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Research article

CLIMATIC AND CHEMICAL HEALTH RISK FACTORS FOR PEOPLE LIVING IN ARCTIC AND SUB-ARCTIC REGIONS: POPULATION AND SUB-POPULATION LEVELS

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The article dwells on climatic and chemical risk factors that influence health of people living in the RF Arctic and sub-Arctic regions on population and sub-population levels. We used a model describing cause-effect relations between environmental factors and life expectancy at birth based on an artificial neural network to predict a future medical and demographic situation in territories with Arctic and sub-Arctic climate in the RF.

Children's health was examined profoundly due to a participating representative sampling. We comparatively analyzed clinical, biochemical and general clinical indicators in the test and reference groups using standard statistical procedures and statistical software packages.

We established that average monthly temperatures in July grew on average by 3.4 % over 2010–2019 on the examined territories in the RF; precipitations in January and July grew by 13.0–15.1 %. The article presents differentiated estimates of emerging influence on life expectancy at birth (LEB) exerted by weather and climatic conditions on the analyzed territories with Arctic and sub-Arctic climate. Losses in LEB vary from 164 days in Yakutia to 349 days in Chukotka. Aggregated influence of weather and climatic factors in the Arctic and sub-Arctic zones in 2010–2019 produced variable effects on LEB, starting from negative ones that resulted in its decline in the Magadan region, the Nenets Autonomous Area, Chukotka, and the Yamal-Nenets Autonomous Area (-254; -211; -109 and -8 days accordingly) and to positive ones that led to the growth in LEB by up to 111 days in Yakutia.

Children who are simultaneously exposed to adverse weather and climatic factors in the sub-Arctic zone and substantial chemical pollution in ambient air have more frequent and more apparent negative changes in their health indicators in comparison with children from the reference group. Thus, respiratory diseases and diseases of the nervous system were by 5.6 times more frequent in the test group; levels of leukocytes, ESR, TSH, Apo-B and Apo-B/ApoA1 in blood were by 1.3–1.7 times higher, p = 0.0001. Levels of Apo A1, hydrocortisone, and serotonin in blood were by 1.2–2.5 times lower, p = 0.0001–0.040, etc. A share contribution made by chemical factors to associated respiratory diseases and diseases of the nervous system amounted to 25–31 %; adverse climatic factors, 10–15 % .

Keywords: *climate in Russia, Arctic, public health, children, life expectancy at birth, LEB, health risk factors, socio-hygienic determinants, ambient air quality, neural networks, prediction of potential LEB growth, profound examinations.*

Human health is influenced by a complex set of interrelated factors such as environmental, climatic, geographic, social and behavioral ones. The human body has to adapt to them to maintain proper functioning [1]. Climate is among the most important factors that determine live activity of the human body including preservation and development of its biological, psychological and physiological functions. These functions are of vital

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importance since they influence a person's working ability and social activity. Climate on a given territory is determined by its geographical position, namely, its latitude, height above sea level, sea to land ratio, topographic peculiarities etc. Climate is the weather conditions prevailing on a given territory over a long-term period[1]. There is another definition stating that climate is the average weather for a particular region taken over a long-term observation period[2]. Climate consists of multiple specific and instant atmospheric conditions, so to say, of multiple variable "weathers" over a long-term period (usually from 50 to 100 years)[3]. Therefore, we can consider climate to be a certain background for a person's live activity and health [2], and the weather is a set of meteorological elements (factors) taking turns according to laws and regularities of specific climate.

Impacts exerted by the weather on the human body can be both positive and negative. They become apparent as meteosensitivity, meteolability or meteotropic reactions, in other words, pathological responses of the human body caused by exposures to adverse weather factors[4]. Meteopathic reactions can occur in the body under exposure to such meteorological factors as air temperature, humidity, pressure, wind speed, solar radiation (including spectral distribution of energy), longwave solar radiation, precipitations (their type and intensity), air composition, atmospheric electricity, atmospheric radiation, infrasound, etc. [2].

Several basic meteorological factors exert the most substantial influence on the human body. First, we should mention *air temperature*, including its peak values in summer and winter seasons, and its fluctuations; then, *air humidity*, which enhances effects produced by air temperature; *atmospheric pressure* and its changes; *precipitation quantities* in various seasons; *insolation*; and some others. Meteorological factors (air temperature and humidity, wind speed, atmospheric pressure, solar radiation intensity etc.) produce combined effects on the human body and can either enhance or weaken each other's influence. The human body tends to bear additional loads under combined adverse exposure to climatic factors [3].

Results of multiple domestic and foreign studies with their focus on assessing influence of weather and climate on human health indicate and predict wide-scale, or even disastrous, effects such as elevated incidence and mortality and, consequently, a reduction in life expectancy at birth (hereinafter LEB) [4–7]. Thus, climate change influences social and ecological determinants of health, namely, clean air, safe drinking water, sufficient amounts of food products and safety (integrity) of housing. According to the WHO [8] over a period from 2030 to 2050 the climate change is expected to cause a growth in a number of deaths by approximately 250 thousand annually because of insufficient nutrition, malaria, diarrhea and exposure to high air temperatures. Direct costs due to negative impacts exerted by climate on health are predicted to reach 2–4 billion US dollars per year by 2030. They do not include costs in some sectors of the economy that govern human health such as agriculture, water supply and sanitation. Areas where public healthcare is underdeveloped (mostly, developing countries) are likely to be unable to cope with this dangerous situation without relevant preparation and equipment. A reduc-

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[1] Vronskii V.A. Ekologiya. Slovar'-spravochnik, 2-e izd. [Ecology. The dictionary and reference book, 2nd ed.]. Rostov-on-Don, Feniks, 2002, 576 p. (in Russian).

[2] Ugryumov A.I. Po svedeniyam Gidromettsentra...: Zanimat. meteorologiya i prognozy pogody [According to the Gidrometeocenter...: Entertaining meteorology and weather forecasts]. St. Petersburg, Gidrometeoizdat, 1994, 230 p. (in Russian).

[3] Oparin R.V., Zhernosenko I.A., Kol'tsov I.A. Problema izmeneniya klimata i zhizn'. Tekhnologiya formirovaniya ekologicheski orientirovannogo mirovozzreniya [Climate change and life. The technology for creating an environmentally-oriented outlook]. Kishinev, Lambert Academic Publishing, 2013, 335 p. (in Russian).

[4] Pivovarov Yu.P., Korolik V.V., Zinevich L.S. Gigiena i osnovy ekologii cheloveka: uchebnik [Hygiene and essentials of human ecology: manual]. Rostov-on-Don, Feniks, 2002, 512 p. (in Russian); Rusanov V.I. Metody issledovaniya klimata dlya meditsinskikh tselei [The methods for examining climate for health purposes]. Tomsk, The Tomsk State University Publ., 1973, 191 p. (in Russian).

tion in greenhouses gases emission due to modernization of vehicles, food products and energy consumption can result in health improvement, especially due to lower levels of ambient air pollution [8].

According to the Report[5] on climatic peculiarities in Russia in 2019, climate changes that have been observed in the country over the last decades follow the overall warming trends. Average annual temperature anomalies (a deviation from the average level in 1961–1990) equaled +2.07 °C. In 2019, average annual temperatures were among five highest ones over the whole observation history in almost every RF region. Negative anomalies were observed only in summer in the North-Western Federal District and Volga Federal District. Growing concentrations of greenhouse gases, primarily carbon dioxide and methane, are considered the basic driver of contemporary warming. Although the global society has been taking substantial efforts to confine greenhouse gases emission into ambient air, their concentrations are only growing further. In 2019 background CO_2 concentrations reached another peak in ambient air at northern latitudes.

We cannot give any unambiguous estimates to influence exerted by warming on climatic conditions for people's lives and activities in Russia. Thus, on one hand, changes in the cryosphere involve a substantial improvement of navigation along the Northern Sea Route. On the other hand, permafrost degradation can result in destruction of house footings and infrastructure. A longer vegetation period created by warming is an obvious bonus for agriculture but it usually entails elevated risks of drought in basic grain-producing regions in the European part of Russia due to precipitation deficiency and higher air temperatures. An observed trend of a shorter heating period and its growing average temperature (up to 0.8 ºC over 10 years in the central Yakutia) makes the existing buildings more thermally effective and stimulates a reduction in energy consumption[6]. Predicted changes in various economic branches due to the observed climate change can become apparent through changes in emerging medical and demographic risks and public health indicators. Regular climatic monitoring and climate change modeling should produce detailed and reliable data about the existing trends in climate change. These data provide the necessary grounds for developing relevant activities aimed at adapting economic branches and human environment to changing climate thereby minimizing climate-induced risks and health harm.

In medicine, cold climate in northern areas is considered an irritating type of climate with typical apparent daily and seasonal ranges of meteorological elements. This climate makes higher demands to adaptation mechanisms. Cold climate in the North is remarkable for its low air temperatures, high relative air humidity, permafrost, polar nights without any solar radiation, strong harsh winds, etc. Peculiarities of this climate induce tension of thermal regulation and hemodynamics in the human body; intensify the basic metabolism and the stomach hypersecretion. They also stimulate adverse changes in the nervous system such as reinforced inhibitory processes, lower conditioned reflex activity, lower working abilities, and sleeping disorders (during the midnight sun). People's reactions and health under exposure to weather factors can be considered disorders of physiological adaptation and outcomes created by an acute meteorological stress. We should note that adverse effects produced by weather are related not so much to absolute values of meteorological parameters but to drastic changes in them. These

[5] Doklad ob osobennostyakh klimata na territorii Rossiiskoi Federatsii za 2019 god [The report on climatic peculiarities in Russia in 2019]. Moscow, Rosgidromet, 2020, 97 p. (in Russian).

[6] Vtoroi otsenochnyi doklad Rosgidrometa ob izmeneniyakh klimata i ikh posledstviyakh na territorii Rossiiskoi Federatsii. Razdel 6. Vozdeistviya izmeneniya klimata na khozyaistvennye ob"ekty i zdorov'e naseleniya. Mery adaptatsii k etim vozdeistviyam [The second estimation report by Rosgidromet on climatic changes and their consequences in the Russian Federation. Section 6. Impacts exerted by climatic change on economic entities and public health. Adaptation to these impacts]. Moscow, The Russian Federal Service for Hydrometeorology and Environmental Monitoring, 2014, pp. 43–56 (in Russian).

changes make higher demands for homeostasis-supporting systems and lead to desynchronization of the internal biorhythms [3].

So, most RF regions are considered territories with adverse climatic conditions. In addition to that, approximately 15–20 % of them are located in zones where high levels of chemical pollution in ambient air (more than 5 $MPC_{av.daily}$) are combined with adverse weather and climatic factors (abnormally low air temperatures, harsh winds, and low insolation). Several priority pollutants are usually detected in ambient air in settlements in such regions. They include benz(a)pyrene, formaldehyde, hydrogen sulfide, particulate matter, hydrogen fluoride, metals (including nickel, copper, aluminum, chromium (VI)), hydrogen chloride, aromatic hydrocarbons etc. They predominantly belong to the 1^{st} or 2^{nd} hazard category[7]. All the aforementioned chemicals and extreme weather and climatic factors can induce restructuring of homeostatic systems in the body; intensify developing deadaptation and strain of the immune-hormone regulation, circulation, and the bronchopulmonary system. They can also make redox processes faster and impair functional state of the barrier organs (liver, kidneys, spleen, lungs, and the immune system) [9–19].

According to the data taken from the IPCC report "Global Warming of 1.5 °C"[8] the most serious and widely spread risks for people, economy and ecosystems are predicted for the Arctic region (Figure 1).

Combined exposure to negative heterogeneous factors can lead to elevated chronic incidence among population. It is especially true for children as they are the most sensitive subpopulation. This is confirmed by higher incidence rates detected on these territories regarding the respiratory diseases, diseases of the nervous and cardiovascular systems. They are by 1.5–2.5 times higher than on average in the country [16].

The outlined problem is rather pressing. This calls for more profound examination of changes in homeostasis indicators that describe negative effects in target organs. This examination makes it possible to substantiate effective prevention of non-communicable diseases associated with combined exposure to chemical and adverse (extreme) climatic factors. The necessity to pay closer attention to impacts exerted by "harsh" weather and climatic factors on public health in the Arctic and sub-Arctic zones in the RF determined topicality of the present study and its goal.

Our research goal was to identify and estimate modifying influence exerted by chemical and climatic health risk factors in the Arctic and sub-Arctic zones at the population and sub-population levels.

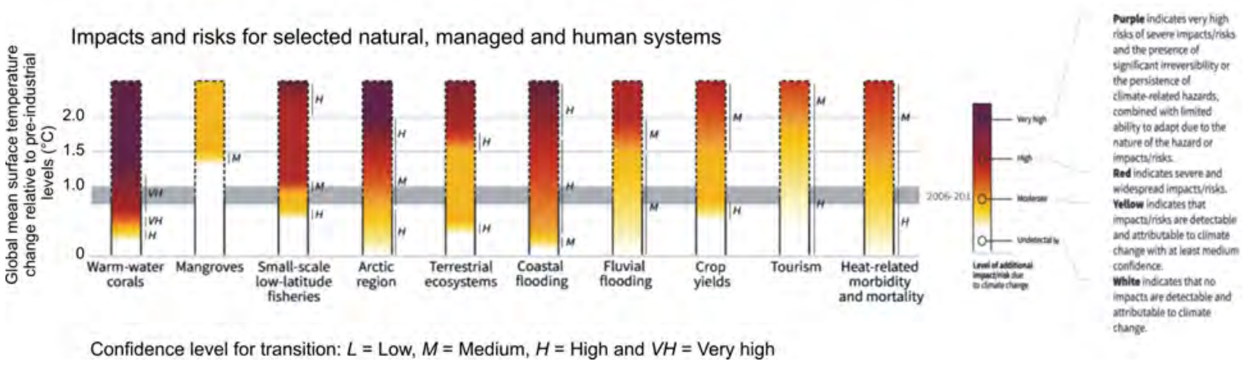

Figure 1. Impacts and risks created by global warming for selected natural, managed and human systems (estimates are based on scientific research and experts' opinions by the IPCC experts)[8]

[7] O sostoyanii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya v Rossiiskoi Federatsii v 2019 godu: Gosudarstvennyi doklad [On sanitary-epidemiological welfare of the population in the Russian Federation in 2019: the State report]. Moscow, The Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 2020, 299 p. (in Russian).

[8] Global Warming of 1.5 °C. *IPCC*. Available at: https://www.ipcc.ch/sr15/ (April 15, 2022).

To achieve that, we set the following research tasks: 1) to quantify influence exerted by climatic risk factors on public health in RF regions located in the Arctic and sub-Arctic zones (the population level); 2) to assess children's health (the sub-population level) under combined exposure to aerogenic chemical factors and adverse climatic factors.

Materials and methods. We took all the initial data for statistical analysis from open and verified sources including statistical forms and reports issued by Rosstat, Rospotrebnadzor, and the RF Public Healthcare Ministry.

We estimated influence exerted by weather and climate on LEB in RF regions that were geographically located in the Arctic and sub-Arctic zones. Our estimates were based on scenario modeling that involved using a digital (neuronet) model in accordance with the Methodical guidelines MR 2.1.10.0269-21[9]. The applied model was based on a matrix with data collected in 2010–2019. The matrix consisted of 148 indicators that were conditionally consolidated into 6 groups: 53 indicators describing sanitary-epidemiological welfare on a given territory; 9 indicators, a public healthcare system; 14 economic indicators; 30 lifestyle-related indicators; 34 sociodemographic indicators; 8 indicators describing weather and climate. The analyzed weather and climate indicators[10] included average monthly air temperatures and precipitation quantity in July and January as well as their deviations from average long-term levels in different RF regions over 2010–2019. Life expectancy at birth (LEB) in a given region was considered a dependent variable. It was estimated based on data[11] collected in 2010–2019 and provided by the Federal Statistic Service.

We took four regions located in the Arctic zone and three regions located in the sub-Arctic zone as example ones in accordance with our goal. The Arctic regions were Yakutia (the northern part), Chukotka (the northern part), the Yamal Nenets Autonomous Area (the northern part), the Krasnoyarsk region (the northern part, more exactly, Norilsk municipal district and Taimyr Dolgan-Nenets municipal district). The sub-Arctic regions were the Magadan region (its continental part), Murmansk region (the northern part), and the Nenets Autonomous Area.

Estimating influence exerted by weather and climate factors on public health in the Arctic and sub-Arctic regions in the RF. Influence exerted by weather and climate on LEB losses was determined by conducting a series of numerical experiments using three sequential computation stages described in our previous article [20]. At the first stage, we substituted values of indicators reflecting weather and climatic conditions in a specific region (a reference region) for all the regions in the RF. All the other variables (determinants) retained their basic value. The second stage involved determining a region in the RF with the greatest losses in LEB, which was conditionally considered the most "favorable" against weather and climatic conditions in a reference region. At the third stage, we determined losses in LEB against a "favorable" region, which were caused by weather and climatic conditions; the procedure was repeated for all Arctic and sub-Arctic regions in the RF. The algorithm was sequentially applied to examine each RF region used as a reference one against other regions in the country. Resulting losses in LEB for each examined Arctic or sub-Arctic region were estimated by averaging values obtained at the third stage.

We established what effects weather and climate produced on LEB over 2010–2019 by

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[9] MR 2.1.10.0269-21. Opredelenie sotsial'no-gigienicheskikh determinant i prognoz potentsiala rosta ozhidaemoi prodolzhitel'nosti zhizni naseleniya Rossiiskoi Federatsii s uchetom regional'noi differentsiatsii: Metodicheskie rekomendatsii [MR 2.1.10.0269-21. Identification of socio-hygienic determinants and predicted potential growth in life expectancy at birth for the RF population considering regional differentiation: The Methodical guidelines]. Moscow, 2021, 113 p. (in Russian).

[10] Rossiiskii statisticheskii ezhegodnik. 2019: Statisticheskii sbornik [Russian annual statistical data collection. 2019: Statistical data collection]. *Rosstat*. Moscow, 2019, 708 p. (in Russian).

[11] Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli. 2019: R32 Statisticheskii sbornik [Regions in Russia. Socioeconomic indicators. 2019: P32 Statistical data collection]. *Rosstat*. Moscow, 2019, 1204 p. (in Russian).

using scenario neuronet modeling. We took actual data on socio-hygienic determinants registered in 2010 as our baseline scenario. A target scenario was set by keeping all the social and hygienic determinants at their baseline level except from indicators that characterized weather and climatic conditions in the analyzed RF regions. These indicators were set at their values determined for 2019. We determined effects produced by weather and climate on changes in LEB in the analyzed RF regions by calculating a difference between a baseline and target scenario.

Krasnoyarsk region has a huge territory and is located in different climatic zones. Bearing this in mind, we selected one representative territory to estimate influences exerted by weather and climate on LEB in the Arctic zone in this region. This territory was Norilsk. The algorithm applied to calculate influence exerted by weather and climate on LEB was similar to calculations performed for other analyzed RF regions. To determine climatic peculiarities in Norilsk, we took the data on average air temperature and precipitations in July and January obtained at "Norilsk. Alykel" monitoring post (No. 23078). We took statistical data obtained for the whole Krasnoyarsk region for the remaining analyzed indicators.

Changes in weather and climatic indicators were analyzed in dynamics as per their average growth rates over the period from 2010 to 2019.

Assessing health of children living under combined exposure to weather and climatic factors in the Arctic / sub-Arctic zone and high levels of aerogenic chemical exposure. This stage involved examining health of children aged 3–6 years. They lived in regions with either isolated exposure to adverse weather and climatic factors typical for a sub-Arctic zone (the test group A was made of 72 children) or with combined exposure to high levels of chemical pollution in ambient air and adverse weather and climatic factors (the test group B included 184 children). Our reference groups included children of the same age who lived in regions with moderate continental climate (the reference group A for the test group A) and in regions with sub-Arctic climate where chemical aerogenic exposure was either absent or negligible (the test group A as a reference group for the test group B). All the children were examined in full conformity with the WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects, 2013. The examinations were approved according to the conventional procedure by the Committee on Biomedical Ethics of the Federal Scientific Center for Medical and Preventive Health Risk Management Technologies. Legal representatives of all the participating children gave their informed voluntary consent to the participation prior to the examinations.

We estimated combined aerogenic exposure to chemicals in ambient air as per contents of aluminum, fluoride-ion, copper and nickel in biological media. According to the Methodical guidelines MUK 4.1.773-99, 4.1.3230-14, 4.1.3589-19 that are valid in the RF, chemical and analytical tests to determine copper and nickel in blood and aluminum and fluoride-ion in urine were performed by using mass spectrometry and ion-selective potentiometry with the following equipment: Agilent 7500cx mass spectrometer with inductively coupled argon plasma (Agilent Technologies, USA), ILA-2 laboratory automated ionometer (Izmeritelnaya tekhnika, Russia). We comparatively assessed indicators in the children from the test groups and those in the children from the reference ones. The assessment involved calculating significance of difference between two independent samplings with using non-parametric Mann – Whitney test ($U \leq U_{cr}$). The level of significance was taken as $p \leq 0.05$ when statistical hypotheses were tested.

To identify possible negative effects in target organs, we examined relevant biochemical and general clinical indicators. They included levels of erythrocytes, leucocytes, and hemoglobin; erythrocytes sedimentation rate (ESR); eosinophils and neutrophils in nasal secretions; eosinophilic index; apolipoproteins A1 (*Apo-A1*) and B100 (*Apo-B*); contents of the thyrotrophic hormone (*TTH*), thyroxin (*T4*), hydrocortisone, and neurotropin-3 in blood serum; levels of catecholamines (adrenaline, dopamine, noradrenaline, and serotonin) in blood plasma.

Data on incidence among the examined children were analyzed as per results obtained by a complex objective medical examination[12]. It fully met the criteria of the International Classification of Diseases (ICD-10) and involved identifying a number of disease cases at the moment the examination took place. Priority diseases, critical organs and system taken into account, were identified based on authentically higher prevalence in a test group against a reference one ($p \leq 0.05$).

Complex impacts exerted by weather and climatic factors in the sub-Arctic zone (air temperature and humidity, wind speed) were estimated as per the normal equivalent effective temperature (NEET). The NEET was calculated as per the formulas introduced by A. Missenard[13] and I.V. But'eva[14]. The NEET values varying from 12 to 24 °C were considered comfortable and sub-comfortable [11]. Hygienic assessment of ambient air quality was performed using data obtained at control points within social and hygienic monitoring activities in 2014–2018.

Statistical analysis and calculations were performed in mathematical computation packages for PC (Statistica 10, RStudio, MS Excel 2010). We applied geoinformation systems (ArcGIS 9.3.1) to visualize our cartographic materials.

Results and discussion. Most RF regions are located in zones with relatively harsh climate. According to the classification[15] created by B.P. Alisov, a scientist and climatologist, Russia is located in three climatic zones, namely, Arctic, sub-Arctic and moderate one. The Arctic Ocean seaboard in Siberia and its islands (the southern island of the Novaya Zemlya excluded) as well as some islands in the Barents Sea are located in the Arctic zone[16] (Figure 2).

In 2019, the lowest average monthly temperatures among all the analyzed RF regions were registered in Yakutia, Magadan region and Chukotka (-34.1 ºC; -27.4 ºC; -23.6 ºC accordingly). The highest average monthly temperatures in July were registered in the Yamal Nenets Autonomous Area, Yakutia, and Magadan region (15.2 ºC; 14.3 ºC; 12.7 ºC accordingly). The greatest average monthly precipitation in January was registered in Murmansk region, the Nenets Autonomous Area and the Yamal Nenets Autonomous Area (37.7; 23.1; 22.6 mm accordingly); in July, in Magadan region, Murmansk region and Yakutia (60.5; 60.4; 52.6 mm accordingly).

If we take basic weather indicators in dynamics over 2010–2019 in the analyzed RF regions in the Arctic and sub-Arctic zones, we can see that average monthly temperatures in July grew by 3.4 % on average (within a range from 0.3 to 5.9 %). Average monthly precipitation in July and January also increased, by 15.1 % and 13.0 % accordingly. Average monthly temperatures in January and July grew by 4.5 % and 1.9 % accordingly on the territories located predominantly in the sub-Arctic climatic zone (Murmansk and Magadan regions). These temperature indicators increased by 2.1 % and 4.2 % accordingly on the mixed-type territories (located in both Arctic and sub-Arctic zones) (Table 1). Average monthly temperatures in July and January grew by 1.2 ºC and 1.9 ºC on average against average long-term values in all the analyzed regions.

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[12] The field medical examination was performed by experts from the Department for Children and Adolescents Hygiene (headed by S.L. Valina, Candidate of Medical Sciences).

[13] Missenard A. L'homme et le climat. Paris, Plon, 1937, 270 p. (in French).

[14] But'eva I.V., Sheinova T.G. Metodicheskie voprosy integral'nogo analiza mediko-klimaticheskikh uslovii [Methodical issues in integral analysis of medical and climatic conditions]. *Kompleksnye bioklimaticheskie issledovaniya*, 1988, pp. 97–108 (in Russian).

[15] Khromov S.P., Petrosyants M.A. Meteorologiya i klimatologiya: uchebnik, 7-e izd. [Meteorology and climatology: manual, 7th ed.]. Moscow, The Moscow University Publ.; Nauka, 2006, 582 p. (in Russian).

[16] O sostoyanii i ob okhrane okruzhayushchei sredy Rossiiskoi Federatsii v 2018 godu: Gosudarstvennyi doklad [The State Report "On the ecological situation and environmental protection in the Russian Federation in 2018"]. Moscow, The Ministry of the Environment and Natural Resources; NPP "Kadastr", 2019, 844 p. (in Russian).

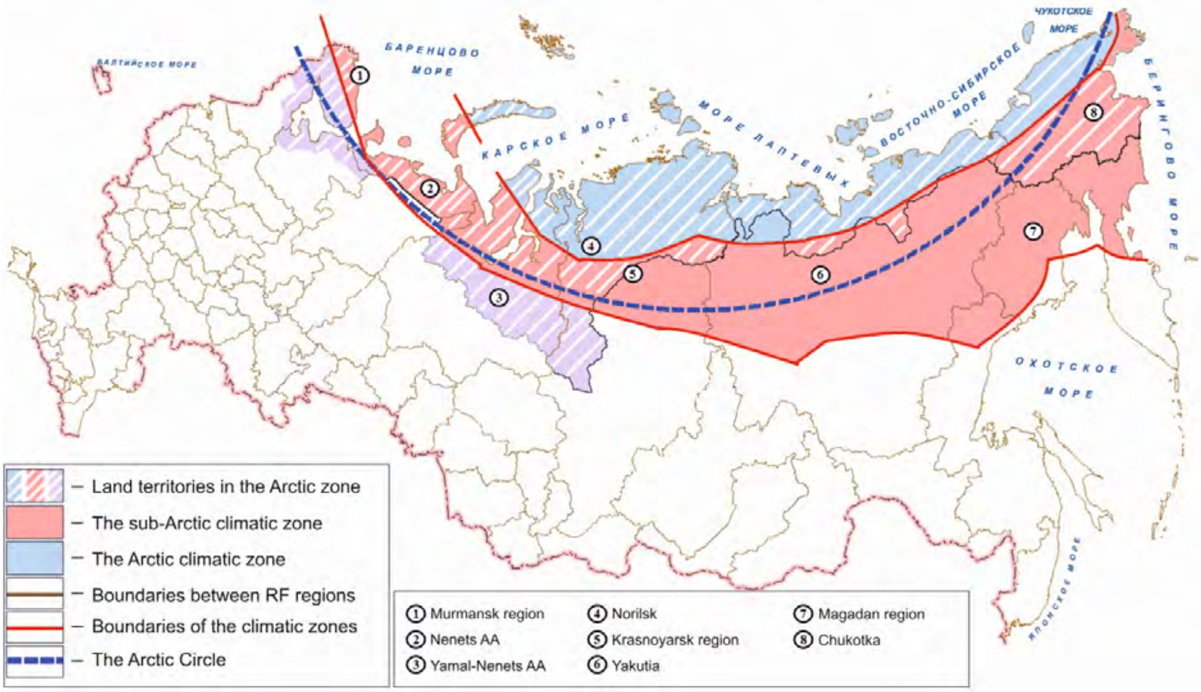

Figure 2. A map showing Arctic and sub-Arctic climatic zones in the RF

Table 1

Changes in weather and climatic indicators taken in dynamics over 2010–2019 as per average growth rates, %

RF region	Climate	Average monthly temperature (January, ºC), % (as per module)	Average monthly temperature (July, ºC), %	Average monthly precipitation (January, mm), %	Average monthly precipitation (July, mm), %
Krasnoyarsk region (the northern part)	Arctic and sub-Arctic	1.0	+1.6	+8.6	+7.0
Nenets AA	Arctic and sub-Arctic	5.6	+5.8	+5.8	+24.2
Yakutia (the northern part)	Arctic and sub-Arctic	1.1	+1.4	+5.4	+1.6
Chukotka	Arctic and sub-Arctic	0	+3.8	+10.1	+6.5
Yamal Nenets AA (the northern part)	Arctic and sub-Arctic	1.7	+5.9	+6.4	+30.9
Magadan region (the continental part)	Sub-Arctic	1.0	+0.3	+44.1	+24.3
Murmansk region (the northern part)	Sub-Arctic	8.0	+3.4	+6.3	+3.2

We accomplished scenario modeling using actual data on the analyzed climatic features. Its results allowed us to obtain differentiated estimates of emerging influence exerted on LEB by Arctic and sub-Arctic weather and climate on the analyzed territories. Climate-induced losses in LEB vary from 164 days in Yakutia to 349 days in Chukotka (Figure 3). Average loss in LEB due to weather and climate amounted to 191.7 days in the RF as a whole[4].

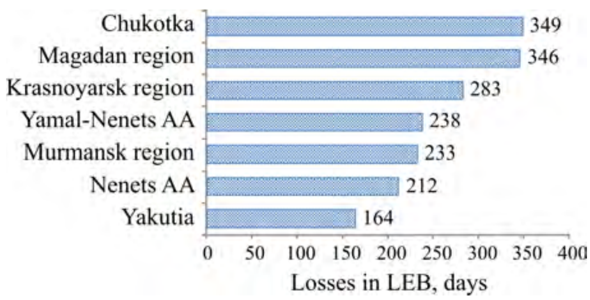

Figure 3. Losses in LEB due to weather and climate, 2018, days

The climate change observed over the last decade in the Arctic and sub-Arctic zones has produced an apparent effect on the integral health indicator, life expectancy at birth. Over 2010–2019 LEB grew on average by 9.7 % in all the RF regions located in the Arctic and sub-Arctic zones. This growth appeared within a range from 4.9 % in Murmansk region up to 18.4 % in Chukotka. The LEB levels were 68.1–74.2 years in these regions (Table 2). The greatest growth in LEB in the analyzed period was established in Chukotka where it equaled 10.6 years; it should be noted that in 2010 the regional LEB there was the lowest in the RF and was equal to 57.5 years.

All the influence of weather and climate in the analyzed period produced variable effects on LEB, either negative, such as its decline in Magadan region, the Nenets Autonomous Area, Chukotka and the Yamal Nenets Autonomous Area (-254; -211; -109 and -8 days accordingly), or positive ones as the growth in it by 111 days in Yakutia. A contribution made by influence of weather and climate to the actual LEB levels varied from -13.2 % (Magadan region) to 4.9 % (Yakutia) according to the results produced by scenario modeling (Table 2). The greatest positive influence exerted by the registered changes in weather and climate was detected in Yakutia where it equaled 111 days. The actual growth in LEB in this region was among the highest detected on the analyzed territories over 2010–2019 (6.3 years). This can be due to both complex and systemic improvement in the sanitary-epidemiological wellbeing on the territory, the socio-demographic situation and people's lifestyle and to gradual changes in weather and climate that have become warmer.

Mostly favorable effects of changes in weather in climate on LEB can probably be due to more favorable navigation conditions along the Northern Sea Route, a longer vegetation period necessary for agriculture, and a declining pressure on regulatory systems in the human body that maintain its adaptation capabilities etc[6]. Still, this influence by weather and climate on LEB turned out to be negative on some territories (Magadan region, the Nenets Autonomous Area, Chukotka, and the Yamal Nenets Autonomous Area). This is probably due to several reasons including soil degradation due to permafrost transformation and thawing followed by destruction of house footings and civil engineering infrastructure; greater areas where blood-sucking arthropods occur; violated balance between local ecosystems; some other reasons for growing population incidence and mortality [8]. Besides, the highest amplitudes were established in Magadan region over 2010–2019 regarding average monthly precipitation in January and July (47 and 96 mm); and there was one of the highest amplitudes of average monthly temperature in January (10.6 ºC) in the region. This indicates there were drastic differences in weather and climatic conditions over the analyzed decade. Such changes can produce negative effects on human health as they exacerbate chronic diseases, create additional burden on adaptation systems in the human body and make socioeconomic conditions worse.

Table 2

Assessment of probabilistic influence exerted by weather and climate on LEB in 2010–2019

RF region	Climate	LEB in 2019 in a given RF region, years	Actual change in LEB over 2010–2019, days (years)	Influence by weather and climate and its contribution to change in LEB over 2010–2019, days (%)
Krasnoyarsk region (the northern part)	Arctic and sub-Arctic	69.8	821.3 (2.3)	49.0 (5.9)
Nenets AA	Arctic and sub-Arctic	73.2	3 019.0 (8.3)	-211.0 (-7.0)
Yakutia (the northern part)	Arctic and sub-Arctic	73.0	2 281.0 (6.3)	111.0 (4.9)
Chukotka	Arctic and sub-Arctic	68.1	3 869.0 (10.6)	-109.0 (-2.8)
Yamal Nenets AA (the northern part)	Arctic and sub-Arctic	74.2	1 507.0 (4.1)	-8.0 (-0.5)
Magadan region (the continental part)	Sub-Arctic	69.7	1 675.0 (4.6)	-254.0 (-13.2)
Murmansk region (the northern part)	Sub-Arctic	71.8	1 212.0 (3.3)	13.0 (1.1)

Table 3

Indicators of negative effects in children exposed to adverse weather and climatic factors in the sub-Arctic zone

Indicator	The test group A, $\bar{X} \pm SEM$	The reference group A, $\bar{X} \pm SEM$	Authenticity of differences $p \leq 0.05$
Blood			
Erythrocytes, $10^{12}/dm^3$	4.71 ± 0.06	4.41 ± 0.07	0.0001
Hemoglobin, g/dm^3	132.87 ± 1.72	132.71 ± 1.63	0.900
Leucocytes, $10^9/dm^3$	6.68 ± 0.35	5.85 ± 0.38	0.0001
ESR, mm/hour	7.53 ± 0.65	4.35 ± 0.38	0.0001
Blood serum			
TTH, $\mu IU/cm^3$	3.45 ± 0.22	2.43 ± 0.23	0.0001
Free T4, $pmol/dm^3$	12.37 ± 0.29	13.76 ± 0.32	0.0001
Apo-B/ApoA1, g/dm^3	0.57 ± 0.027	0.45 ± 0.035	0.0001
Apo A1, g/dm^3	1.42 ± 0.03	1.69 ± 0.09	0.0001
Apo-B, g/dm^3	0.82 ± 0.03	0.72 ± 0.04	0.0001
Hydrocortisone, $nmol/cm^3$	241.59 ± 18.71	281.85 ± 31.89	0.040
Blood plasma			
Adrenaline, pg/cm^3	79.49 ± 2.01	69.55 ± 3.97	0.0001
Dopamine, pg/cm^3	58.44 ± 2.9	59.35 ± 3.91	0.710
Noradrenaline, pg/cm^3	383.99 ± 19.29	384.23 ± 24.22	0.990
Serotonin, ng/cm^3	99.18 ± 13.57	250.06 ± 29.05	0.0001

We assessed influence exerted by weather and climate on LEB on the territories in Krasnoyarsk region located in the Arctic and sub-Arctic zone. The assessment revealed that, in spite there was a certain decline in average monthly temperatures in January (from -23.2 ºC in 2010 to -24.8 ºC in 2019 in Norilsk) and a significant increase in average monthly temperatures in July (from 12.3 ºC to 17.2 ºC), the detected climatic trends resulted in a growth in LEB that equaled 49 days over the analyzed period (Table 2).

We assessed how weather and climate influenced children's health. The assessment revealed that children living in the sub-Arctic zone were exposed to adverse weather and climatic factors (the NEET index being lower by 4.3 times and daily drops in atmospheric pressure being by 2.4 times higher and with a greater amplitude), which were absent on the reference territory (with moderate continental climate).

The children from the test group A had statistically significant changes in blood indicators under exposure to the analyzed adverse weather and climatic factors. Levels of leucocytes and ESR in blood were by 1.7 times higher in them than in the children from the reference group A (Table 3). This may indicate developing inflammatory reactions, first of all, in the upper airways.

We discovered strain in the thyroid function indicated by 1.4 times higher TTH levels in blood serum against the same indicator in the reference group A (p = 0.0001). According to data available in peer-reviewed sources, levels of thyroid hormones in blood tend to grow under exposure to low air temperatures and especially to drops in them. These hormones facilitate compensatory tolerance to effects produced by low temperatures due to growing oxygen consumption and greater heat production [14, 15]. Long-term strain in the thyroid function can disrupt ventricle relaxation and induce supraventricular arrhythmia, elevated blood pressure and a further cascade of pathological processes that ultimately lead to vascular disorders [21].

We comparatively assessed certain indicators of the lipid spectrum in the children from the test group A and the reference group A. As a result, we revealed that *Apo A1* levels were by 1.2 times lower and *Apo-B* and *Apo-B/ApoA1* levels were by 1.3 times higher in blood serum in the test group A (p = 0.0001). This can be considered a risk of early developing vascular disorders. Detected changes in apolipoproteins are confirmed by the results of proteome profile analysis, which allow assuming probable negative effects concerning endothelial dysfunction. We established changes in apolipoprotein A1

(*APOA1* gene), apolipoprotein C-II (*APOC2* gene), apolipoprotein C-III (*APOC3* gene), amyloid protein A-1 (*SAA1* gene), and P2Y purinoceptor 12 (*P2RY12* gene).

Atherosclerotic changes in vessels develop from early endothelial dysfunction to atherosclerotic plagues. These processes involve cardiac muscle hypoxia and production of pro-inflammatory cytokines that induce local arrhythmogenic activity. The latter develops with participating disorders of the sympathoadrenal regulation [22]. Given that, we should mention rather alerting changes in certain hormones and neuromediators. They indicate that the sympathoadrenal system has been deregulated. Thus, the children in the test group A had by 1.2–2.5 times lower levels of hydrocortisone and serotonin (p = 0.0001–0.040) together with elevated adrenaline contents in blood (p = 0.0001) against their counterparts from the reference group A. Low hydrocortisone correlates with impaired central regulation of corticotrophin-releasing factor production. This regulation is performed by the limbic system of the brain linked with production of neurotransmitters, serotonin included [23]. Imbalance between catecholamines and serotonin secretion in blood under exposure to adverse climatic factors is probably a sign that the protective and adaptive functions of the body have been impaired. This makes for lower resistance to hyperthermia and hypoxia as well as deteriorated endogenous vasomotion in the cardiac muscle tissues and impaired metabolism of cardiomyocytes [24].

The next step was to perform comparative analysis of chemical contents in blood under aerogenic exposure to chemical factors (copper, nickel, aluminum, and gaseous fluorides in concentrations from 0.005 mg/m^3 to 0.02 mg/m^3 or from 1.5 to 7.5 $MPC_{av.daily}$). We established that the exposed children had elevated copper and nickel concentrations in blood and aluminum and fluoride-ion in urine that were by 1.2–3.0 times higher and by 2.5–4.0 times higher accordingly than the same indicators in the non-exposed children and by 3.5–6.0 times higher than the reference levels. Elevated contents of toxic chemicals in biological media can result in a wider range and more apparent negative health outcomes in exposed children. We identified a set of indicators with their deviation clearly showing that negative effects were developing as a response to combined exposure to chemical and adverse climatic factors. These effects included sensitization of the upper and lower airways (eosinophils being by 1.2 times higher in nasal secretion and elevated total IgG in blood); impaired balance of neuromediators (acetylcholine being lower by 1.2 times and serotonin being by 1.9 times higher in blood serum); changes in the humoral immunity (lower *IgA*, *IgM* levels in blood); disrupted recovery of damaged neuronal structures (neurotropin-3 being by 1.3 times higher in blood serum) (Table 4).

The established changes occur in biochemical indicators that characterize developing negative effects in target organs, namely, the endocrine, nervous and circulatory systems. These changes are actually confirmed by elevated frequency of developing relevant diseases. Thus, the children who live under combined exposure to chemical and adverse weather and climatic factors suffer from respiratory diseases (hypertrophy of tonsils, chronic rhinitis) by 1.7 times more frequently than their counterparts from the reference group (p = 0.010–0.024); circulatory diseases (sick sinus syndrome), by 5.6 times more frequently (p = 0.0001–0.007); diseases of the nervous system (functional disorders), by 2.6 times more frequently (p = 0.031); diseases of the endocrine system (other disorders of thyroid), by 1.2 times more frequently (p = 0.033) (Table 5).

We established rather alerting frequency of thyroid diseases (5.9 %) and cardiomyopathy (5.9 %) in the children from the test group B whereas the children from the test group A did not have these diseases at all (p = 0.010). The data on frequency of certain diseases in the examined children are consistent with the results of foreign and Russian studies indicating that adverse climate and chemical factors contribute to developing respiratory and neuroendocrine diseases. A share contribution made by chemical factors to associated respiratory diseases reached 31.0 %; diseases of the nervous system, 25 %. A contribution made by adverse weather and climatic factors to associated respiratory diseases and diseases of the nervous system equaled 12 % and 10 % accordingly.

Table 4

Indicators of negative effects in children under combined exposure to adverse weather and climatic factors in the sub-Arctic zone and aerogenic chemical factors

Indicator	Average group value, $\bar{X} \pm SEM$		Authenticity of inter-group differences, $p \leq 0.05$
	The test group B	The test group A	
Nasal secretion			
Eosinophilic index, %	1.890 ± 0.426	2.001 ± 0.682	0.789
Neutrophils, units in field of view	22.806 ± 1.621	21.956 ± 2.753	0.602
Eosinophils, units in field of view	5.931 ± 1.874	5.112 ± 1.029	0.046
Blood			
Hemoglobin, g/dm^3	133.27 ± 1.36	132.87 ± 1.72	0.721
Erythrocytes, 10^{12}/dm^3	4.77 ± 0.05	4.71 ± 0.06	0.127
Leucocytes, 10^9/dm^3	6.28 ± 0.32	6.68 ± 0.35	0.104
ESR, mm/hour	5.79 ± 0.82	7.53 ± 0.65	0.002
Blood serum			
Total IgE, IU/cm^3	106.92 ± 29.45	100.60 ± 18.724	0.039
Neurotropin-3, pg/cm^3	8.39 ± 1.26	6.74 ± 1.05	0.048
Acetylcholine, pg/cm^3	28.18 ± 1.33	33.02 ± 2.09	0.0001
IgG, g/dm^3	10.23 ± 0.22	11.39 ± 0.38	0.0001
IgM, g/dm^3	1.39 ± 0.04	1.49 ± 0.06	0.011
IgA, g/dm^3	1.22 ± 0.05	1.34 ± 0.08	0.022
ApoB/ApoA1, g/dm^3	0.59 ± 0.03	0.57 ± 0.03	0.191
Apolipoprotein A1, g/dm^3	1.61 ± 0.09	1.42 ± 0.03	0.0001
Apolipoprotein B-100, g/dm^3	0.89 ± 0.03	0.82 ± 0.03	0.001
Free T4, pmol/dm^3	13.43 ± 0.16	12.42 ± 0.36	0.095
TTH, µIU/cm^3	2.93 ± 0.15	3.20 ± 0.25	0.069
Hydrocortisone, nmol/cm^3	277.28 ± 20.60	241.59 ± 18.71	0.141
Blood plasma			
Dopamine, pg/cm^3	62.35 ± 2.01	58.44 ± 2.94	0.034
Noradrenaline, pg/cm^3	389.46 ± 12.75	383.99 ± 19.29	0.637
Adrenaline, pg/cm^3	77.49 ± 1.54	79.49 ± 2.01	0.122
Serotonin, ng/cm^3	185.24 ± 14.88	99.18 ± 13.57	0.0001

Table 5

Frequency of diseases in the groups: comparative analysis, %

Category of diseases / Nosology (ICD-10)	Frequency in the test groups, %		Authenticity of inter-group differences ($p \leq 0.05$)
	The test group B	The test group A	
Diseases of the respiratory system (J00–J99), including:	59.2	44.9	0.010
- hypertrophy of tonsils (J35.1)	24.8	14.7	0.024
- chronic rhinitis (J31.0)	19.3	8.7	0.003
Diseases of the circulatory system (I00–I99), including:	18.8	5.5	0.0001
- cardiac murmur, unspecified (R01.0)	5.9	0.0	0.010
- sick sinus syndrome (I49.5)	10.1	1.8	0.007
Endocrine diseases (E00–E920), including:	53.7	44.95	0.033
- other disorders of thyroid (E07)	5.9	0.0	0.010
Functional disorders of the CNS and ANS including: - autonomic dysfunction (G90.8); - asthenoneurotic syndrome (G93.8)	11.9	4.6	0.031

Conclusions:

1. Over 2010–2019 average monthly air temperatures grew by 3.4 % on average (within a range from 0.3 to 5.9 %) on the analyzed territories in the RF regions located in the Arctic and sub-Arctic zones. Average monthly precipitation grew by 15.1 % and 13.0 % in July and January accordingly. Average monthly temperatures in January and July grew by 4.5 % and 1.9 % accordingly on the territories located

predominantly in the sub-Arctic climatic zone (Murmansk and Magadan regions). On the mixed-type territories (located in both Arctic and sub-Arctic zones), these temperatures grew by 2.1 % and 4.2 % accordingly. Air temperatures in July and January deviated from average long-term values towards growth by 1.2 ºC and 1.9 ºC accordingly. Overall, the detected changes, namely, growing average monthly temperatures and precipitations as well as their average annual deviations are well in line with the current climatic theory on global warming.

2. We established losses in LEB due to weather and climate on the analyzed territories against the background influence exerted by a set of social-hygienic determinants within a range from 349 days (Chukotka) to 164 days (Yakutia). The greatest losses were detected in Chukotka and Magadan region (349 and 346 days accordingly)

3. Climate warming detected over the last decade in the Arctic and sub-Arctic zones has resulted in variable effects produced by weather and climate on LEB. The greatest positive effects are detected in Yakutia (the northern part) where LEB has grown by 111 days and Krasnoyarsk region (the northern part), growth by 49 days. The greatest negative effects are detected in Magadan region where LEB has declined by 254 days

4. The established effects produced by weather and climate on human health are in line with the current estimates given by experts from the governmental and international organizations. The experts believe these effects to be rather ambiguous given the future prospects in global warming development. This requires further research aimed at establishing multiple effects produced by weather, climatic and meteorological factors on the medical-demographic situation including that existing on the arctic territories in the Russian Federation.

5. Long-term combined exposure to aerogenic chemical and adverse weather and climate factors has resulted in negative health outcomes in children aged 3–6 years. We established changes in biochemical and clinical indicators that characterized these effects. They included strain in the thyroid function, developing inflammatory processes, a risk of early vascular disorder, impaired endogenous vasomotion in the cardiac muscle tissues and neuroendocrine regulation. These negative effects were confirmed by elevated prevalence of respiratory lymphoproliferative diseases, functional disorders of the nervous, endocrine and circulatory systems. It was by 5.6 times higher than in the reference group. A contribution made by chemical factors to respiratory diseases and diseases of the nervous system equaled 25–31 %; a contribution made by adverse weather and climatic factors was 10–12 %.

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