Anthropogenic and technogenic air pollution: case study of Bratsk

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Abstract. In the Russian Federation, the problem of atmospheric air pollution is relevant for most regions. Based on the dispersion calculations, the risk to the Bratsk population’s health from the chemicals that pollute the air was assessed. It was found that short-term effects of atmospheric pollution cause non-carcinogenic risks to the respiratory system, the immune and blood systems, systemic disorders and damage developmental processes. More than 95% of the contribution to the aggregate level of acute risks are made by dust, nitrogen dioxide, sulfur dioxide, gaseous fluorides, and benzene. Chronic exposure increases the level of the carcinogenic risk, causes the non-carcinogenic risk to the respiratory system, the skeletal system, blood damage and developmental disorders. More than 95% of the contribution are made by nitrogen oxides, sulfur dioxide, gaseous and poorly soluble fluorides, benzene, benzo (a) pyrene, carbon, hexavalent chromium and dust. A list of 13 priority pollutants that should be regularly monitored in Bratsk was compiled.

1. Introduction
In the Russian Federation, the problem of atmospheric air pollution is relevant for most regions. In order to improve the quality of atmospheric air in contaminated areas, the federal project "Clean Air" has been implemented.

The project is aimed at reducing the level of air pollution in large industrial centers, reducing at least 20 percent of the total volume of pollutants emitted into the air in the most polluted cities [1].

Bratsk is one of the 12 large industrial centers where the federal project has been implemented. The environmental situation has remained difficult for many years due to air pollution. According to the state monitoring data, the level of atmospheric air pollution is very high; the main contribution to the high pollution index is made by substances such as benzo (a) pyrene, carbon disulfide, formaldehyde, suspended solids, and hydrogen fluoride. More than 112 thousand tons of pollutants are emitted into the atmospheric air by industrial enterprises and vehicles [2].

Air pollution is a global environmental problem and one of the most serious risk factors for human health. Millions of people die each year from diseases caused by air pollution [3-5].

An assessment of the health risk as one of the methods of hygienic assessments is an effective and internationally recognized tool for analyzing and forecasting the sanitary situation which is used to study both the current and potential levels of negative impacts of the environmental pollution [6–13].

The study aims to assess the public health risk from chemicals that pollute the atmospheric air in Bratsk.
2. Materials and methods

Bratsk (Irkutsk Region) is located in the central region of the Central Siberian Plateau on the left bank of the northern part of the Bratsk Reservoir. Residential buildings are separated by forest zones, the Angara River, the reservoir and industrial enterprises.

Bratsk is a large industrial center of Russia and the second largest city in Irkutsk region, with a population of more than 200 thousand people (as of January 1, 2020 - 226,269 thousand people) and an area of 42.8 thousand km². The main industries are non-ferrous and ferrous metallurgy, pulp and paper and woodworking industries, and the fuel and energy complex.

The surface concentration of pollutants was calculated at points corresponding to the geometric centers of residential buildings. Values of the surface concentration of pollutants were determined at 12,100 points characterizing the residential development, according to the list of 47 priority substances isolated at the stage of hazard identification.

The risk indicators were calculated in accordance with R 2.1.10.1920-04 "Guidelines for assessing the risk to public health when exposed to chemicals that pollute the environment" [14].

The carcinogenic risk to public health was assessed by the level of the carcinogenic risk under the lifetime exposure, the non-carcinogenic risk - by the coefficients and hazard indices under the acute and chronic exposure.

The acceptance criteria and the grading of the carcinogenic risk were taken in accordance with Section 7 of R 2.1.10.1920-04. In accordance with R 2.1.10.1920-04, the level of the target risk for the populated areas of Russia is $10^{-5}$–$10^{-6}$.

Criteria and grades of the non-carcinogenic risk were adopted in accordance with R. 2.1.10.1920-04, taking into account MR 2.1.10.0156-19 “Assessment of the quality of atmospheric air and analysis of the risk to public health in order to make informed management decisions in ensuring the quality of atmospheric air and sanitary epidemiological well-being of the population” [15]:

- health risks expressed by hazard indices for the development of non-carcinogenic effects for groups of substances with an unidirectional action at a level of less than 1.0 were considered as minimal (target);
- risks expressed by hazard indices from 1.1 to 3.0 were considered acceptable, requiring special attention and monitoring;
- risks expressed by hazard indices ranging from 3.1 to 6.0 were considered alarming;
- risks expressed by hazard indices for the development of non-carcinogenic effects for groups of substances with an unidirectional action in the range above 6.0 were considered high.

3. Results

3.1. Characterization of the carcinogenic risk

The assessment of carcinogenic risks showed that out of 34 substances emitted into the atmosphere by stationary and mobile sources of pollution, carcinogenic effects have benz (a) pyrene, hexavalent chromium, carbon (soot), formaldehyde, benzene, acetaldehyde, ethylbenzene, lead and its compounds.

The results of the calculation and assessment of the carcinogenic risk created by these substances showed that the levels of the total individual lifelong carcinogenic risk TCR at the analyzed points of residential development ranged from $1.08 \times 10^{-6}$ to $1.97 \times 10^{-5}$. The city average value of carcinogenic risk was $3.38 \times 10^{-6}$.

The levels of carcinogenic risk formed in the study area are assessed as acceptable and subject to constant monitoring.

More than 4,700 people live in the zones of permissible carcinogenic risks (more than $1.0 \times 10^{-5}$) (about 2% of the population). The zones are close in terms of carcinogenic risk levels, but these risks are created by different substances and different sources of pollution (Figure 1).
The priority substances (in terms of the maximum contribution to the total level of the carcinogenic risk at the points under study) with a carcinogenic effect are benzo (a) pyrene (contribution up to 64.67%), hexavalent chromium (up to 85.39%), carbon (soot) (up to 61.69 %) and benzene (up to 67.28%). Other carcinogens contribute less than 1% to the total carcinogenic risk at all points of residential development. The estimated population risk is small and amounts to 0.1 cases per year.

3.2. Characterization of the acute non-carcinogenic risk

The assessment of acute inhalation exposure revealed an excess of the permissible hazard coefficient (HQ = 1) for nitrogen dioxide (up to 1.63 HQ), benzene (up to 8.37 HQ), inorganic dust with a content of 70–20% SiO2 (up to 4.09 HQ), inorganic dust with a content up to 20% SiO2 (up to 4.33 HQ).

The analysis of the total levels of the acute non-carcinogenic risk (values of hazard indices - HIac) revealed that the short-term exposure to chemicals that pollute the atmospheric air, high levels of risk to the respiratory organs (up to 7.80 HIac), the immune system and blood (up to 8.87 HIac) are formed. They also cause systemic disorders (up to 7.03 HIac) and developmental processes (up to 8.87 HIac).

In general, acute risks to the respiratory system are formed due to a combination of dust, nitrogen dioxide, sulfur dioxide and gaseous fluorides. Other impurities do not make significant contributions to this type of risk. More than 156.3 thousand people live in the areas with a level of the permissible acute non-carcinogenic risk in the range from 3.00 to 7.80 HIac (high risk) - almost 500 people.

The high level of the non-carcinogenic impact on the immune system and blood (up to 8.87 HIac) is due to benzene whose contribution is 100% at all the points of residential development. The total population in the affected zones is about 1,500 people.

In general, acute non-carcinogenic risks of systemic disturbances are due to the sum of dusts emitted by stationary and mobile sources of emissions. Substances that form a contribution of 90% to the non-carcinogenic acute risk of systemic disorders (HIac> 3) include inorganic dust with a content of 70-20% SiO2, inorganic dust with a content of up to 20% SiO2, wood dust and resinous substances (sublimates pitch) as part of electrolysis dust. About 12,180 people live in areas with levels of an acceptable hazard index in the range of up to 3.0 HIac. 12 people live in the zone of the high acute risk in the Central District (HIac 3.33–7.03).

2,497 people live in the zones with an acceptable level of risk of developmental disorders (HIac 1.10–2.62). 531 people live in areas with a “alarming” risk level (HIac from 3.69 to 5.39). The risk
factor is benzene, which forms more than 90% of the contribution to the total non-carcinogenic acute risk throughout the entire residential area.

3.3. Characterization of the chronic non-carcinogenic risk

The assessment of chronic inhalation exposure revealed an excess of the permissible hazard coefficient (HQ = 1) for benzo (a) pyrene (up to 8.83 HQ), and nitrogen dioxide (up to 1.03 HQ).

The analysis of the chronic non-carcinogenic risk (hazard indices - HIcr) revealed that with prolonged exposure to chemicals that pollute the atmospheric air, there are risks to the respiratory organs (up to 3.40 HIcr), blood (up to 1.64 HIcr), the skeletal system (up to 2.02 HIcr), developmental processes (up to 8.93 HIcr).

In general, there are chronic risks to the respiratory system due to nitrogen dioxide, nitrogen oxide, sulfur dioxide, gaseous and poorly soluble fluorides, chlorine, chlorine dioxide and dust (with the greatest contributions of inorganic dust with a content of > 70% SiO2, inorganic dust with a content of up to 20% SiO2, resinous substances (sublimates of pitch) in electrolysis dust). More than 114.0 thousand people live in areas with chronic non-carcinogenic risks in the hazard index range from 1.1 to 3.0 HIcr (acceptable risk); about 15 people live in the areas with risk levels which range from 3.02 to 3.40 HIcr (alarming risk).

The chronic non-carcinogenic risk to blood is caused by nitrogen dioxide and nitrogen oxide, the contribution is more than 95% throughout the entire residential area. About 600 people live in the zones with an acceptable level of chronic non-carcinogenic risk in the range from 1.10 to 1.64 HIcr.

In the city, chronic risks to the skeletal system up to 2.02 HIcr are caused by fluoride compounds (about 68.5% of the risk are gaseous fluorides, 31.5% - poorly soluble fluorides). 25 people live in the zone of permissible chronic exposure.

There are zones with hazard indices of the impact on developmental processes which range from 1.10 (acceptable risk) to 8.93 HIcr (high risk). In the zones with levels above 1HIcr, 102.5 thousand residents live; in the zones with an “alarming” risk level, 640 people live; with a “high” risk level, about 50 people live. The risk factor is benzo (a) pyrene.

3.4. Priority substances that pose risks to public health

The generalization of data on the aerogenic risk factors that make the largest total contributions to the calculated risks made it possible to compile a list of 13 substances which should be regularly monitored:

- hexavalent chromium (carcinogenic risk);
- nitrogen dioxide (acute risk to the respiratory system, chronic risk to the respiratory system, immune system and blood);
- nitric oxide (chronic risk to the respiratory system, immune system and blood);
- carbon (soot) (carcinogenic risk);
- sulfur dioxide (acute risk to the respiratory system, chronic risk to the respiratory system);
- gaseous fluorides (acute risk of exposure to the respiratory system, chronic risk of exposure to the respiratory system and the skeletal system);
- poorly soluble fluorides (chronic risk to the respiratory system and the skeletal system);
- benzene (carcinogenic risk, acute risk to the immune system and blood, developmental processes);
- benzo (a) pyrene (carcinogenic risk, chronic effects on developmental processes);
- inorganic dust with a content of 70–20% SiO2 (acute risk to the respiratory system, systemic disorders, chronic risk to the respiratory system);
- inorganic dust with a content of up to 20% SiO2 (acute risk ure to the respiratory system, systemic disorders, chronic risk to the respiratory system);
- wood dust (acute risk to the respiratory system, systemic disorders, chronic risk to the respiratory system);
- resinous substances (pitch fumes) in electrolysis dust (acute risk to the respiratory system, systemic disorders, chronic risk to the respiratory system).

Reducing emissions of these impurities can minimize health risks.
The results indicate the need to develop environmental, technological, hygienic, medical and preventive, architectural and planning measures aimed at improving the quality of atmospheric air and minimizing the risk levels. The most effective measures are a reduction of emissions of those impurities that form significant contributions to the health risks: nitrogen oxides, dust, fluoride compounds, benzene, benzo (a) pyrene. At present, all of these impurities are included in the programs for systematic monitoring of atmospheric air. Due to significant discrepancies between the surface concentrations obtained by the calculation and during the instrumental monitoring, it seems expedient and relevant to adjust the initial consolidated database on the sources, structure and mass of emissions of substances from the subsequent specification of risk values and factors that form it. In addition, it seems expedient to combine state monitoring programs with programs for monitoring the quality of atmospheric air at industrial facilities, in which it is recommended to include substances that are markers for emissions [16–19].

4. Conclusion
The calculation and assessment of the public health risk, which are based on the modeling of the dispersion of harmful impurities from the stationary and mobile sources in Bratsk, revealed that the risk levels are caused by both short-term and long-term exposure to atmospheric pollution.

1. short-term (20-30 minute) impacts of atmospheric pollution on the residential development cause
   • dysfunctions of the respiratory system (HIac up to 7.80, under the high influence - more than 156 thousand people - almost 70% of the population);
   • dysfunctions of the immune system and blood (HIac up to 8.84, under the high influence - more than 1.5 thousand people);
   • systemic disorders (HIac up to 7.03, under high impact - about 12.2 thousand people);
   • negative impacts on the development processes (HIac up to 8.87, in high risk areas - almost 2.5 thousand people).

More than 95% of the total non-carcinogenic acute risks are caused by: the amount of dust (solid substances) emitted into the air, nitrogen dioxide, sulfur dioxide, gaseous fluorides, benzene.

2. long-term (including lifelong) exposure to chemicals causes:
   • dysfunctions of the respiratory system (HIac up to 3.40, under the alarming exposure - almost 115 thousand people - more than 50% of the population);
   • blood damage (HIac up to 1.64, under the permissible exposure - 600 people);
   • damage to the skeletal system (HIac up to 2.02, under the permissible impact - 25 people);
   • violations of development processes (HIac up to 8.93, under high impact - more than 101 thousand people, almost 45% of the population);
   • carcinogenic risks (levels of total individual life-long carcinogenic risk up to 1.97·10^{-5}, under the permissible exposure - 4.7 thousand people).

More than 95% of the total chronic risks are contributed by nitrogen dioxide, nitrogen oxide, sulfur dioxide, gaseous and hardly soluble fluorides, benzene, benzo (a) pyrene, hexavalent chromium, carbon and the amount of dust.

3. By the health risk, a list of priority impurities that should be regularly monitored has been compiled: hexavalent chromium, nitrogen dioxide, nitrogen oxide, carbon (soot), sulfur dioxide, gaseous fluorides, poorly soluble fluorides, benzene, benzene (a) pyrene, total dust (with possible release: inorganic dust with 70–20% SiO2, inorganic dust with up to 20% SiO2; wood dust; resinous substances (pitch fumes) in electrolysis dust).

All these impurities are currently included in the environmental monitoring programs and social and hygienic monitoring programs in Bratsk.

References
[1] Passport of the federal Clean Air Project Retrieved from: https://www.mnr.gov.ru/activity/directions/natsionalny_proekt_ekologiya/ (date of address: 18.02.2020)
[2] Review of the state and pollution of the environment in the Russian Federation 2018 State report 2019 (Moscow: Ministry of Natural Resources of Russia; STP Cadastre)

[3] Addressing air pollution from mining activities Retrieved from: https://www.wipo.int/ip-outreach/ru/ipday/2020/case-studies/qaira.html (date of address: 18.02.2020)

[4] Ambient air quality and health Retrieved from: https://www.who.int/ru/news-room/factsheets/detail/ambient-(outdoor)-air-quality-and-health (date of address: 18.02.2020)

[5] Popova A Yu, Onishchenko G G, Zaitseva N V et al 2020 Social and economic determinants and potential for growth in life expectancy of the population in the Russian Federation taking into account regional differentiation Health Risk Analysis 1 4–17

[6] Popova A Yu, Zaitseva N V and May I V 2019 Population health as a target function and criterion for assessing efficiency of activities performed within “Pure air” Federal Project Health Risk Analysis 4 4–13

[7] Zaitseva N V, May I V, Kleyn S V and Goryaev D V 2019 Methodical approaches to selecting observation points and programs for observation over ambient air quality within social and hygienic monitoring and “Pure air” Federal Project Health Risk Analysis 3 4–17

[8] Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks Retrieved from: www.who.int/airpollution/ambient/health-impacts/en/ (date of address: 18.02.2020)

[9] Pope C A 2000 Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk? Environmental Health Perspectives 108(4) 713–723

[10] Pataud J P, Van Dingenen R, Alastuey A, Bauer H, Birmili W, Cyrys J, Flentje H, Sandro F et al 2010 A European aerosol phenomenology – 3: Physical and chemical characteristics of particulate matter from 60 rural, urban, and kerbside sites across Europe Atmospheric Environment 44(10) 1308–1320

[11] Brunekreef B 2008 Environmental Epidemiology and Risk Assessment Toxicology Letters 180(2) 118–122

[12] Wolf J, Corvalan C, Neville T, Bos R and Neira M 2017 Diseases due to unhealthy environmental: as updated estimate of the global burden of diseases attributable to environmental determinants of health Journal of Public Health 39(3) 464–475

[13] P 2.1.10.1920-04 Guidelines for Assessing Public Health Risks from Exposure to Environmental Polluting Chemicals

[14] MP 2.1.10.0156-19 Assessment of the quality of atmospheric air and analysis of the risk to public health in order to make informed management decisions in the field of ensuring the quality of atmospheric air and sanitary and epidemiological well-being of the population

[15] Zaitseva N V and May I V 2020 New mechanisms for regulation of industrial emissions into the atmosphere: a conceptual look at prospects and problems from sanitary-epidemiological point of view Health Risk Analysis 2 4–15

[16] Revich B A, Khark’kova T L and Kvasha E A 2020 Selected health parameters of people living in cities included into “Pure air” Federal Project Health Risk Analysis 2 16–27

[17] Revich BA National project "Clean Air" in the context of public health protection Retrieved from: http://ecovestnik.ru/index.php/2013-07-07-02-13-50/nashi-publikacii/3132-natsionalnyj-proekt-chistyy-vozdukh-v-kontekte-okhrany-zdorovya-naseleniya (date of address: 18.02.2020)

[18] Tisiser O A, Podgurskaya O A 2020 National project "Ecology" - Federal project "Clean Air": plans, implementation and prospects in the Chelyabinsk region Horizons of civilization 1(11) 315–327

[19] Chernyaeva V A and Wang D H 2019 Regional environmental features and health indicators dynamics pollution of the earth's atmosphere and international air quality standards IOP Conference Series: Earth and Environmental Science 267(6) 062012

