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Research article

ASSESSING HEALTH RISKS CAUSED BY EXPOSURE TO CLIMATIC FACTORS FOR PEOPLE LIVING IN THE FAR NORTH

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Extreme climatic conditions in the Far North region create health risks for people living there. Given the necessity to adapt to these conditions, it seems vital to assess health risks caused by exposure to extreme climatic factors. Such an assessment will give an opportunity to establish and quantify influence exerted by climatic factors on public health.

The task was to assess risk rates for adults and children living in the Far North region in Russia. To do that, we analyzed the "exposure – effect" relationship for previously established climatic factors (atmospheric pressure and atmospheric air temperature, air humidity, and wind speed (as an index of the normal equivalent-effective temperature – NEET). Additional likelihood of incidence associated with exposure to climatic factors and occurring risk rates were calculated and then characterized based on the results of the analysis using mathematical modeling techniques.

As a result, we identified parameters of a cause-effect relation between average monthly NEET, daily pressure drops and incidence among population living in the Far North. We established unacceptable health risks for adults caused by diseases of the circulatory system that were associated with effects produced by NEET and atmospheric pressure, diseases of the respiratory system, injury, poisoning and certain other consequences of external causes associated with effects produced by NEET. We also established unacceptable health risks for children caused by diseases of the respiratory system, injury, poisoning and certain other consequences of external causes associated with effects produced by NEET. The results produced by this study can provide a guideline for developing activities aimed at facilitating adaptation to the existing climatic conditions in order to preserve public health.

Keywords: *risk assessment, climatic factors, risk characteristic, analysis of the "exposure – effect" relationship, atmospheric pressure, NEET index, adaptation, climate change, public health.*

The RF President Order issued on December 17, 2009 No. 861-rp "On the Climatic Doctrine of the Russian Federation" identifies certain negative outcomes caused by expected climate change; elevated public health risks (growing mortality and morbidity) are among them[1]. Given that, a priority task within the climate policy is to develop and implement activities that facilitate adaptation to occurring climate change [1–3]. To do that, a national action plan on adaptation to climate change was developed in the country. It was approved

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[1] O Klimaticheskoi doktrine Rossiiskoi Federatsii: Rasporyazhenie Prezidenta Rossiiskoi Federatsii ot 17.12.2009 № 861-rp [On the Climatic Doctrine of the Russian Federation: The RF President Order issued on December 17, 2009 No. 861-rp]. *The RF Government*. Available at: http://government.ru/docs/all/70631/ (May 20, 2022) (in Russian).

by the RF Government Order issued on December 25, 2019 No. 3183-r[2]. Risk assessment is a most significant component in developing and planning actions that facilitate adaptation to climate change. Use of it makes it possible to quantify and predict outcomes for public health caused by exposure to climatic factors [4, 5].

Extreme natural and climatic factors are quite typical for the Far North regions. They create health risks for people living there. These factors include low atmospheric air temperatures that persist over a long period, drastic atmospheric air pressure drops with high amplitudes, high air humidity, squalls, etc. [6–9]. Effects produced by them make for greater functional strains of specific organs and systems, reduce biological stability of the body and lead to changes in those organs and systems where adaptation resources are engaged most intensely and adaptive restructuring is the most obvious [10, 11]. All this creates health risks for adults and children living in the Far North. At the same time, climate change is developing significantly faster in this region than anywhere else on the planet [12, 13]. Given that, when people have to adapt to the existing conditions, it is vital to assess health risks caused by exposure to climatic factors. Such an assessment allows quantifying effects produced on public health by climatic factors, establishing and estimating comparative significance of the existing threats for public health.

Previously, we identified hazards for health and established that it was advisable to use the normal equivalent effective temperature (NEET) index and daily atmospheric pressure drops as key indicators for estimating effects produced by climatic factors on health of people living in the Far North. These selected factors have predominantly complex effects and this gives an opportunity to comprehensively assess their influence on public health without overestimating occurring health risks. We established that the selected key indicators had authentic cause-effect relations with diseases of the respiratory system (J00–J99), diseases of the circulatory system (I00–I99), endocrine, nutritional and metabolic diseases (E00–E90), mental and behavioral disorders (F00–F99), as well as injury, poisoning and certain other consequences of external causes (S00–T98) [7, 10].

Our research goal was to calculate and assess risk rates associated with effects produced by atmospheric pressure (daily drops) and atmospheric air temperature, air humidity and wind speed (NEET index) for adults and children living in the Far North.

Materials and methods. We calculated and assessed public health risks associated with atmospheric pressure (daily drops) and atmospheric air temperature, air humidity and wind speed (NEET index) that were previously established as key indicators at the hazard identification stage [7, 10]. Calculations and assessment covered both adults and children living in a large industrial city located beyond the Polar Circle (69 degrees north latitude).

To achieve our goal, we analyzed the "exposure – effect" relationship for the examined climatic factors. The analysis results gave grounds for calculating additional likelihood of incidence associated with effects produced by climatic factors. The calculations were performed by using mathematical modeling techniques and their results were used as a basis for calculating risk rates. These risks rates were a product of additional likelihood of incidence associ-

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[2] Ob utverzhdenii natsional'nogo plana meropriyatii pervogo etapa adaptatsii k izmeneniyam klimata na period do 2022 goda: Rasporyazhenie Pravitel'stva RF ot 25.12.2019 № 3183-r (red. ot 17.08.2021) [On approval of the national action plan at the first stage of adaptation to climate change for the period up to 2022: The RF Government Order issued on December 25, 2019 No. 3183-r (last edited on August 17, 2021)]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_342408/f62ee45faefd8e2a11d6d88941ac66824f848bc2/ (May 20, 2022) (in Russian).

ated with exposure to climatic factors multiplied by weighted average severity of diseases used as health outcomes in exposed population.

The stage when the "exposure – effect" relationship was estimated involved establishing quantitative associations between exposure to climatic factors (atmospheric pressure and atmospheric air temperature, air humidity and wind speed (as the NEET index)) and categories of diseases that were previously determined at the hazard identification stage (diseases of the respiratory system (J00–J99), endocrine, nutritional and metabolic diseases (E00–E90), diseases of the circulatory system (I00–I99), injury, poisoning and certain other consequences of external causes (S00–T98), mental and behavioral disorders (F00–F99)). We additionally specified nosologies that could be used as health outcomes when assessing effects produced by the analyzed climatic factors within previously established categories of diseases. To do that, we analyzed more than 100 literature sources that included up-to-date research works covering results produced by both fundamental and applied studies. All they were found in universally recognized citation databases (Google Scholar, Web of Science, Scopus, NCBI PubMed etc.) and were considered relevant for the subject of this study. We also used the methodical guidelines "Assessment of risks and damage caused by climate change that influences growing mortality and morbidity in high-risk population groups"[3] to specify relevant nosologies.

We analyzed data available in research works and established exposure levels regarding the NEET index and the atmospheric air pressure (daily drops) that would not probably lead to the established health outcomes in exposed population.

We calculated additional likelihood of incidence among adults and children to quantify risk rates associated with effects produced by atmospheric air pressure and atmospheric air temperature, air humidity and wind speed (as the NEET index). The calculation was based on a system of parameterized relationships between average monthly incidence among population due to the aforementioned causes and an average monthly NEET and a number of days with daily pressure drops exceeding the established no-effect exposure (that did not produce any unfavorable effects as established at the stage of estimating the "exposure – effect" relationship) per month.

We took our initial data on climatic parameters from databases with the results produced by observations at meteorological stations located in the analyzed region over the period from January 01, 2014 to December 31, 2018 (daily averaging): atmospheric air pressure (inter-daily drops) at the level at which a station was located (GPa), atmospheric air temperature (°C), relative air humidity (%), and wind speed (m/sec). Based on these data, we calculated average monthly indexes of the normal equivalent effective temperature (NEET) [14, 15].

Initial data on incidence were taken from databases provided by the Fund for Mandatory Medical Insurance. We used data on a number of insured people who lived on the analyzed territory and applied for medical assistance there over 2014–2018. The data were taken as per age groups (adults and children) and as per specific nosologies falling within several categories of diseases including diseases of the respiratory and circulatory systems, injury, poisoning, and certain other consequences of external causes. Relative incidence rates (per 1000 people).

[3] 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 [Assessment of risks and damage caused by climate change that influences growing mortality and morbidity in high-risk population groups: methodical guidelines]. Moscow, Rospotrebnadzor's Federal Center for Hygiene and Epidemiology, 2012, 48 p. (in Russian).

Table 1

Formulas for modeling cause-effect relations between the NEET, atmospheric pressure and incidence among population

№	Formula	Designation
1	$Y^j = a_0^j + \sum_i a_1^{ij} X^{ij}$	Y^j is relative incidence or mortality among population due to the *j*-th cause, cases per 1000 people; a_0^j, a_1^{ij} are the model coefficients; X^{ij} is the *i*-th factor influencing the *j*-th health outcome
2	$\Delta Y^{ij} = a_1^{ij}(X^{ij} - X_N^{ij})$	ΔY^{ij} is additional incidence or mortality among population due to the *j*-th cause associated with exposure to the *i*-th factor, causes per 1000 people; a_1^{ij} is the model coefficient; X_N^{ij} is a value of a factor that would not probably cause adverse health outcomes in a person exposed to this factor
3	$P^j = 1-(1-1/1000)^{Y^j}$	P^j is likelihood of a disease due to the *j*-th cause during a calendar year
4	$\Delta P^{ij} = P^j(X^{ij}) - P^j(X_N^{ij})$	ΔP^{ij} is additional likelihood of a disease due to the *j*-th cause associated with exposure to the *i*-th factor

were calculated based on the absolute number of cases by dividing this absolute number by the number of insured people and multiplying by 1000

Cause-effects relations between the NEET, atmospheric air pressure and incidence among population were modeled by using mathematical statistics methods. All the models were tested to check statistical significance of the established relations ($p < 0.05$) and to perform expert estimates of their conformity with biomedical concepts.

An overview of cause-effects relations is given with a linear multiple regression model (Table 1, Formula 1). Incidence associated with exposure to the analyzed climatic factors was calculated as a difference between estimates obtained with an actual value of a factor and a value of a factor that would not probably cause any adverse health outcomes in an exposed person (Table 1, Formula 2). Likelihood of a disease during a year was calculated based on the obtained data (Table 1, Formula 3). Additional likelihood of a disease associated with exposure to effects produced by atmospheric pressure and NEET was determined as a difference between estimates of incidence calculated with an actual value of a factor and a value of a factor that would not probably cause any adverse health outcomes in an exposed person (Table 1, Formula 4).

Risk rates were calculated as a product of additional likelihood of incidence associated with exposure to climatic factors multiplied by weighted average severity of diseases as per their categories that were applied in the formulas as health outcomes. Severity of diseases was determined in accordance with the “WHO methods and data sources for global burden of disease estimates 2000–2019” and was measured as a dimensionless coefficient with its value falling within the range from 0 to 1[4].

Results and discussion. We analyzed relevant research data to estimate the “exposure – effect” relationship. As a result, we established that atmospheric air pressure or, to be exact, such a parameter of the factor as daily drops produced adverse effects on the circulatory system. These effects induce

[4] WHO methods and data sources for global burden of disease estimates 2000–2019: Global Health Estimates Technical Paper WHO/DDI/DNA/GHE/2020.3. Geneva, WHO, 2020, 47 p.

functional disorders of the cardiovascular system (including changes in blood pressure, vascular crises and internal hemorrhages etc.) [16–18]. According to data obtained by several relevant foreign studies, daily drops in atmospheric air pressure that equal 7.5 mm Hg can lead to acute cardiovascular diseases including acute myocardial infarction, subarachnoid hemorrhage, hypertensive crises, acute cerebrovascular accidents, acute coronary diseases etc. [19–21]. Therefore, we established that atmospheric air pressure as a specific climatic factor produced certain effects on the cardiovascular system and it was advisable to link it to acute cardiovascular diseases as health outcomes (effects) occurring due to exposure to it. These diseases include essential (primary) hypertension (I10), hypertensive heart disease (I11), angina pectoris (I20), acute myocardial infarction (I21), subarachnoid hemorrhage (I60), and stroke, not specified as hemorrhage or infarction (I64). These effects are the most likely to occur when daily drops in atmospheric air pressure are equal to 7.5 mm Hg or more. Given that, it is advisable to use this value as an exposure level, which does not probably produce harmful effects on public health that are associated with exposure to this factor. Averaging over five years completed, we established that a number of days with inter-daily drops in atmospheric air pressure being equal to 7.5 mm Hg or more amounted to 80.4 days per year.

The identified nosologies have been established to be more typical for adult population [19–23]; therefore, further calculations and identification of risk rates associated with exposure to atmospheric air pressure as an influencing climatic factor will be performed exclusively for adults living on the analyzed territory.

Having analyzed relevant data available in literature, we established that a range from 17.0 to 22.0 °C was considered comfortable for the NEET index. Any temperature that is beyond this range imposes stricter demands to thermoregulation mechanisms [3, 8]. Given that, an air temperature of 17 °C can be applied as an exposure level that does not probably produce any harmful effects on public health associated with exposure to this factor. The NEET index value did not exceed this level on the analyzed territory over the examined period.

We made a more precise list of nosologies within the previously identified categories that would probably be the most climate-sensitive health outcomes caused by effects of the NEET. It is advisable to use acute respiratory infections (J00–J22) and chronic lower respiratory diseases (J40–J44) as health outcomes associated with exposure to the NEET within the category that comprises diseases of the respiratory system; diabetes mellitus (E10–E14), with the category of endocrine, nutritional and metabolic diseases; hypertensive diseases (I10–I15) and ischemic heart diseases (I20–I25), within the category comprising diseases of the circulatory system; mental and behavioral disorders due to use of alcohol (F10), neurotic, stress-related and somatoform disorders (F40–F48), behavioral and emotional disorders with onset usually occurring in childhood and adolescence (F90–F98), within the category of mental and behavioral disorders; frostbites, within the category covering injuries, poisoning and certain other consequences of external causes (T33–T35) [24–35].

Table 2 provides the results produced by correlation and regression analysis (a_0, a_1 are the model parameters, R^2 is the determination coefficient). We selected only statistically significant correlations ($p < 0.05$). A negative value of the coefficient a_1 means that the related incidence grows as the NEET value decreases.

The accomplished calculations made it possible to establish that additional probable incidence regarding diseases of the circulatory system amounted to $1.1 \cdot 10^{-2}$ among adults living in a large industrial city located beyond the Polar Circle. A health risk caused by diseases of the circulatory system was equal to $6.33 \cdot 10^{-3}$.

Table 2

Parameters of statistically significant linear regression models ($p < 0.05$)

Category of diseases as per ICD-10	Risk factor	a_0	a_1	R^2
Diseases of the circulatory system (I00–I99)	Atmospheric air pressure drops	93.23	0.205	0.04
Diseases of the respiratory system (J00–J99)	NEET	308.230	-7.808	0.3
Diseases of the circulatory system (I00–I99)		103.651	-1.051	0.2
Injuries, poisoning and certain other consequences of external causes (S00–T98)		0.72	-0.078	0.59

Table 3

Risk rates for children and adults associated with exposure to the NEET

Category (ICD-10)	Age	Additional likelihood of diseases	Risk rate
Diseases of the respiratory system	Children	$3.91 \cdot 10^{-1}$	$4.70 \cdot 10^{-2}$
Injury and poisoning		$7.06 \cdot 10^{-4}$	$2.63 \cdot 10^{-4}$
Diseases of the respiratory system	Adults	$1.56 \cdot 10^{-1}$	$3.34 \cdot 10^{-2}$
Diseases of the circulatory system		$2.51 \cdot 10^{-2}$	$1.45 \cdot 10^{-2}$
Injury and poisoning		$9.59 \cdot 10^{-4}$	$4.24 \cdot 10^{-4}$

Table 3 provides the results produced by calculating risk rates for adults and children associated with exposure to air temperature, humidity and wind speed (as the NEET index).

The calculations revealed that additional likelihood of respiratory diseases associated with effects produced by the NEET amounted to $3.91 \cdot 10^{-1}$ for children and $1.56 \cdot 10^{-1}$ for adults; additional likelihood of circulatory diseases, $2.51 \cdot 10^{-2}$; for adults; additional likelihood of injury and poisoning (frostbite), $7.06 \cdot 10^{-4}$ for children and $9.59 \cdot 10^{-4}$ for adults. The calculated health risk caused by diseases of the respiratory system amounted to $4.7 \cdot 10^{-2}$ for children and $3.34 \cdot 10^{-2}$ for adults; diseases of the circulatory system, $1.45 \cdot 10^{-2}$ for adults; injury, poisoning and certain other consequences of external causes (frostbite), $2.63 \cdot 10^{-4}$ for children and $4.24 \cdot 10^{-4}$ for adults.

The following classification was applied to characterize the calculated risk rates:

1) $1.0 \cdot 10^{-6}$ or below, minimal risk;

2) $1.1 \cdot 10^{-6}$–$1.0 \cdot 10^{-4}$, permissible (acceptable) risk;

3) $1.1 \cdot 10^{-4}$–$1.0 \cdot 10^{-3}$, alerting risk;

4) $> 10^{-3}$, high risk.

Alerting and high risks are characterized as unacceptable; in case such risk rates are identified, it is advisable to develop certain actions aimed at preventing health disorders and preserving public health. Such actions should always concern those organs and systems for which these unacceptable risk rates have been identified.

According to the suggested classification, we established unacceptable health risks for adults living in a large industrial city located beyond the Polar Circle. These health risks were caused by diseases of the circulatory system associated with effects produced by the NEET and atmospheric air pressure as well as diseases of the respiratory systems, injury, poisoning and certain other consequences of external causes that were associated with exposure to the NEET. We established unacceptable health risks for children caused by diseases of the respiratory system, injury, poisoning and certain other consequences of external causes that were associated with exposure to the NEET.

Conclusion. We estimated the "exposure – effect" relationship by analyzing relevant data available in research works and established certain exposure levels for the analyzed climatic factors that would produce certain harmful effects associated with exposure to them on public health. Thus, it is advisable to use an average monthly NEET value equal to 17 °C and lower and inter-daily atmospheric air pressure drops equal to 7.5 mm Hg and more as exposure levels that would certainly lead to negative health outcomes in exposed population.

Having calculated and estimated risk rates for people living in the Far North, we established unacceptable health risks for adults caused by diseases of the circulatory system that were associated with exposure to the NEET and atmospheric air pressure ($1.45 \cdot 10^{-2}$ and $6.33 \cdot 10^{-3}$ accordingly); diseases of the respiratory system ($3.34 \cdot 10^{-2}$) and injury, poisoning and certain other consequences of external causes that were associated with exposure to the NEET ($4.24 \cdot 10^{-4}$). We also established unacceptable health risks for children caused by diseases of the respiratory system ($4.70 \cdot 10^{-2}$) and injury, poisoning and certain other consequences of external causes ($2.63 \cdot 10^{-4}$) that were associated with exposure to the NEET.

These research results make it possible to predict negative health outcomes in people living in the Far North. These health outcomes occur under combined exposure to climatic factors (atmospheric air pressure (daily drops) and atmospheric air temperature, air humidity and wind speed (as the NEET index)). They can also serve as a guideline for developing actions aimed at facilitating adaptation to the existing conditions in order to preserve public health.

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