Eco logical human health risk in aluminum producing areas of Baikal region

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Abstract. The 2017 list of Russian cities with the highest level of air pollution included 21 cities, 7 of which (30%) are located in the Irkutsk region. Among them are large industrial centers of non-ferrous metallurgy - Shelekhov and Bratsk. The purpose of the article is to assess the health risk for the population living in the aluminum producing areas (Shelekhov, Irkutsk region). The health risk was assessed on the basis of G 2.1.10.1920-04 using modern sanitary and hygienic standards. Air quality in 2007-2017 and load on the urban population inhaling polluted air (inhalation route) were determined. Two groups of hazardous effects were identified. Carcinogenic and non-carcinogenic risks were distinguished. Individual inhalation risks were calculated and hazardous substances were identified. The total carcinogenic risk exceeds an acceptable level and is mainly due to inhalation of formaldehyde and chromium (46.7% and 52.3%, respectively). The chronic non-carcinogenic risk is due to the suspended substances, formaldehyde and benzopyrene inhalation. The non-cancerogenic effect of air on the respiratory organs, the immune system and eye pathology is crucial. The article suggests measures (implementation of advanced production technologies, reconstruction of heating systems, etc.) to prevent hazardous risks.

1. Introduction

It is evident that adverse environmental factors play an important role in shaping the health status of the population. These factors can be compared with genetic predisposition and quality of medical care.

In many industrial cities of the Russian Federation, despite all government efforts, habitat objects are deteriorating. It should be noted that more than half of the Russian cities with high and very high levels of air pollution are located in the Siberian Federal District. In 2017, the Priority List of the Russian cities with the highest level of pollution included 21 cities, 7 of which (30%) are located in Irkutsk region [1].

The largest industrial enterprises of non-ferrous metallurgy (RUSAL aluminum plants in Shelekhov and Bratsk with productivity levels of more than 400 thousand and 1 million tons of aluminum per year respectively), ferroalloy plants (Shelekhov and Bratsk); chemical industry enterprises (Angarsk, Sayansk); timber processing enterprises (Bratsk and Ust-Ilimsk); heat and power engineering enterprises (CHP plants); motor transport enterprises [2].

In Shelekhov and Bratsk, the ecological situation is acute. Meteorological factors (inversions, frequent calm and weak winds, fogs and a small amount of precipitation) significantly increase the negative impact of industrial emission. These conditions contribute to intense man-made pollution.
In this regard, assessment of the health risk is a crucial task. The only way to determine quantitative characteristics of a public health threat is to use a risk assessment method. A significant number of researches deal with theoretical and applied issues of health risk assessment [3-15]. Most researchers assess risks for various external factors. The existing risk assessment method helps identify the individual value of environmental pollutants which is an important aspect when planning risk management measures.

The purpose of this work is to assess the health risk for people living in the area of aluminum production (Shelekhov).

2. Materials and methods
Shelekhov is located in the south of Irkutsk region near the Trans-Siberian Railway. According to the Russian Statistics Service, the number of the population in Shelekhov district whose administrative center is Shelekhov was 64,283 in 2017 (2.7% of the population of Irkutsk region).

The industrial profile of the city is determined by non-ferrous metallurgy: RUSAL, Shelekhov section of the Novo-Irkutsk CHP IrkutskEnergo, ZAO Kremny. Besides the aluminum production industry, electrical machinery and equipment (finished metal products, non-metallic mineral products, etc.) are produced in Shelekhov. There are operating highways and railways, stove heated houses. These sources of air pollution determine the quantitative and qualitative composition of emitted chemicals.

The risk was assessed using Guidelines 2.1.10.1920-04 (2004) [16]. According to it, all health risks are grouped into carcinogenic or non-carcinogenic ones. Carcinogenic risk is a probability of developing malignant neoplasms caused by potential carcinogens. It is the upper level of an additional lifetime risk. Non-carcinogenic risks are characterized by a "hazard ratio" (HR) which is the ratio of the exposure dose / concentration of a chemical to its safe (reference) exposure level. The risk indicators for carcinogenic and non-carcinogenic effects are assessed separately.

3. Results and discussions
Hazard Identification. The priority compounds include compounds that characterize a real health risk for the population living in the area under study: substances that determine the air pollution level - benzo(a)pyrene, suspended solids, ozone, nitrogen dioxide, formaldehyde, specific emissions of aluminum production - solid fluorides and hydrogen fluoride, as well as heavy metals - lead, chromium and nickel. Generalized information on toxicity (factors of carcinogenic potential, safe exposure levels) and harmful effects of the substances is presented in Table 1.

All these substances are resorptive, i.e. they have toxic, gonadotoxic, embryotoxic, mutagenic, carcinogenic, and other effects. The occurrence of these effects depends on the concentration of the substance and inhalation duration.

Assessment of exposure and dose-response dependence. To calculate and assess risks, average annual concentrations (for 2006–2017) of the substances in the air obtained from regular observations (Federal State Budgetary Institution Irkutsk UGMS) [17] were used.

Analysis of the dynamics of changes in average annual concentrations of harmful substances showed that annual concentrations of B(a)P and formaldehyde (until 2015) exceeded the MPC value by more than 3 times, and annual concentrations of suspended solids and hydrogen fluoride exceeded the MPC value by 1,2 times (Table 1).

Nitrogen dioxide concentration slightly exceeded the MPC value only in 2007, 2012, 2014 and 2017, and the content of heavy metals did not change much. It did not exceed the sanitary standards. Since 2015, ozone is included in the priority list of air pollution in Shelekhov. Its concentration exceeds the MPC value by 1,2 times. In general, there is an increase in formaldehyde, B(a)P and suspended solids in the air of Shelekhov.

The assessment phase of the dose-response relationship is fundamentally different for carcinogens and non-carcinogens. To assess the carcinogenic risk, a linear non-threshold model with values of carcinogenic risk potentials SFi is used. Their values for the substances under study are presented in
To calculate the non-carcinogenic risk, an exponential non-threshold model is used. It provides a probability of an increase in the primary incidence in response to long-term non-carcinogen exposure.

### Table 1. Values of carcinogenic potential and safe levels of chemicals used for risk assessment.

| Pollutant            | Classification of carcinogenicity | Reference concentration RfC, mg/m³ | Average annual concentration ±standard deviation² | Cancerogenic potential SFi (mg/(kg·d))¹ |
|----------------------|----------------------------------|-----------------------------------|--------------------------------------------------|---------------------------------------|
| Benzopyrene          | 2A                               | 1,00E-0,6                         | 3,36±1,25                                       | 3,9                                   |
| Formaldehyde         | 2A                               | 0,003                             | 0,010±0,002                                     | 0,046                                 |
| Lead                 | 2A                               | 0,0005                            | 0,018±0,004                                     | 0,042                                 |
| Chrome               | 1                                | 0,0001                            | 0,015±0,003                                     | 42                                    |
| Nickel               | 2B                               | 0,00005                           | 0,016±0,005                                     | 0,84                                  |
| Suspended solids     | -                                | 0,075                             | 0,204±0,039                                     | -                                     |
| Nitrogen dioxide     | -                                | 0,04                              | 0,039±0,004                                     | -                                     |
| Solid fluorides      | -                                | 0,013                             | 0,007±0,001                                     | -                                     |
| Hydrogen fluoride    | -                                | 0,014                             | 0,006±0,001                                     | -                                     |
| Ozone                | -                                | 0,03                              | 0,036±0,004                                     | -                                     |

Note: 1 - IARC - classification of the International Agency for Research on Cancer; US EPA - classification of evidence of carcinogenicity for humans; 2 - average annual concentration for B(a)P in ng/m³; for formaldehyde, nitrogen dioxide, suspended solids, hydrogen fluoride and solid fluorides - in mg/m³; for heavy metals - in µg/m³.

**Risk profile.** A mandatory step in assessing the carcinogenic risk is calculation of the lifetime average daily dose (LADD), calculation of the carcinogenic risk for each mixture component as well as the total carcinogenic risk for the whole mixture. Doses and risks were calculated by standard formulas [16].

The calculated lifetime average daily doses of carcinogens and individual carcinogenic risks are presented in Table 2.

### Table 2. Individual carcinogenic risks caused by inhalation of chemicals.

| Pollutant    | Average daily dose, mg/(kg·day) | Value of the of individual risk | Risk assessment based on [16] |
|--------------|---------------------------------|---------------------------------|-------------------------------|
| Benzopyrene  | 5,0E-07                         | 2,0·10⁻⁶                        | Maximum allowable            |
| Formaldehyde | 0,0015                          | 7,0·10⁻⁵                        | Maximum allowable            |
| Lead         | 3,0E-06                         | 1,3·10⁻⁷                        | Allowable                    |
| Chrome       | 2,0E-06                         | 8,0·10⁻⁵                        | Maximum allowable            |
| Nickel       | 2,0E-06                         | 2,0·10⁻⁶                        | Maximum allowable            |
| Total risk   | 1,5·10⁻⁴                        | Unacceptable to the public      |

The assessment of individual carcinogenic risks indicates high values of carcinogenic risks and carcinogenic risk indices. The risk level was referred to the third range (individual lifetime risk was more than 1·10⁻⁴, but less than 11·10⁻⁴) which is unacceptable for the population and requires development and implementation of planned curative measures. The high level of carcinogenic risks is due to high concentrations of formaldehyde and chromium in the air (46.7% and 52.3%, respectively).
For non-carcinogenic substances, an international risk assessment method involves threshold levels — reference doses (RfD) and concentrations (RfC). No harmful effects occur below these levels (see Table 1). The excess of the reference (safe) dose does not necessarily cause harmful effects: the higher the acting dose and the more it exceeds the reference dose, the higher the probability of adverse responses [16].

Health risks are assessed by calculating the hazard coefficient [16]. The calculation data on the health hazard coefficient are presented in Fig. 1. The quantitative values of the risk are relative values characterizing the comparative priority of certain pollutants.

![Figure 1. The structure of the non-carcinogenic risk for Shelekhov and its suburbs.](image)

Suspended solids (25%), formaldehyde (27%) and B(a)P (30%) contribute more to the non-carcinogenic risk. The hazard coefficient for these substances exceeds the safe level by three times. Thus, diseases or poisoning are caused by inhalation of these compounds.

As a conservative approach to the assessment of the combined effect of non-carcinogens, it was assumed that substances acting on the same organs or systems are additive. Assessment of non-carcinogenic risks under combined and complex impacts of chemical compounds involves calculation of the hazard index (HI).

The hazard index (HI) for simultaneous inhalation of several substances is defined as the sum of hazard coefficients (HQ) for the substances affecting one system (organ). These indicators are presented in Table 3.

| Organs / systems      | Total hazard index (HI) | Hazardous substances                      |
|-----------------------|-------------------------|-------------------------------------------|
| Respiratory system    | 8,92                    | Formaldehyde, suspended solids, solid fluorides, hydrogen fluoride, nitrogen dioxide, benzopyrene, formaldehyde |
| Immune system         | 6,4                     |                                          |
| Eyes                  | 3,0                     | Formaldehyde                              |
| Blood system          | 1                       | Nitrogen dioxide                          |
| Bone system           | 0,95                    | Solid fluorides, hydrogen fluoride        |

The highest hazard index was obtained for the total exposure of the respiratory organs to harmful substances. B(a)P and formaldehyde have a negative effect on the immune system. The latter compound also causes eye diseases. There is a negative effect of harmful substances on the blood and bone systems. Children and teenagers are the most vulnerable part of the population. For instance, according to the official data [2,18,19], in 2012-2017, the number of diseases of the blood and nervous systems, eye diseases, diseases of the musculoskeletal and respiratory systems (including chronic bronchitis) in the adolescents of Shelekhov district exceeded the average regional number by 1.4, 1.8; 1.4; 2.0; 1.3 (5.2) times, respectively.
According to our previous studies [20], the residents of Bratsk, one more Baikal city having aluminum production enterprises, also inhale harmful substances (HQt = 16.94). Formaldehyde emissions are a major contributor to this hazard. According to our estimates, the individual carcinogenic risk of formaldehyde inhalation in Bratsk is unacceptable (1.7 \cdot 10^{-4}).

4. Conclusion

Thus, inhalation effects of chemicals polluting the air form a high level of carcinogenic and chronic non-carcinogenic risks to health of the population living in the impact zone of aluminum production (Shelekhov).

The total inhalation carcinogenic risk exceeds an acceptable level and is caused by formaldehyde and chromium. Average annual concentration of chromium and formaldehyde in the air does not exceed the MPC value. The chronic non-carcinogenic risk is mainly due to suspended substances, formaldehyde, and B(a)P. The non-cancerogenic effects on the respiratory organs, immune system and eye pathology are most significant.

The risk characteristics can be perceived as ranks of the problems which have to be a basis for setting priorities for preventive measures aimed at reducing adverse effects of environmental factors on the public health. Among these measures are implementation of advanced production technologies, replacement of heating systems (replacement of coal with alternative fuels, electrical energy, etc.), improvement of internal combustion engines; development of territorial programs aimed at improving the environment, reducing mortality and preventing diseases.

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