Quantitative assessment of the health risk, associated with drinking water quality in the Gusinoozersk industrial hub

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Abstract. Drinking water, as one of the main components of the habitat, determines human health and quality of life. In the past few decades, almost all water sources, both surface and underground, have been subject to intensive anthropogenic and technogenic impact. Lake Gusinoye, which is the main source of drinking water supply to adjacent settlements, is experiencing significant anthropogenic pressure. Based on the results of hydrochemical studies, the toxic effect of heavy metals on the population health, resulting from the consumption of drinking water of the centralised water supply from Gusinoye Lake, was considered. The results of a quantitative assessment of public health hazards showed that the risk of non-carcinogenic (toxic) effects is high in the territory of the Gusinoozersk industrial hub.

1. Introduction

Drinking water, as one of the main components of the habitat, whose quality is subject to very stringent requirements, determines human health and quality of life. In the past few decades, almost all water sources, both surface and underground, have been subject to intense anthropogenic and technogenic impact. The data from the ‘Environmental Safety Strategy of the Russian Federation for the period up to 2025’ show that only 11% of wastewater enters to Russian water bodies treated to the established standards. This means that about 40% of the country’s population regularly use water that does not meet hygienic standards. Due to the contamination of drinking water with chemicals and microorganisms, the risk of mortality and morbidity of the population increases [1]. Therefore, providing the population with good-quality water is now a worldwide priority. According to the state report “On the state of sanitary and epidemiological well-being of the population in the Russian Federation in 2017” [2], the use of low-quality water is characterized by a high level of general morbidity of the population associated with negative environmental factors.

There is a fresh groundwater deposit in the Yelnik river valley (nearby the Gusinoozersk industrial hub); the reserves of the deposit were preliminary estimated in the early 1980s. Exploration of the reserves began in the early 1990s, but it has not yet been completed due to a lack of funding [3]. Despite the potential suitability of these reserves for water supply, the problems of acute shortage of quality drinking water in the surrounding population centres have not yet been resolved.
The main source of household and drinking water supply for the industrial hub is Lake Gusinoye, which experiences a significant anthropogenic load. Anthropogenic impact is caused by heated waters of the Gusinozersk GRES, the unremediated overburden heaps of the Kholboldzhinsky coal mine, and wastewater treatment facilities of Gusinozersk city and Gusinoye Ozero settlement, that discharge wastewater into the lake tributaries [4]. Consequently, it is relevant to study the chemical composition of the Lake Gusinoye waters, as an important environmental factor affecting the health of the population living in the area.

The purpose of this work is to assess the toxic risk to the health of the population of the Gusinozersk industrial hub associated with the consumption of drinking water from water supply systems.

2. Models and Methods

The daily intake doses of harmful substances into the human body were established based on the average concentrations of substances in the water of Gusinoye Lake, which were obtained from monitoring studies [4-6]. Calculations and risk analysis of non-carcinogenic effects in adults and children as a result of chronic consumption of surface waters were assessed based on the values of hazard coefficient \( HQ \) according to the methodology developed by the US EPA [7]:

\[
HQ = \frac{CDI}{RfD}
\]  

(1)

where \( CDI \) – chronic daily dose of potentially hazardous component in human body, mg/kg per day; RfD – reference dose (maximum safe value of the concentration of a potentially hazardous component), mg/kg per day. The reference dose was chosen according to the US EPA methodology [7, 8].

Average chronic daily intake was estimated using the following formula:

\[
CDI = \frac{(C \cdot WI \cdot EF \cdot ED)}{(BW \cdot AT)}
\]  

(2)

where \( C \) is the concentration of a chemical element in water, mg/l; \( WI \) – daily water consumption, l/day, taken equal to 2 l/day (1 l/day for children) according to statistical data [10]; \( EF \) – exposure frequency, days/year, taken equal to 350 days/year according to US EPA recommendations; \( ED \) – duration of exposure, years, US EPA recommends taking this value to be 30 years for adults and 6 years for children, taking into account population migration; \( BW \) – body weight, kg, taken to be 70 kg for adults and 15 kg for children; \( AT \) – a value characterizing averaging over time, days, calculated as \( ED \cdot 365 \) days.

To assess the total (cumulative) risk of non-carcinogenic effects from the simultaneous exposure of several potentially hazardous components to the human body, the hazard index \( HI \) was used:

\[
HI = \sum HQ_i
\]  

(3)

where \( \sum HQ_i \) is the sum of the hazard coefficients of individual components, combined into groups according to the mechanism of their effect on the human body.

The development of non-carcinogenic effects in the population is probably with an \( HQ (HI) \) value of 1 or more, while the risk increases in proportion to the \( HQ (HI) \) value. Based on the calculation results, the risks were estimated based on the hazard coefficient \( HQ \) values for adults and children [7, 8].

3. Results and Discussion

The household and drinking water for the Gusinozersk industrial hub is supplied from the surface water of Lake Gusinoye. The study of physical and chemical composition of the water of Lake Gusinoye during the research period (2016-2018) showed that the waters are slightly alkaline (pH 7.8-8.8), with predominantly medium salinity (380-481 mg/dm³), with satisfactory concentrations of dissolved oxygen (8.7-11.55 mg/dm³), and of a sulphate-hydrocarbonate calcium-sodium type.
A comparison was made with the results of hydrochemical studies conducted before the construction of the Gusinoozersk GRES and the beginning of industrial development of the Kholbodzhinsky coal mine in 1965. The comparison showed that over 50 years there was an increase in water salinity with a corresponding increase in the content of ions in the macro-component composition, especially sulphate ions and alkali metals [2, 6].

Among the trace elements found in the surface waters of Lake Gusinoye, the priority pollutants considered were arsenic, cadmium, cobalt, nickel, lead and chromium, which are hazardous to health (Table 1).

| CAS   | Pollutant          | MAC<sup>b</sup>, mg/dm<sup>3</sup> | Content, mg/dm<sup>3</sup> | C<sub>min</sub> | C<sub>max</sub> | C<sub>medium</sub> |
|-------|--------------------|-----------------------------------|---------------------------|----------------|----------------|------------------|
| 7440-38-2 | Arsenic(As)<sup>a</sup> | 0.050                            | 0.0001                    | 0.0005         | 0.0002         |
| 7440-43-9 | Cadmium (Cd)<sup>a</sup> | 0.001                            | 0.0001                    | 0.002          | 0.001          |
| 7440-48-4 | Cobalt (Co)<sup>a</sup> | 0.100                            | 0.001                     | 0.005          | 0.004          |
| 7440-02-0 | Nickel (Ni)<sup>a</sup> | 0.100                            | 0.001                     | 0.003          | 0.002          |
| 7439-92-1 | Lead (Pb)<sup>a</sup>  | 0.030                            | 0.001                     | 0.007          | 0.005          |
| 7440-47-3 | Chromium (Cr)<sup>a</sup> | 0.050                            | 0.001                     | 0.028          | 0.010          |

<sup>a</sup> carcinogens [8];

<sup>b</sup> SanPiN 2.1.4.1074-01 [9].

In accordance with [9], hazard classes were established for these substances and their comparison with corresponding maximum allowable concentrations (MACs) were made. The comparison with MACs for the investigated chemical substances in water showed that there were no exceedances of the standards for most of the detected chemical substances, except for the maximum concentrations of cadmium. Based on the results obtained, doses of daily intake of microelements through consumption of drinking water from Lake Gusinoye were calculated for adults and children (Table 2).

| Pollutant      | CDI                  | RfD                    |
|----------------|----------------------|------------------------|
|                | Adults               | Children               |                     |
|                | Min.     | Max.     | Average | Min.     | Max.     | Average |                     |
| Arsenic(As)    | 0.000082 | 0.000575 | 0.000411 | 0.00001 | 0.00004 | 0.00003 | 0.0003            |
| Cadmium (Cd)   | 0.000082 | 0.000411 | 0.000164 | 0.00001 | 0.00003 | 0.00001 | 0.0005            |
| Cobalt (Co)    | 0.000822 | 0.004110 | 0.003288 | 0.00006 | 0.00032 | 0.00026 | 0.020              |
| Nickel (Ni)    | 0.000822 | 0.002466 | 0.001644 | 0.00006 | 0.00019 | 0.00013 | 0.020              |
| Lead (Pb)      | 0.000822 | 0.005753 | 0.004110 | 0.00006 | 0.00045 | 0.00032 | 0.0035            |
| Chromium (Cr)  | 0.000822 | 0.023014 | 0.008219 | 0.00006 | 0.00179 | 0.00064 | 0.005              |

Calculations show that the daily intake of potentially hazardous microelements into the body of adults is higher than that of children. Average daily doses of arsenic, lead, chromium entering to the body of adults exceed the RfD reference (safe) doses per day, which may indicate a more pronounced toxic effect. The assessment of the risks of toxic (non-carcinogenic) effects of chemical elements on adult and child health was carried out based on the calculation of individual hazard coefficients (HQ<sub>i</sub>) and hazard index (HI) (Table 3).
Table 3. Values of hazard coefficient \((HQ)\) and hazard index \((HI)\) for adults and children consuming surface water of Lake Gusinoje.

| Pollutant       | Adults          | Children       |
|-----------------|-----------------|----------------|
|                 | Min. | Max. | Average | Min. | Max. | Average |
| Arsenic(As)     | 0.2740 | 1.9178 | 1.3699 | 0.0213 | 0.1492 | 0.1065 |
| Cadmium (Cd)    | 0.1644 | 0.8219 | 0.3288 | 0.0128 | 0.0639 | 0.0256 |
| Cobalt (Co)     | 0.0411 | 0.2055 | 0.1644 | 0.0032 | 0.0160 | 0.0128 |
| Nickel (Ni)     | 0.0411 | 0.1233 | 0.0822 | 0.0032 | 0.0096 | 0.0064 |
| Lead (Pb)       | 0.2348 | 1.6438 | 1.1742 | 0.0183 | 0.1279 | 0.0913 |
| Chromium (Cr)   | 0.1644 | 4.6027 | 1.6438 | 0.0128 | 0.3580 | 0.1279 |

\(HI\)

0.9198 9.315 4.7633 0.0716 0.7246 0.3705

Based on the results of the calculations, it was found that the lowest toxic hazard \((HQ)\) poses nickel, for which the hazard coefficient is less than 0.11 at the average concentration in water. Significant hazard coefficients are characteristic of arsenic, cadmium, lead and chromium at their average concentrations in water, however, the combined presence of other trace elements in water increases their total toxic hazard [10-11]. Medium non-carcinogenic risk \((HQ\) between 1-5) is characteristic of 3 elements: arsenic, lead and chromium, with hazard ratios above 1 \((HQ>1)\) for adults. A low risk level \((HQ\) within 0.1-1) is typical for children, when chromium concentrations are above 0.11 \((HQ>0.11)\) (Table 3).

The calculated total hazard index \((HI)\) ranges from low to high level of carcinogenic risk \((0.9198-9.315)\) for the adult population, which indicates a high probability of developing toxic effects from the action of all the elements considered while maintaining their maximum concentrations in consumed water. For children, the total hazard index \((HI)\) is in the range of 0.0716-0.7246, from minimal to low. The toxic effect of arsenic, lead and chromium at their maximum concentrations exceeds the level of safe exposure \((HQ>0.11)\) and corresponds to a low (acceptable) level of non-carcinogenic risk \((HQ\) within 0.1-1).

4. Conclusion

Potential risks to the population arising from consumption of drinking water containing hazardous substances with carcinogenic properties have been determined by quantitative risk assessment using a hazard coefficient for the territory of the Gusinozersk industrial hub. The average daily doses of arsenic, lead, and chromium, consumed by the adult population with drinking water, exceed the reference (safe) intake doses.

The cumulative hazard index \((HI)\) reaches a high level of non-carcinogenic risk for adults, and a low level for children. This indicates a high probability of toxic effects of all the studied elements while persisting at their maximum concentrations in the consumed water.

Thus, it has been established that in the territory of the Gusinozersk industrial hub, the risks of toxic effects on public health, associated with the quality of drinking water are high. Consequently, it is necessary to optimise water supply conditions for the population of Gusinozersk and provide them with good quality, physiologically adequate drinking water; and to take certain measures to reduce health risks, including measures for finding an alternative and safer source of water.

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