2.40 \cdot 10^{-5}$	$1.39 \cdot 10^{-5}$	**$1.11 \cdot 10^{-4}$**	76.24	23.76
Adults older than working age	Other cardiac arrhythmias (I49)	$8.81 \cdot 10^{-6}$	$5.09 \cdot 10^{-6}$	$4.07 \cdot 10^{-5}$	92.44	7.56

Risk levels were identified for the selected diseases of the circulatory system for working age population and people older than working age; they were $7.68 \cdot 10^{-5}$ (I20–I25) and $1.11 \cdot 10^{-4}$ (I60–I69) for the former age group and these risk levels are categorized as permissible (acceptable) and alerting (unacceptable) accordingly. The risk level identified for people older than working age was $4.07 \cdot 10^{-5}$ (I49); this level is considered permissible (acceptable).

Contributions made by heat waves to development of such diseases as 'ischemic heart disease' (I20–I25) and 'cerebrovascular diseases' (I60–I69) equaled 88.35 and 76.24 % accordingly; contributions made by carbon oxide were 11.65 and 23.76 % accordingly. Contributions made by the analyzed climatic factor (heat waves) and chemical factor (carbon oxide) to development of' 'other cardiac arrhythmias' (I49) equaled 92.44 % and 7.56 % accordingly for people older than working age. This indicates that the analyzed climatic factor had the greatest influence on development of these nosologies in Perm in 2020.

Therefore, when testing the suggested approaches, we established the unacceptable health risk ($1.11 \cdot 10^{-4}$) for working age adults in Perm in 2020 due to cerebrovascular diseases. This risk was associated with combined exposure to climatic factors (heat waves) and chemical air pollution caused by them (carbon oxide). Risk levels caused by diseases of the circulatory system within the selected nosologies (ischemic heart disease (I20–I25) and other cardiac arrhythmias (I49)) were considered permissible (acceptable) for working age population and people older than working age.

Conclusion. We have suggested methodical approaches eligible for calculating, assigning a category and assessing acceptability of public health risks under combined exposure to climatic factors and chemical air pollution caused by them.

This includes approaches to establishing priority climatic factors able to create elevated health risks and associated health outcomes; calculating exposure to climatic factors; identifying a relevant list of chemicals with their levels being prone to influence of climatic factors and probable health outcomes caused by their effects; establishing chemical levels associated with influence of climatic factors; calculating and identifying a category of health risks occurring under combined exposure to climatic factors and chemical air pollution caused by them using a multiple logistic regression model.

These approaches were tested using data collected in Perm. As a result, an unacceptable risk level ($1.11 \cdot 10^{-4}$) was established for working age population in 2020. This health risk was caused by cerebrovascular diseases (I60–I69) and was associated with combined exposure to climatic factors (heat waves) and chemical pollution with carbon oxide in ambient air caused by them. Risks levels caused by diseases of the circulatory system (ischemic heart disease (I20–I25) and other cardiac arrhythmias (I49)) were categorized as permissible (acceptable) for working age population and people older than working age. They were $7.68 \cdot 10^{-5}$ and $4.07 \cdot 10^{-5}$ accordingly. The contribution by the analyzed climatic factor (heat waves) ranged between 76.24 and 92.44 %; the analyzed chemical factor (carbon oxide), between 7.56 and 23.76 %.

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References

1. Es'kov V.M., Nazin A.G., Rusak S.N., Filatova O.E., Khadartseva K.A. The system analysis and synthesis of influence of dynamics of climatic and ecological factors on disease of the population in North. *Vestnik novykh meditsinskikh tekhnologii*, 2008, vol. 15, no. 1, pp. 26–29 (in Russian).
2. Zaitseva N., Chetverkina K., Khasanova A. Hazard identification of climate risk factors on health of the far north population. *20th International Multidisciplinary Scientific GeoConference – SGEM 2020*. Vienna, Austria, December 08–11, 2020, book 4.2, vol. 20, pp. 163–168. DOI: 10.5593/sgem2020V/4.2/s06.20
3. Zero regrets: scaling up action on climate change mitigation and adaptation for health in the WHO European Region. Key messages from the Working Group on health in climate change. *WHO*, 2021. Available at: https://www.who.int/europe/publications/i/item/WHO-EURO-2021-3198-42956-60023 (February 21, 2023).
4. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland, IPCC, 2014. Available at: https://www.ipcc.ch/report/ar5/syr/ (March 15, 2023).
5. Crimmins A., Balbus J.L., Gamble C.B., Beard C.B., Bell J.E., Dodgen D., Eisen R.J., Fann N. [et al.]. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. *U.S. Global Change Research Program*. Washington, DC, 2016. Available at: https://health2016.globalchange.gov/ (March 15, 2023).
6. Tretii otsenochnyi doklad ob izmeneniyakh klimata i ikh posledstviyakh na territorii Rossiiskoi Federatsii. Obshchee rezyume [The third assessment report on climate change and its consequences on the territory of the Russian Federation. General summary]. Saint Petersburg, Naukoemkie tekhnologii, 2022, 124 p. (in Russian).
7. Doklad ob osobennostyakh klimata na territorii Rossiiskoi Federatsii za 2021 god [A report on climate features on the territory of the Russian Federation in 2021]. Moscow, Russian Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET), 2022, 104 p. (in Russian).
8. Sokolov Yu.I. Riski ekstremal'nykh pogodnykh yavlenii [Risks of extreme weather events]. *Problemy analiza riska*, 2018, vol. 15, no. 3, pp. 6–21 (in Russian).
9. Khasnulin V.I., Gafarov V.V., Voevoda M.I., Razumov E.V., Artamonova M.V. Influence of meteorological factors in different seasons on incidence of hypertensive disease complications in Novosibirsk residents. *Ekologiya cheloveka*, 2015, no. 7, pp. 3–8 (in Russian).
10. Varakina Zh.L., Yurasova E.D., Revich B.A., Shaposhnikov D.A., Vyazmin A.M. Air temperature impact on mortality in Arkhangelsk in 1999–2008. *Ekologiya cheloveka*, 2011, no. 6, pp. 28–36 (in Russian).
11. Beker B.M., Cervellera C., De Vito A., Musso C.G. Human Physiology in Extreme Heat and Cold. *Int. Arch. Clin. Physiol.*, 2018, vol. 1, no. 1, pp. 1–8. DOI: https10.23937/iacph-2017/1710001
12. McMichael A.J., Lindgren E. Climate change: present and future risks to health, and necessary responses. *J. Intern. Med.*, 2011, vol. 270, no. 5, pp. 401–413. DOI: 10.1111/j.1365-2796.2011.02415.x

13. Brasseur G.P. Implications of Climate Change for Air Quality. *WMO*. Available at: https://public.wmo.int/en/bulletin/implications-climate-change-air-quality (February 18, 2023).

14. Brasseur G.P., Schultz M., Granier C., Saunois M., Diehl T., Botzet M. [et al.]. Impact of climate change on the future chemical composition of the global troposphere. *J. Climate*, 2006, vol. 19, no. 16, pp. 3932–3951. DOI: 10.1175/jcli3832.1

15. WMO Bulletin. Weather, Climate and the Air We Breathe, 2009, vol. 58, no. 1. Available at: http://mgmtmo.ru/edumat/wmo/bulletin_58-1_ru.pdf (February 8, 2023) (in Russian).

16. The Atlas of mortality and economic losses from weather, climate and water extremes (1970–2019). *WMO*, 2021, 90 p. (in Russian).

17. Sidorov P.I., Men'shikova L.I., Buzinov R.V., Vyaz'min A.M., Degteva G.N., Sannikov A.L., Balaeva T.V., Boltenkov V.P. [et al.]. Strategiya adaptatsii k vozdeistviyu izmeneniya klimata na zdorov'e naseleniya dlya Arkhangel'skoi oblasti i Nenetskogo avtonomnogo okruga Rossiiskoi Federatsii [Strategy for adaptation to the impact of climate change on public health for the Arkhangelsk region and the Nenets Autonomous Area of the Russian Federation]. Arkhangel'sk, OOO «Triada», 2012, 98 p. (in Russian).

18. Stafoggia M., Schwartz J., Forastiere F., Perucci C.A., SISTI Group. Does temperature modify the association between air pollution and mortality? A multicity case-crossover analysis in Italy. *Am. J. Epidemiol.*, 2008, vol. 167, no. 12, pp. 1476–1485. DOI: 10.1093/aje/kwn074

19. Akimov L.M., Akimov E.L. Seasonal Dynamics and Spatial Distribution of Anthropogenic Pollutants Concentrations in the Air of Voronezh. *Regional'nye geosistemy*, 2021, vol. 45, no. 4, pp. 545–557 (in Russian).

20. Grigor'eva I.G., Tunakova Yu.A., Shagidullina R.A., Valiev V.S., Kuznetsova O.N. Otsenka vliyaniya kompleksa meteoparametrov na rasseivanie vybrosov ot statsionarnykh istochnikov zagryazneniya na primere territorii goroda Nizhnekamska [Assessment of the impact of a set of meteorological parameters on the dispersion of emissions from stationary sources of pollution on the example of the territory of the city of Nizhnekamsk]. *Vestnik tekhnologicheskogo universiteta*, 2015, vol. 18, no. 15, pp. 268–270 (in Russian).

21. Climate change and health. *WHO*, 2021. Available at: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health (March 18, 2023).

22. Brinchuk M.M. Natural disasters as a factor in society's adaptation to climate change. *Yuridicheskii vestnik Dagestanskogo gosudarstvennogo universiteta*, 2020, vol. 34, no. 2, pp. 14–21. DOI: 10.21779/2224-0241-2020-34-2-14-21 (in Russian).

23. WHO methods and data sources for global burden of disease estimates 2000–2019. *WHO*, 2020. Available at: https://cdn.who.int/media/docs/default-source/gho-documents/global-health-estimates/ghe2019_daly-methods.pdf?sfvrsn=31b25009_7 (March 16, 2023).

24. Shur P.Z., Kiryanov D.A., Kamaltdinov M.R., Khasanova A.A. Assessing health risks caused by exposure to climatic factors for people living in the Far North. *Health Risk Analysis*, 2022, no. 3, pp. 53–62. DOI: 10.21668/health.risk/2022.3.04.eng

25. Revich B.A., Grigorieva E.A. Health risks to the Russian population from weather extremes in the beginning of the XXI century. Part 1. Heat and cold waves. *Problemy analiza riska*, 2021, vol. 18, no. 2, pp. 12–33. DOI: 10.32686/1812-5220-2021-18-2-12-33 (in Russian).

26. Kozlovskaya I.L., Bulkina O.S., Lopukhova V.V., Chernova N.A., Ivanova O.V., Kolmakova T.E., Karpov Yu.A. Heat and cardiovascular diseases: A review of epidemiological surveys. *Terapevticheskii arkhiv*, 2015, vol. 87, no. 9, pp. 84–90. DOI: 10.17116/terarkh201587984-90 (in Russian).

27. Kilbourne E.M. The spectrum of illness during heat waves. *Am. J. Prev. Med.*, 1999, vol. 16, no. 4, pp. 359–360. DOI: 10.1016/s0749-3797(99)00016-1

28. Revich B.A. Heat-waves in metropolises and thresholds of their impact on public health. *Gigiena i sanitariya*, 2017, vol. 96, no. 11, pp. 1073–1078. DOI: 10.47470/0016-9900-2017-96-11-1073-1078 (in Russian).

29. Revich B.A., Shaposhnikov D.A. Excess mortality during heat waves and cold spells in Moscow, Russia. *Occup. Environ. Med.*, 2008, vol. 65, no. 10, pp. 691–696. DOI: 10.1136/oem.2007.033944

30. Chernykh D.A., Taseiko O.V. Assessment of the risk mortality from heat waves in Krasnoyarsk city. *Aktual'nye problemy aviatsii i kosmonavtiki*, 2017, vol. 2, no. 13, pp. 678–680 (in Russian).
31. Toxicological profile for carbon monoxide. Atlanta, GA, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, 2012, 347 p.

Shur P.Z., Khasanova A.A., Tsinker M.Yu., Zaitseva N.V. Methodical approaches to assessing public health risks under combined exposure to climatic factors and chemical air pollution caused by them. Health Risk Analysis, 2023, no. 2, pp. 58–68. DOI: 10.21668/health.risk/2023.2.05.eng

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