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Chemical pollution in Arctic cities: public health risk assessment and solutions

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Abstract. The research presents characteristics of non-carcinogenic and carcinogenic inhalation and aquatic chemical risk caused by chemical pollutants of atmospheric air and drinking water exposure to the health of the population of the Arctic city of Salekhard. It has been established that carcinogenic risks with inhalation exposure to chromium, soot and formaldehyde as well as with oral exposure to cadmium, beryllium, lead and hexavalent chromium correspond to the upper limit of the acceptable risk and are subject to constant monitoring. The risk of oral exposure to arsenic needs to be minimized through the development and implementation of additional health measures. The calculated indices of non-carcinogenic risk for inhalation and oral exposure, not exceeding 1.0, that shows a low probability of adverse effects from critical organs / systems.

Keywords: environmental pollution, inhalation risk, water risk, risk assessment, health of the Arctic population

Authors' contributions: *M.A. Rusakova* – the concept and design of the study, collection and processing of material, writing a text; *R.A. Kolesnikov* – collection and processing of material, redaction; *E.V. Shinkaruk* – collection and processing of material, redaction. All authors are responsible for the integrity of all parts of the manuscript and approval of final version.

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Химическое загрязнение арктических городов: оценка рисков здоровью населения и пути решения

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Аннотация. Представлены результаты расчета канцерогенного и неканцерогенного ингаляционного и водного химического риска, обусловленного воздействием химических загрязнителей атмосферного воздуха и питьевой воды, для здоровья населения арктического города Салехард. Установлено, что канцерогенные риски при ингаляционном воздействии шестивалентного хрома, сажи и формальдегида, при пероральном – кадмия, бериллия, свинца и шестивалентного хрома соответствуют верхней границе приемлемого риска и подлежат постоянному контролю. Риск, связанный с пероральным воздействием мышьяка, требует разработки и проведения плановых оздоровительных мероприятий. Рассчитанные индексы неканцерогенной опасности при ингаляционном и пероральном воздействии, не превышающие 1,0, свидетельствуют о низкой вероятности проявления неблагоприятных эффектов со стороны критических органов/систем.

Ключевые слова: загрязнение окружающей среды, ингаляционный риск, водный риск, оценка риска, здоровье населения Арктики

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Introduction

Even minimal anthropogenic risks, which seem insignificant for industrial regions from the middle zone, are unacceptable for the Arctic territories. The vulnerability of the north nature and the long period of its recovery, extreme natural and climatic factors that affect human life negatively, dictate strict requirements for environmental safety [1].

Severe climatic conditions of Salekhard city depend on its location on the Arctic Circle. The population undergo high functional stress on the body. It is causes by frequent magnetic disturbances, "ultraviolet starvation", sharp fluctuations in atmospheric pressure, low air humidity, a decrease of oxygen density in the air, low temperatures, disturbances in homeostasis, vitamin status, nutritional structure, photoperiodicity and many others factors that increase the sensitivity to pollutants and leads to a high risks for health [2–6]. So, it became important to minimize the risks of anthropogenic impact to the population health.

Works of risk assessment has shown its value for identifying main pollutants and improving chemical safety management [7–10].

The purpose of our research is to assess the non-carcinogenic and carcinogenic inhalation and water chemical health risk of the population of the Salekhard city in connection with the impact of chemical environmental factors and creating risk management solutions.

The particularity of the work is to carry out a complex and multistage process: from identifying the probability of a negative effect on human health caused by exposure to chemically contaminated atmospheric air and potable water as well as assessing the consequences of this impact to measures development for preventing and reducing it.

Materials and methods

As a methodological basis for the work, the "Guidance for the assessment of risk to human health when exposed to chemicals that pollute the environment" R 2.1.10.1920-04, approved by the chief state sanitary doctor of the Russian Federation on March 05, 2004 (hereinafter – R 2.1.10.1920-04) was used[1].

Calculations of the dispersion of noxious substances in the atmosphere were performed using the unified program for calculating the level of atmospheric pollution "Ecolog", version 4.6, which implements methods for calculating the dispersion of emissions of pollutants in the air[2].

Analysis of information on emissions from stationary sources to assess inhalation risk is based on data from the annual forms of state statistical reporting "2-TP Air", Federal and Regional registers of objects that have a negative impact on the environment for 2019. The basis for the assessment of water chemical risk was the water supply and sewerage scheme of the Salekhard city and data from the results of monitoring carried out by the federal budgetary health institution "Center for Hygiene and Epidemiology in the Yamal-Nenets Autonomous Okrug".

[1] Guidance for the Human Health Risk Assessment from Environmental Chemicals. R 2.1.10.1920-04. Moscow: Federal'nyy tsentr gossanepidnadzora Minzdrava Rossii. (In Russ.) Available from: http://docs.cntd.ru/document/1200037399 (accessed: 30.03.2022).

[2] Order of the Ministry of Natural Resources and Environment of the Russian Federation №. 273 of 6 June 2017 "On approval of methods for calculating the dispersion of emissions of harmful (polluting) substances in the air". (In Russ.). Available from: https://docs.cntd.ru/document/456074826 (accessed: 30.03.2022).

Results

Inhalation chemical health risk assessment 67 substances in the amount of 3077.529 t / year from 163 sources of emissions enter the atmospheric air on the territory of the Salekhard city. The average annual concentrations of toxic substances entering the atmospheric air with emissions do not exceed the admissible concentration limits.

26 main air pollutants were selected, taking into account their danger and the amount of emissions into the atmosphere for further analysis.

Blood, cardiovascular system, respiratory organs, immune system, central nervous system, reproductive system, endocrine system, kidneys, liver are most vulnerable to inhalation exposure to selected air pollutants. 2 substances (sulfur dioxide, suspended solids) can cause death.

According to the Guide R 2.1.10.1920-04 individual carcinogenic risks throughout life depend on lead, benzene, ethylbenzene, benz(a)pyrene, tetrachloromethane and acetaldehyde exposure, less than 10^{-6} causes to one additional case of serious illness or death per more than 1 million individuals but all other people perceive them as negligible usual risks (see Table 1).

Table 1. Carcinogenic risks from exposure to priority air pollutants

Code	Substance	Individual carcinogenic risk		Population carcinogenic risk		Population annual risk	
		Residential development		Residential development		Residential development	
		min	max	min	max	min	max
184	Lead	9.59E-12	2.46E-10	1.50E-08	3.85E-07	2.14E-10	5.50E-09
203	Chromium	2.76E-08	4.65E-06	4.32E-05	7.28E-03	6.16E-07	1.04E-04
328	Soot	2.10E-07	5.18E-06	3.28E-04	8.10E-03	4.69E-06	1.16E-04
602	Benzene	2.38E-08	4.66E-07	3.73E-05	7.30E-04	5.33E-07	1.04E-05
627	Ethylbenzene	8.86E-11	1.73E-09	1.39E-07	2.71E-06	1.98E-09	3.88E-08
703	Benz(a)pyrene	3.42E-10	2.71E-09	5.36E-07	4.24E-06	7.65E-09	6.06E-08
906	Tetrachloromethane	4.67E-12	9.10E-11	7.65E-09	6.06E-08	7.65E-09	6.06E-08
1317	Acetaldehyde	4.90E-11	7.63E-09	7.66E-08	1.19E-05	1.09E-09	1.71E-07
1325	Formaldehyde	9.97E-08	4.07E-06	1.56E-04	6.37E-03	2.23E-06	9.09E-05
	Total risk	5.77E-07	9.58E-06	9.03E-04	1.50E-02	1.29E-05	2.14E-04

Exposure risks to chromium, soot and formaldehyde in the range from 1×10^{-6} to 1×10^{-4} require constant monitoring, since they correspond to the maximum permissible risk.

The total carcinogenic risks in the residential area are from 5.8×10^{-7} to 9.6×10^{-6}. Chromium is the most significant participation in the total individual carcinogenic risks.

Inhalation exposure to chromium, benzene, lead, ethylbenzene, soot, carbon tetrachloride, benz(a)pyrene, acetaldehyde and formaldehyde does not cause a significant level of cancer throughout the life of the population living in the surveyed residential area. The predicted population carcinogenic risk ranges from 9.0×10^{-4} to 1.5×10^{-2} and the annual population risk ranges from 1.3×10^{-5} to 2.1×10^{-4}.

Individual non-carcinogenic inhalation risks on the territory of residential buildings range from 8.1×10^{-8} to 7.9×10^{-1}.

The highest hazard indices are due to exposure to nitrogen dioxide (HQ from 5.0×10^{-2} to 7.3×10^{-1}), kerosene (HQ from 2.0×10^{-2} to 7.9×10^{-1}) and dimethylamine (HQ from 2.0×10^{-2} to 3.5×10^{-1}).

The obtained hazard indeces (HQ) do not exceed 1.0 and indicate a low probability of adverse effects from exposure to all priority air pollutants.

Due to the fact that multicomponent chemical pollution of environmental objects takes place in the study area, the study of the total risks caused by the simultaneous exposure to several chemical compounds at once was of undoubted interest. We have carried out a non-carcinogenic risk assessment, taking into account the data on the effects of chemicals on critical organs and systems. Priority substances with a unidirectional effect on critical organs and systems were grouped:

- 16 chemicals (soot, sulfur dioxide, dihydrosulfide, chromium, nitrogen dioxide, ammonia, nitrogen oxide, formaldehyde, fluoride gaseous compounds, a mixture of saturated hydrocarbons C_1H_4-C_5H_{12}, suspended solids, dimethylbenzene, hydroxybenzene, butyl acetate, acetaldehyde, inorganic dust, silicon dioxide in %: 70–20) have a unidirectional effect on the respiratory system. Hazard indices (HI) for residential areas range from 6.8×10^{-2} to 1.11. The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to priority substances on the respiratory system is made by nitrogen dioxide;
- 6 chemicals have a unidirectional effect on blood (lead, nitrogen dioxide, nitrogen oxide, carbon oxide, benzene, propan-2-on). Hazard indices (HI) for residential areas range from 5.5×10^{-5} to 7.4×10^{-1}. The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to priority substances on the blood is made by nitrogen dioxide;
- 8 chemicals (lead, carbon oxide, a mixture of saturated hydrocarbons C_1H_4-C_5H_{12}, benzene, dimethylbenzene, carbon tetrachloride, hydroxybenzene, propan-2-on) have a unidirectional effect on the central nervous system. Hazard indices (HI) for residential areas range from 2.0×10^{-3} to 1.1×10^{-2}. The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to priority substances on the central nervous system is made by carbon oxide;
- 6 chemicals (lead, carbon oxide, benzene, ethylbenzene, benz(a)pyrene, carbon tetrachloride) have a unidirectional effect on development processes. Hazard indices (HI) for residential areas range from 1.0×10^{-3} to 1.1×10^{-2}. Carbon oxide makes the most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to priority substances on development processes;
- 4 chemicals (benzene, benz(a)pyrene, formaldehyde, inorganic dust containing silicon dioxide in %: 70–20) have a unidirectional effect on the immune system. Hazard indices (HI) for residential areas range from 4.0×10^{-3} to 1.1×10^{-1}.

The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to the immune system is made by inorganic dust containing silicon dioxide in %: 70–20;

- 3 chemicals (carbon oxide, benzene, hydroxybenzene) have a unidirectional effect on the cardiovascular system. Hazard indices (HI) for residential areas range from 1.0×10^{-3} to 1.0×10^{-2}. The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to the cardiovascular system is made by carbon oxide;
- 2 chemicals (lead, benzene) have a unidirectional effect on the reproductive system. Hazard indices (HI) for residential areas range from 1.1×10^{-4} to 2.0×10^{-3}. Benzene makes the most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to the reproductive system;
- 2 chemicals (lead, eilbenzene) have a unidirectional effect on the endocrine system. Hazard indices (HI) for residential areas range from 1.9×10^{-6} to 4.1×10^{-5}. Lead makes the most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to the endocrine system;
- 7 chemicals (a mixture of saturated hydrocarbons C_1H_4-C_5H_{12}, dimethylbenzene, ethylbenzene, carbon tetrachloride, hydroxybenzene, propan-2-on, kerosene) have a unidirectional effect on the liver. Hazard indices (HI) for residential areas range from 2.5×10^{-2} to 7.9×10^{-1}. The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to the liver is made by kerosene;
- 7 chemicals (lead, a mixture of saturated hydrocarbons C_1H_4-C_5H_{12}, dimethylbenzene, ethylbenzene, carbon tetrachloride, hydroxybenzene, propan-2-on) have a unidirectional effect on the kidneys. Hazard indices (HI) are in the residential area from 5.2×10^{-4} to 8.5×10^{-3}. The most significant participation in the risk of developing non-carcinogenic effects during chronic exposure to the kidneys is made by hydroxybenzene;
- 2 chemicals (sulfur dioxide, suspended solids) have a unidirectional effect, leading to death. Hazard indices (HI) for residential areas range from 9.0×10^{-3} to 2.4×10^{-1}. The most significant participation in the risk of developing non-carcinogenic effects in chronic exposure to mortality is made by sulfur dioxide.

Hazard indices for toxic substances in all receptor points according to the methodological recommendations MR 5.1.0158-19.5.1.[3] refer to acceptable risk and indicate a low probability of negative effects from critical organs / systems.

Assessment of water chemical risk to public health.

The quality of potable water in Salekhard according to the production control data for 2019 and 2020 meets the requirements of SanPiN 2.1.4.1074-01.

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[3] Methodical recommendations approved by the Chief State Sanitary Doctor of the Russian Federation on 02 December 2019 "MR 5.1.0158-19 Assessment of economic efficiency of the implementation of measures to reduce air pollution levels based on an assessment of public health risk". (In Russ.). Available from: http://www.consultant.ru/document/cons_doc_LAW_359666/ (accessed: 30.03.2022).

Drinking water contains: 2 chemicals of the 1st hazard class, 7 chemicals of the 2nd hazard class, 8 chemicals of the 3rd class, 4 substances of 4 hazard class, 11 substances standardized for sanitary and toxicological signs of harm, 9 substances – for organoleptic characteristics.

Blood, immune system, central nervous system, endocrine system, gastrointestinal tract, development, nervous system, kidneys, mucous membranes, skin are most sensitive to the oral intake of main pollutants in potable water.

According to the forecast, exposure to cadmium, beryllium, lead and hexavalent chromium from drinking water leads to individual carcinogenic risks ranging from 1×10^{-6} to 1×10^{-4}. These levels of risk should be monitored continuously (see Table 2).

Individual carcinogenic risks when exposed to arsenic with drinking water range from 1×10^{-4} to 1×10^{-3}, which requires the development and implementation of additional health improvement measures, since the value of the risk is unacceptable for the population.

Table 2. Carcinogenic risks from exposure to priority potable water pollutants

CAS	Substance	Individual carcinogenic risk	Population carcinogenic risk	Population annual risk
7440-43-9	Cadmium	1.09E-06	5.44E-02	7.77E-04
7440-41-7	Beryllium	1.23E-05	6.15E-01	8.79E-03
7440-38-2	Arsenic	1.07E-04	5.36E+00	7.66E-02
18540-29-9	Chromium Cr(6+)	1.20E-05	6.01E-01	8.58E-03
7439-92-1	Lead	1.34E-06	6.72E-02	9.60E-04
	Total risk	1.34E-04	6.70	0.10

As a result of oral exposure to arsenic, cadmium, beryllium, lead and hexavalent chromium with drinking water, 7 cases of oncological diseases are predicted during the life of the population. The total individual carcinogenic risk is 1.3×10^{-4}, the projected population carcinogenic risk is 6.7, and the annual population risk is 0.1. Arsenic makes the most significant participation in the total carcinogenic risk.

The obtained hazard coefficients of individual non-carcinogenic risks (HQ) do not exceed 1.0 and indicate a low probability of adverse effects from exposure to all priority chemicals in drinking water.

The largest values of hazard ratios were established in connection with exposure to arsenic (HQ 4.8×10^{-1}), fluorides (HQ 5.0×10^{-2}) and nitrites (HQ 4.0×10^{-2}).

To calculate the total non-carcinogenic risk, chemicals were grouped according to their unidirectional effect on critical systems and organs. The highest values of hazard indices are established for toxic substances affecting the cardiovascular system (HI 5.3×10^{-1}), the immune system (HI 5.0×10^{-1}) and skin (HI 5.0×10^{-1}). In general, hazard indices do not exceed 1.0 and indicate a low probability of adverse effects from critical organs / systems.

The priority factor of the total assessment of the organoleptic risk from the use of drinking water is iron, but its value is less than 0.1.

Potential chronic risk from exposure to priority substances in drinking water on the population of the Salekhard city is 7.2×10^{-2} and thus indicates the absence of adverse health effects associated with drinking water consumption.

Discussion

With the help of risk assessment methodology the acquired information makes it possible to develop specific measures to prevent the negative impact of the anthropogenically polluted environment on the population health.

It is necessary to control the atmospheric air during the period of unfavorable meteorological conditions at enterprises with the largest volume of emissions and enterprises that have an impact even with insignificant gross emissions, based on calculations taking into account the ranking of chemical compounds according to the degree of hazard, in accordance with RD 52.04.52-85, developed by the Main Geophysical Observatory named after A.I. Voeikov[4].

For the development and improvement of control and supervision activities in areas of high air pollution in the studied area it is important to expand the volume of laboratory support, enlarge the list of detected harmful impurities in the atmospheric air, including heavy metals, increase the number of monitoring posts for atmospheric air pollution (snow cover), increase the number of places and points of sampling when determining the concentration of impurities in the atmospheric air by purchasing a mobile post for monitoring environmental pollution. Sources of emissions of chromium, soot and formaldehyde are subject to special control.

It is necessary to reduce the negative impact on the environment from mobile and stationary sources of pollution through the use of natural gas and other alternative types of energy resources.

To provide the population of the Salekhard city with drinking water of guaranteed quality it's important to ensure control over the observance of technological regimes for wastewater treatment, organize sanitary protection zones for water sources, eliminate and prevent the formation of sources of chemical and microbial pollution of surface and underground water sources in water protection zones, dispose and clean industrial and storm waste water. It is also necessary to check the state of hygienic conditions for water use during hydrological periods with the most unfavorable sanitary conditions of water bodies during sanitary and epidemiological supervision over the protection of water bodies from pollution and centralized drinking water supply to the population.

Additional recreational measures should be developed for the population of Salekhard to reduce the impact of arsenic, cadmium, beryllium, lead and hexavalent chromium supplied with drinking water.

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Conclusion

In the circumpolar regions both anthropogenic, natural and climatic factors characterized by extremeness demand high human functional systems. Therefore, even with insignificant calculated health risks of the population of Salekhard city it is important to increase attention and control, technological measures, the implementation of recreational activities are necessary to reduce the intensity of those factors that can be influenced by a person. The results of our study will serve as the driver for the development of targeted measures for environmental safety and scientifically based recommendations for decision makers in the field of environmental protection, public health and housing and communal services of the Yamal-Nenets Autonomous Okrug.

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