Assessing potential hazard of technogenic formations of natural and man-made complexes of some sulphide deposits of the Eastern Zabaykalye

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Abstract. The analysis of chemical composition of technosol and soil samples from Akatuyevsky and Blagodatsky polymetallic deposit mines of the Eastern Zabaykalye revealed that the main pollutant in the soil samples is As. Material excess of the Maximum allowable concentrations was registered for Pb, Zn, Cd and Mn. Calculation of potential hazard coefficients showed that the most hazardous for the environment are man-made formations of Akatuyevsky and Blagodatsky mines. Of all the chemical elements which are most commonly encountered at the Akatuyevsky and Blagodatsky mines technosol the most hazardous are As, Pb, Zn and Cu. It is noted that these chemical elements are part of sulphide ore minerals.

Mining territories of the Eastern Zabaykalye are potentially hazardous for the environment. Heavy metals which accumulate in the tailings facilities and in the soil affect physiological processes of plants and animals. The areas of Akatuyevsky and Blagodatsky polymetallic deposits located in the Nerchinsko-Zavodsky and Alexandrovo-Zavodsky districts of the Zabaykalsky krai are also potentially hazardous (figure 1).

Technosol and soils are characterized by high contents of As, Pb, Zn, Cd, Cu, Cr and Co (table 1). The main pollutant in the soil samples from Akatuyevsky and Blagodatsky mines is As (567 and 89.1 times in excess of the Maximum allowable concentrations). In addition, Akatuyevsky mine soil samples have significant excess of the Maximum allowable concentrations for Pb (35.4 times), Zn (33.5 times), and Cd (22.1 times), and Blagodatsky mine samples have excessive content of Zn (9.6 times), Mn (5.8 times), and Cd (3.5 times).

Technosol samples also have high content of Cu: technosol sampled from Akatuyevsky mine contains 256 g/t (0.74% in relation to ore concentration), technosol sampled from Blagodatsky mine contains 176 g/t (8.2%); Cr – 35 g/t (54.21%) and 51.8 g/t (28.1%); Co – 7.7 g/t (2.27%) and 6.9 g/t (49.9 %). The contents of these elements in the soil samples are: Cu – 68.3 g/t and 40.1 g/t, Cr – 117 g/t and 230 g/t, Co – 11.8 g/t and 16.4 g/t.

It is known that the component distribution series as pertains to the average content of leaching water in the technogenic water are the following: As>Zn>Mn>Fe>Sr>Cd>U>Pb>Sb>Mo>Cs>Se>Co – water from Akatuyevsky mine tailings facilities, As>Pb>Sb>Zn>Cd>Mn>Mo>Al>La>Sr>Cu>U – water from Blagodatsky mine tailings facilities [3].
Figure 1. Layout plan of Akatuyevsky (1) and Blagodatsky (2) polymetallic deposits. I – polymetallic deposits, II – administrative borders.

Potential hazard of the deposit mines technsol will be assessed with the method developed by a group of authors from All-Russian Scientific-Research Institute of Mineral Resources named after N M Fedorovsky [1]. According to this method environmental hazard of a potentially “toxic ore deposit” is assessed on the basis of the “lithotoxicity” of chemical elements (Tl).

Table 1. Average concentrations of chemical elements of the I, II and III hazard class in the samples of technsol and soil taken from the tailings facilities of Akatuyevsky and Blagodatsky mines and their Maximum allowable concentrations.

| As  | Pb  | Cd  | Zn  | Co  | Cu  | Sb  | Cr  | Ba  | Sr  | V   | Mn  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|     |     |     |     |     |     |     |     |     |     |     |     |
| Akatuyevsky mine Technsol (n=26) |     |     |     |     |     |     |     |     |     |     |     |
| 8757 | 3328 | 48.3 | 9311 | 7.7 | 256.2 | 47.8 | 35.2 | 141.2 | 633.7 | 43.8 | 2729 |
| 1134 | 1132 | 11.1 | 1842 | 11.8 | 65.9 | 14.4 | 121.1 | 584  | 306.2 | 72.9 | 1633 |
| Blagodatsky mine Technsol (n=27) |     |     |     |     |     |     |     |     |     |     |     |
| 8015 | 7124 | 76.5 | 1592 | 4  | 6.95 | 175.8 | 323.4 | 51.8 | 49.1 | 170.1 | 17.3 | 4376 |
| 178.2 | 46.3 | 1.7  | 525.9 | 16.4 | 40.1 | 2.5  | 230  | 534.2 | 159.2 | 93.9 | 8729 |
| Soil (n=59) |     |     |     |     |     |     |     |     |     |     |     |
| Maximum allowable concentration |     |     |     |     |     |     |     |     |     |     |     |
| 2   | 32  | 0.5  | 55  | 5   | 33  | 4.5  | 100 | 165 | 600 | 150 | 1500 |

“Potential toxicity of ore deposit” is calculated as (1):

\[
GEo = \sum_{i=1}^{n} (Tl \times B) + \ldots + (Tl \times B)_n,
\]

where \(GEo\) – potential toxicity of the ore deposit; \(Tl\) – element lithotoxicity coefficient; \(B = X/Q\), where \(X\) – element concentration, \(Q\) – element contents in the environment.

Calculation of "potential toxicity" of the technsol revealed that tailings facilities of the
Blagodatsky (\(GEo = 74441\)) and Akatuyevsky (\(GEo = 61803\)) polymetallic deposits are characterized by high environmental hazard. “Potential toxicity” of the soil samples is substantially lower – Akatuyevsky deposit (\(GEo = 8987\)), Blagodatsky deposit (\(GEo = 1855\)). According to the method described above the calculated \(GEo\) values correspond to the coefficients of potential toxicity of the polymetallic deposits.

In order to assess sanitary and hygienic pollution of the soil at the area, immediately adjacent to the technogenic landscapes we should calculate \(Z_c\). It is calculated with the following formula (2):

\[
Z_c = \left( \sum_{i=1}^{n} K_i \right) - (n - 1),
\]

(2)

where \(K_i\) – concentration coefficient of the i-th chemical element, \(n\) – number equal to the number of elements included in the geochemical association. Concentration coefficient \(K_i\) is calculated as follows: \(K_i = C_i / C_{\text{background}}\), where \(C_i\) – actual contents of the element; \(C_{\text{background}}\) – geochemical background.

According to the calculation, the soil of Akatuyevsky deposit mine is \(Z_c = 68.9\), whereas the calculations for the territory immediately adjacent to the tailings facility of Blagodatsky deposit showed \(Z_c = 55\). This value conforms to hazardous pollution of soil [2].

The calculations show high potential hazard of technogenic formations of Akatuyevsky and Blagodatsky mines. However, the methods used above do not take into account such properties of chemical elements as the rate of their dissemination in the environment under acidic and recovery conditions, and their aggregate content in potentially hazardous objects.

Therefore, in order to identify the degree of potential hazard of some chemical elements we will use the methods to calculate Pollution Load Index (\(PLI\)) and Geoaccumulation index \(I_{geo}\), which are widely used in international research [4, 5].

The assessment of potential hazard of soil pollution with heavy metal compounds from the tailings facility in this method is done with the following equations (3) and (4):

\[
PLI = \frac{C_{\text{soil}}}{C_{\text{background}}},
\]

(3)

\[
PLI = \left( PI_{\text{As}} + PI_{\text{Ba}} + PI_{\text{Cu}} + PI_{\text{Pb}} + PI_{\text{Sn}} + PI_{\text{Sr}} + PI_{\text{W}} + PI_{\text{Zn}} \right)^{\frac{1}{n}},
\]

(4)

where \(PI\) is the single factor pollution index of each metal \(1 < PI < 2\) is non polluted; \(1 < PI < 2\) is slightly polluted; \(2 < PI < 3\) is moderately polluted; \(PI > 3\) highly polluted; \(C_{\text{soil}}\) and \(C_{\text{background}}\) are the concentrations of metal in the soil sample and background respectively (mg/kg). \(PLI\) is pollution load index \(2 < PLI < 4\) is moderately polluted; \(4 < PLI < 6\) is highly polluted; \(PI\) is the single factor pollution index of each metal, and \(n\) is the number of pollutants assessed (eight in the current study); \(PI\) is the single factor pollution index of each metal.

The calculations show that based on the soil pollution load index the surroundings of Akatuyevsky and Blagodatsky mines can be referred to moderately polluted territories \(2 < PLI < 4\). The highest \(PI\) values were accounted for As, Pb, Zn and Cu in the soil samples from Akatuyevsky mine. In the Blagodatsky mine soil samples high \(PI\) values are registered for As, Pb and Ba (table 2).

**Table 2.** Calculated Pollution Load Index (\(PLI\)) and pollution index of each metal \(PI\) [4].

| As (\(PI\)) | Ba (\(PI\)) | Cu (\(PI\)) | Pb (\(PI\)) | Sn (\(PI\)) | Sr (\(PI\)) | W (\(PI\)) | Zn (\(PI\)) |
|-------------|-------------|-------------|-------------|-------------|-------------|------------|-------------|
| 175.1       | 0.2         | 25.6        | 65.2        | 2.5         | 2.8         | 10.3       | 74.8        |
|             |             |             |             |             |             |            |             |
| Blagodatsky mine tailings facility (\(PLI = 2.1\)) |             |             |             |             |             |            |             |
| 2268.5      | 0.2         | 7.2         | 185.8       | 14.5        | 0.9         | 1.1        | 199.1       |
|             |             |             |             |             |             |            |             |
| Soil from Akatuyevsky mine (\(PLI = 1.8\)) |             |             |             |             |             |            |             |
| 22.7        | 0.7         | 6.6         | 22.2        | 1.7         | 1.3         | 16.3       | 14.8        |

3
Soil from Blagodatsky mine (PLI = 1.7)

50.4 2 1.6 1.2 1.3 0.9 0.3 6.6

According to the method suggested by Müller [5] geoaccumulation index \( I_{\text{geo}} \) in the soil can be calculated as follows (5):

\[
I_{\text{geo}} = \log_2 \frac{C_n}{1.5 \times B_{E_n}},
\]

where \( C_n \) is measured concentration of heavy metal compounds in the sample; \( B_{E_n} \) is average background concentration of the measured elements.

This index reflects the level of exposure for such toxic compounds as arsenic, copper, antimony and lead within the boundaries of effect of tailings facilities of the studied abandoned mines. In the current study in order to insure the most accurate estimate of the potential hazard of the chemical elements we calculate the indices for As, Pb, Zn and Cu.

The index values are divided as follows: \( I_{\text{geo}} \leq 0 \) – practically unpolluted; \( 0 < I_{\text{geo}} \leq 1 \) – unpolluted to moderately polluted; \( 1 < I_{\text{geo}} \leq 2 \) – moderately polluted; \( 2 < I_{\text{geo}} \leq 3 \) – moderately polluted; \( 3 < I_{\text{geo}} \leq 4 \) – strongly polluted; \( 4 < I_{\text{geo}} \leq 5 \) – strongly polluted to extremely polluted; \( I_{\text{geo}} > 5 \) – extremely polluted.

According to the calculations the highest accumulation index \( I_{\text{geo}} \) is observed for As, followed by Zn and Pb, with the smallest index for Cu (table 3). It is noted that the index values for Akatuyevsky mine soil is generally higher than for samples taken from Blagodatsky mine; the only exception is 5.1 for As in the Blagodatsky mine soil samples. At the same time potential hazard of Blagodatsky tailings is generally higher than the same material from Akatuyevsky mine.

Table 3. Geoaccumulation index \( I_{\text{geo}} \) for technosol and soil from Atakuyevsky and Blagodatsky mines.

|       | As  | Cu  | Pb  | Zn  | As  | Cu  | Pb  | Zn  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|
| Akatuyevsky mine Technosol (n=26) | 6.9 | 4.1 | 5.4 | 5.6 | 10.6| 2.3 | 7   | 7.1 |
| Soil (n=40)                      | 3.9 | 2.1 | 3.9 | 3.3 | 5.1 | 0.1 | -0.3| 2.1 |
| Blagodatsky mine Technosol (n=27)|     |     |     |     |     |     |     |     |
| Soil (n=59)                      |     |     |     |     |     |     |     |     |

Thus, the calculations show that of all the studied chemical elements the highest potential hazard comes from As, Pb, Zn – I and II hazard class chemical elements. This fact is explained by the mineral composition of flotation tailings of the initial lead-zinc ore of Akatuyevsky and Blagodatsky mines (figure 2).

Figure 2. Photographs of heavy fraction polished sections (analytical laboratories of Geological Institute of the Siberian Branch of the RAS, Ulan-Ude): a) Akatuyevsky deposit tailings facility. 1 – Plattnerite (PbO₂), 2, 7 – Galena (PbS), 3, 5 – Pyrite (FeS₂), 4 – Arsenopyrite (FeAsS), 6 – Pyrrhotite (Fe₉S₈n); b) Tailings facility of Blagodatsky deposit. 1 – Pyrite (FeS₂), 2 – Arsenopyrite (FeAsS), 3-6 – Boulangerite (Pb₂Sb₄S₁₁).
Analysis of photographs of polished sections of technosol from Akatuyevsky mine reveals the following composition: pyrite, sphalerite, galena, arsenopyrite, copper sulfosalt minerals, calcite, potassium feldspar, and occasional inclusions of pyrrhotite and lead oxide. Whereas the tailings of Blagodatsky mine have the following composition: pyrite, sphalerite, galena, boulangerite, arsenopyrite, dolomite, cerussite, plattnerite.

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