Ecological and toxicological assessment of heavy metal pollution of the Bienda-Stemme Lake (West Spitsbergen)

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Abstract. According to the literature, linear-exponential mathematical models have been developed that link the magnitude of the risks (probabilities) of fatal outcomes when metal cations affect daphnia in a wide range of concentration variations. The approach to a comprehensive assessment of heavy metal pollution of surface waters of land has been improved (risk of combined exposure). The classification of water quality is given depending on the magnitude of the combined risks. The broken-stick model was used in order to classify water quality according to metal contamination levels. The developed approach was applied for an interannual assessment of lake pollution. The results of ecological and toxicological assessment of the dynamics of metal pollution (such as iron, manganese, zinc, copper, nickel, cobalt, lead, chromium, mercury and cadmium) of the Bienda-Stemme lake, located in Western Spitsbergen (Svalbard), in the spring of 2003-2019 are presented. It was established that the quality of the Bienda-Stemme lake water varied from “good” in 2003-2004, 2013-2015 to “satisfactory” in 2017 and 2018. In the period of 2007-2012, as well as in 2019, the water quality of the lake was characterized as “very good”. On average for the period of 2003-2019 the water quality of the lake in the spring was characterized as “good”. The main contribution to the metal pollution of the Bienda-Stemme lake is due to compounds of copper, mercury and zinc. A significant advantage of the considered approach to assessing the pollution of the Bienda-Stemme lake by metals is that this approach does not use the system of federal standards for MPC (maximum permissible concentrations). Moreover, up to present, regional standards have not been developed in Russia.

1. Introduction

The Bienda-Stemme lake, located on the western shore of the Groenfjorden Bay (arch. Spitsbergen) (Figure 1), is a source of drinking and household water for residents of the village of Barentsburg [1].

Active economic activity in the Arctic and global warming intensified by the influence of regional natural factors can lead to a shortage of fresh water resources in this territory [2].

Knowledge of the characteristics of the chemical composition of lake waters and its changes is fundamental when conducting a wide variety of environmental studies. The Bienda-Stemme lake is located in the intermountain basin, consequently the lake is fed by the influx of water from the Vardeborg glacier, located to the north of the lake, and the waters of the Vöring glacier, the moraine of which supports the southern shore of the lake. The mirror area of the lake is 0.013 km², the catchment
area is 5.2 km², the maximum volume of the lake is 516 thousand m³, the maximum depth is 12.8 m. The configuration of the lake bowl is irregular in shape, length 595.5 m, width 377.0 m. Coordinates: 78°3'18"N 13°57'55"E.

Among all trace elements found in samples of the waters of the Benda-Stemme lake, heavy metal ions should be especially noted. The lake’s waters contain all the most common heavy metals, and in some years the content of some carcinogenic elements such as arsenic and mercury is also recorded. However, their concentrations are low and average 0.32 μg / L and 0.008 μg / L for arsenic and mercury, respectively.

The aim of the study was to assess the trend of metal contamination of the Lake Bienda-Stemme for the period 2003-2019.

**Figure 1.** Map-scheme of the Spitsbergen Archipelago

2. Materials and research methods
The existing approach to quantizing and isolating the boundary values of numerical attributes used to group water bodies by quality classes is often quite arbitrary as it is based on the experience of the researcher [3].

In recent decades, biotesting is often used to assess water quality. In the second half of the 20th century in many countries of the world Daphnia magna Straus bioassays began to be used. Daphnia
is a powerful water filter: with a mass of 3-4 mg, one individual filters 20-30 ml of water during the day. A human with this ability would have to filter 700 thousand liters of water per day.

According to the literature on the toxicity of metals for daphnia (copper, iron, manganese, nickel, zinc, aluminum), linear-exponential mathematical models were constructed that relate the risks (probabilities) of deaths when these substances act on daphnia in a wide range of concentrations (Table 1).

Table 1. Mathematical models for calculating the risks of deaths when metals are exposed to daphnia

| Substance | Model |
|-----------|-------|
| Hg^{2+}  | Risk = 1 - exp(-13.777C^{0.547}) |
| Cu^{2+}  | Risk = 1 - exp(-25.103C^{0.956}) |
| Pb^{2+}  | Risk = 1 - exp(-0.2653C^{1.1}) |
| Cd^{2+}  | Risk = 1 - exp(-1880409C^{4.6135}) |
| Zn^{2+}  | Risk = 1 - exp(-2.02C^{1.168}) |
| Co^{2+}  | Risk = 1 - exp(-0.011C^{1.36}) |
| Fe^{2+}  | Risk = 1 - exp(-0.017C^{1.319}) |
| Mn^{2+}  | Risk = 1 - exp(-0.007C^{1.489}) |
| Ni^{2+}  | Risk = 1 - exp(-0.078C^{2.0861}) |
| Cr^{6+}  | Risk = 1 - exp(-0.00004338C^{16.284}) |

For the calculations, the following formula was used [4]:

$$R_{\text{comb}} = 1 - (1 - R_{\text{i}})(1 - R_{\text{i}}_2)(1 - R_{\text{i}}_3)\ldots(1 - R_{\text{i}}_n),$$  \hspace{1cm} (1)

where

- $R_{\text{comb}}$ — is the risk of the combined effect of a combination of metals,
- $R_{\text{i}}$ — is the risk of exposure to individual metals.

The broken stick model was used in order to classify water quality according to metal pollution levels [5, 6] (Table 2).

Table 2. Classification of water quality by the values of combined risks

| Water quality      | Combined Risk, $R_{\text{comb}}$ | Quality class |
|--------------------|-----------------------------------|---------------|
| Very good          | 0.00-0.04                         | I             |
| Good               | 0.04-0.09                         | II            |
| Satisfactory       | 0.09-0.16                         | III           |
| Poor               | 0.16-0.26                         | IV            |
| Very poor          | 0.26-1.00                         | V             |

For the calculations, the primary data of the North-West branch of the FSI SPA “Typhoon” were used.

3. Results and discussions

The given technique, based on the models given in Table 1 and Formula 1, was used to assess the dynamics of water quality of the Bienda-Stemme lake in 2003-2019.

3.1. Water quality assessment of the Bienda-Stemme lake
The results of the ecological-toxicological assessment of water pollution by heavy metals based on the combined risk criterion (Table 3) show a high dynamics of changes in lake water quality:

1) the oscillatory process of quality change within a period of 12 years (“very good” began in 2007 and renewed in 2019);

2) the time of quality decline from “very good” to “satisfactory” within 5 years (2012-2017).

### Table 3. Dynamics of the Bienda-Stemme lake water quality in the spring

| Year | Combined Risk, $R_{comb}$ | Water quality |
|------|---------------------------|---------------|
| 2003 | 0.06                      | Good          |
| 2004 | 0.05                      | Good          |
| 2007 | 0.03                      | Very good     |
| 2008 | 0.04                      | Very good     |
| 2009 | 0.03                      | Very good     |
| 2010 | 0.03                      | Very good     |
| 2011 | 0.04                      | Very good     |
| 2012 | 0.04                      | Very good     |
| 2013 | 0.07                      | Good          |
| 2014 | 0.05                      | Good          |
| 2015 | 0.05                      | Good          |
| 2017 | 0.10                      | Satisfactory  |
| 2018 | 0.10                      | Satisfactory  |
| 2019 | 0.02                      | Very good     |

As follows from the data given in Table 3, water samples taken in 2017 and 2018 are most highly contaminated with heavy metals. The main negative contribution to the metal pollution of the Bienda-Stemme lake is due to copper, mercury and zinc compounds.

3.2. **Linear trend estimation of the Bienda-Stemme lake**

In addition to the foregoing, a linear trend of combined risks for the period 2003-2019 was determined (figure 2). Chaddock’s scale was used to assess the trends [7].

The value of the determination coefficient $R^2 = 0.1257$ given in Figure 2 corresponds to the correlation coefficient $R = 0.35$. According to the Chaddock’s scale, this indicates a moderate positive trend of metal pollution of the Bienda-Stemme lake waters in spring.

![Figure 2. Water quality dynamics of the Bienda-Stemme lake in spring ($R^2 = 0.1257$).](image-url)
In conditions of climate warming, this trend can manifest itself much stronger, because the water balance of the lake is largely dependent on the glacier mass and speed of the melting [2], [8], [9]. However, according to experts, climate warming will lead to the expansion of economic activity in the Arctic region [10], [11], [12], [13], [14]. With this in mind, a significant increase in anthropogenic pressures on the territory and the need for water is expected in the coming years.

4. Conclusions
A comprehensive environmental and toxicological assessment of the metal pollution of the Bienda-Stemme lake in the autumn of 2003-2019 was carried out. A “moderate positive” trend in water quality has been identified. The main negative contribution to the metal pollution of the Bienda-Stemme lake is due to compounds of copper, mercury and zinc. The scientific novelty of the ecological-toxicological approach considered is in the joint use of hydrochemical and hydrobiological indicators that were previously used separately. A new combination (a new mathematical model) allows us to improve methods for assessing the quality of water and water bodies.

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