Health risk assessment for people consuming agricultural products grown in the zone of aluminum production

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Abstract. Most of the Russian people consume products grown in their gardens located near large industrial centers. Toxic substances can enter the human body together with agricultural products grown on polluted land. The article aims to assess carcinogenic and non-carcinogenic risks to health of people consuming agricultural products (root and tuber crops) grown in the area affected by aluminum production (the Southern Baikal region). The risk was assessed using a model developed by U.S.EPA. The carcinogenic risk for average concentrations of benz(a)pyrene in vegetables was CR=1.09·10^{-4}. The value is between maximum permissible and unacceptable levels. The chronic non-carcinogenic risk exceeds the safe value four times (HI = 4.15) due to large doses of iron (HQ=2.47) and nickel (HQ=0.88). The total value of the hazard coefficient for fluorine (HQ=0.74) entering the human body with root and tuber crops does not exceed the permissible level, despite the fact that it is one of the main components of soil pollution near aluminum production plants.

1. Introduction

Traditionally, most of the Russian people eat products grown in their gardens located near cities and industrial centers. The territory of pollution can be located 50-200 km away from pollution sources. According to Russian researchers, almost 11% of soils are “dangerous” and “moderately dangerous” in terms of the content of heavy metals [1]. Harmful substances can accumulate in agricultural plants eaten by humans.

As a rule, the most powerful sources of soil pollution are mining enterprises, large plants of non-ferrous metallurgy and chemical enterprises [1-5]. The problem of technogenic soil pollution with TM and other toxicants is relevant in many countries [6–9]. Th researchers [10] say that soil is polluted with fluorine at a distance of 30 km away from the Norwegian aluminum smelters.

A large aluminum plant is located in the southern Baikal region of Russia (Shelehkov). In the 0.5-8 km zone of this industrial center, the agricultural land is contaminated with fluorine and benzo(a)pyrene (B(a)P) [11]. In this zone, there are three rural settlements and more than six thousand summer cottages growing vegetables. There is no regular control over their quality.

National hygienic food safety requirements include standards for the content of toxicants (lead, arsenic, cadmium and mercury) in vegetables. There are no permissible levels of other heavy metals, fluorine and B(a)P in vegetables. The only way to assess a potential threat to public health is a risk assessment method. This method is widely used by foreign experts to assess food safety [12-18].

The purpose of this article is to assess carcinogenic and non-carcinogenic risks to public health as a result of consuming vegetables (roots and tubers) grown in the zone of aluminum production (Shelehkov district, Irkutsk region) in the South Baikal region.
2. Materials and Methods
Shelekhov district is located in the south of Irkutsk region, 80 km away from the Baikal lake. Its administrative center is Shelekhov located in the valley of the Irkut and Olkha rivers. In the town, there is a large aluminum enterprise. The industrial profile of the town is determined by non-ferrous metallurgy.

The agriculture is an auxiliary branch presented by a small agricultural enterprise and six farms. All the lands are located within a small area between the Irkut and Olkha rivers.

A large number of industrial enterprises pollute air and soil in Shelekhov and its suburbs. The 2013 studies carried out as part of the project “Comprehensive Environmental Audit of the Baikal Natural Territory and the Lake Baikal Ecosystem — an area of the World Natural Heritage” [19] found that accumulation of B(a)P in soil near the industrial zone exceeds the permissible level 800 times, and the MAC— 120 times. According to L. Belykh and her co-authors [11], water-soluble fluorine and benzo(a)pyrene with a concentration exceeding national standards (MAC) 7 and 5 times pollutes soil in Shelekhov district. Concentrations of Fe, Ti, Mn, V, Pb did not exceed permissible levels with the exception of 2–4 background and 1.5–2 MAC of As, Ni, Zn in the areas of local pollution.

According to the official data, in 2016, more than 93% of the territory of Shelekhov district and 100% of the territory of Shelekhov did not meet the hygienic standards. In the town, fluorine content exceeded the MAC five times; in the suburban areas, it exceeded the MAC 2–5 times [20].

In 2017, the number of residents of Shelekhov district was 64.3 thousand. More than 80% of them live in the town consuming agricultural products (vegetables, fruits, berries) grown in the suburban area. Most of these products are root and tuber crops.

To assess non-carcinogenic and carcinogenic effects on the population consuming vegetables grown in the polluted area, a model developed by U.S.EPA was used. In Russia, this model is a basis of the P 2.1.10.1920-04 manual [21]. According to the model, the carcinogenic risk is a likelihood of developing malignant neoplasms throughout the human life due to the exposure to potential carcinogens. It is the upper limit of an additional lifetime risk. The non-carcinogenic risk is characterized by a "hazard coefficient" (HQ) determined as a ratio of the exposure dose / concentration of a chemical to its safe (reference) level of exposure (Hazard). If HQ <1, there is no danger or risk to health. If HQ> 1, there is a danger of a disease or poisoning which is greater the more the HQ exceeds 1. The risk indicators for carcinogenic and non-carcinogenic effects were assessed separately.

The calculations are based on scientific data on the content of harmful substances in vegetables grown in the zone of aluminum production in the southern Baikal region.

3. Results and Discussion
Priority components of soil pollution in the vicinity of aluminum production sources are fluorine and B(a)P; lead, zinc, nickel and B(a)P are identified near transport highways [11].

These harmful substances can accumulate in agricultural plants [4, 5, 14]. Researchers identified a positive relationship between fluorine content in plants and soil contamination [7, 9, 10]. Significant pollution of root and tuber crops with fluorine was identified by L.V. Pomazkina [22]. The author says that the average fluorine content in potato tubers at a soil contamination level of 6-10 MAC was 7.1-10 mg/kg; in carrots and beets, it varied from 4.0 to 8.0 mg/kg.

In addition, Zn, Ni, and Fe accumulate in potato tubers. The analysis of literature data showed that Zn content in potatoes can vary. However, beets accumulate it more than potatoes and carrots.

The work by L.I. Belykh and I.A. Ryabchikova [11] presents information on the content of B(a)P, fluorine and metals (Zn, Ni, Fe) in vegetables grown in Shelekhov district. Other harmful substances (arsenic, lead, manganese and vanadium) in roots and tubers were not identified. These data were used as a basis for calculating environmental effects on the population consuming vegetables grown on polluted soils (Table 1). It was taken into account main vegetables grown in the south of Irkutsk region are potatoes, carrots and beets. According to the official data of the Federal State Statistics Service of Russia (2017), in Irkutsk region, their consumption is 126; 37.5 and 12.8 kg per person. The share of local products in the total consumption was 100 %.
Table 1. The content of benzo(a)pyrene (mcg/kg), fluorine and metals (mg/kg) in vegetables grown in the zone of aluminum production.

| Plant          | B(a)P   | Fluorine | Zinc      | Iron          | Nickel       |
|----------------|---------|----------|-----------|---------------|--------------|
| Potatoes (n = 5-24) | 0.46 ± 0.13 | 19.2 ± 8.1 | 9.0 ± 6.4 | 372 ± 593.8   | 8.64 ± 13.9  |
| Carrots (n = 5-12)  | 9.1 ± 1.7  | 6.4 ± 1.5 | -         | -             | -            |
| Beets (n = 7)       | 0.9 ± 0.5  | 8.9 ± 6.5 | -         | -             | -            |

Note: «-» - no data.

To assess the non-carcinogenic risk, the R 2.1.10.1920-04 method [21] was used. It is based on standard formulas for calculating average daily doses (I) and a hazard coefficient (HQ). Reference doses of harmful substances, as well as organs and systems affected by them are presented in Table 2.

Table 2. Reference doses in case of chronic oral intake of harmful substances.

| CAS   | Substance | RfD, mg/kg | Critical organs and systems                       |
|-------|-----------|------------|--------------------------------------------------|
| 7782-41-4 | Fluorine | 0.06       | teeth, bone system                                |
| 7439-89-6 | Iron     | 0.3        | mucous membranes, skin, blood, immune system      |
| 7440-66-6 | Zinc     | 0.3        | blood, biochemical composition (superoxide dismutase) |
| 7440-02-0 | Nickel   | 0.02       | liver, cardiovascular system, digestive tract, blood, weight |

The hazard coefficient (HQ) was calculated on the basis of vegetable consumption. The results are presented in Tables 3 and 4.

Table 3. Health risks when consuming vegetables containing fluorine.

| Plant | Average daily dose (I), mg/(kg·day) | Hazard Coefficient (HQ) |
|-------|-------------------------------------|--------------------------|
| Potatoes | 0.039                             | 0.65                     |
| Carrot  | 0.004                              | 0.06                     |
| Beet    | 0.002                              | 0.03                     |
| ΣHQ     |                                    | **0.74**                 |

Table 4. Health risks when consuming potatoes containing metals.

| Metal | Average daily dose (I), mg/(kg·day) | Hazard Coefficient (HQ) |
|-------|-------------------------------------|--------------------------|
| Iron  | 0.742                               | 2.47                     |
| Zinc  | 0.018                               | 0.06                     |
| Nickel| 0.018                               | 0.88                     |

In case of simultaneous intake of several substances, the hazard index (HI) is calculated as a sum of hazard coefficients for each substance. The HI was 4.15. The results indicate that there is a risk to human health when eating vegetables grown on contaminated soils. Iron is an essential element in the risk structure (Figure 1). Therefore, iron has the most negative impact on the hematopoietic and immune systems and integumentary tissues.
Figure 1. The share of toxicants in the structure of non-carcinogenic risks to health of the population of the Southern Baikal region, %.

An obligatory step in the assessment of carcinogenic risks is calculation of the average daily dose of carcinogen substances in the human body (LADD). According to the classification of the International Agency for Research on Cancer (IARC), B(a)P and nickel were referred to group 2 (probably carcinogenic substances). However, due to the absence of a carcinogenic potential factor \( SF_0 \) for nickel entering the human body perorally, the carcinogenic risk of B(a)P was assessed \( SF_0 = 7.3 \text{ mg/(kg·day)} \). Calculations were carried out using standard formulas [21]. According to our data, the average daily dose of B(a)P consumed with vegetables was LADD = 0.000015 mg/(kg·day), and the individual carcinogenic risk was CR = 1.09·10\(^{-4}\), the population risk (PCR) was 7 additional diseases to the background number. The value of CR was between maximum permissible and unacceptable levels.

4. Summary and Conclusion

The results indicate that vegetables grown on contaminated soils are dangerous. The non-carcinogenic risk (HQ = 4.15) is due to increased content of iron (59.5%) and nickel (21%), while the carcinogenic risk is caused by benzo(a)pyrene content (CR = 1.09·10\(^{-4}\)). Iron poses a non-carcinogenic risk. It affects the hematopoietic and immune systems, integumentary tissues and causes allergies. The non-cancerogenic risk is due to the high content of iron (HQ=2.47) and nickel (HQ=0.88); the cancerogenic risk is due to the high content of benz(a)pyrene (CR=1.09·10\(^{-4}\)).

The value of the hazard coefficient (HQ = 0.74) for fluorine entering the human body with roots and tubers does not exceed the permissible level despite the fact that it is one of the main components of soil pollution by aluminum production plants. The blood and immune systems are affected by such non-carcinogenic substances as iron and nickel entering the body perorally.

Despite a relatively high peroral risk level, it should be taken into account that it is part of the multi-environment impact of harmful substances in the zone of aluminum production. It is necessary to search for methods which can reduce them.

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