Assessment of the technogenic impact of the mining industry on the environment of the economic corridors "China - Mongolia – Russia" of the territory of Mongolia and the Baikal region

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Abstract. The paper considers ecological consequences of the technogenic impact of the development of mineral deposits located in the economic corridors "China - Mongolia - Russia" within Mongolia and the Baikal region including the Irkutsk region, the Republic of Buryatia and the Transbaikal region. Administrative districts along the Transsiberian railway from Ulan-Ude to Ulaanbaatar to the border with China and Karymskoe-Zabaikalsk are being examined. A model that reveals an approach and main directions of the research has been developed. The structure of the model includes blocks containing information on objects and subjects of impact, environmental transformation and its assessment. A mapping method of the ecological situation was adopted as the main one. We created an original mapping language, consisting of a system of mapping signs that reflect the various environmental aspects of mining enterprises. We proposed criteria to assess technogenic impact within the fields and administrative regions. For the local assessment of the technogenic transformation of mining areas, we have taken the type of raw materials, its toxicity, the method of extraction, and the area of disturbed lands as environmental indicators. For spatial assessment, indicators of the environmental state in municipal areas have been adopted. The results of the studies are presented on six environmental maps that provide a visual representation of the mining impact on the environment, including its integrated assessment. A detailed description of the environmental consequences of mining enterprises activity, waste products that have the strongest impact on natural complexes, living conditions, economic activity and public health is given. The problems and prospects of further research are determined.

1. Introduction
On June 24, 2016 in Tashkent, at the SCO summit between the Russian Federation, the People's Republic of China and Mongolia, a tripartite agreement was signed to create an economic corridor "Mongolia - Russia - China." This economic corridor will be created, first of all, to increase trade turnover and development of transport infrastructure of the countries-participants of this agreement [1]. It is assumed that the implementation of the Agreement will entail an influx of investments into the adjacent regions, which may lead to an increase in technogenic load on the environment.

Mining industry complex is the most important basic element of national economy. At the same time, it has a significant impact on the environment. Due to the importance of this problem, the
assessment of environmental impact of mining enterprises within transport corridors is of great importance to the countries that are parties of this Agreement. This is especially relevant for ecologically vulnerable territories [2], including the Central Ecological Zone of the Baikal Natural Territory [3], national parks and reserves [4].

In the present work, the assessment of the technogenic impact is carried out in relation to the administrative areas along the transit railways running through the territory of Mongolia and the Baikal region. In these areas there are deposits of various minerals, both currently being developed and that have been preserved. The implementation of transport corridor construction projects will improve the transport and economic situation of the adjacent areas. This will give impetus to the further development of settlement systems, to a network of closely interconnected industries, including the mining industry, which will require additional environmental measures.

The research is conducted on the basis of a model, the content of which is disclosed in six associated environmental maps, discussed below.

The present study is a continuation and deepening of previous work on this subject [4, 5]. The maps compiled give a clear idea of the environmental consequences of the impact of mining on mineral deposits and environmental conditions in municipal areas. This information is the basis for planning and protective measures that allow to optimize technogenic load on the environment, which contributes to the conservation of ecosystems in the study region.

2. Models and methods
A model has been developed, that we adopted as a structural scheme - a model for solving different research tasks for assessing and mapping the technogenic impact of the mining industry on the environment of administrative regions within transport corridors (figure 1).

The model contains a number of blocks that reveal the ecological effects of the interaction of natural and technogenic systems.

Block "Subjects of impact" means enterprises of the mining complex. Sources of impact on the extraction method: underground (galleries, mines, wells), open (quarries, ditches, pits), and combined. Additionally - Production infrastructure (concentrating factories, tailing dumps, etc.).

Block "Objects of influence" means the environment: natural and socio-economic spheres that experience technogenic impact of the mining industry.

Block "Environmental impacts/local" is presented on the mining deposits, “Areal” within the boundaries of the districts.

Block "Estimated indicators" means qualitative and quantitative indicators, according to which the degree of technogenic impact is calculated. Local - the area of disturbed land in the fields, the toxicity of raw materials. Areal - indicators of the state of the environment in the areas.

Block “Integral indicator of environmental transformation” is estimated by the totality of the indicators on a five-point scale. To reveal the content of the model, a mapping method was adopted as the main one. The maps are compiled in the ArcMap program based on the interpretation of high-resolution space images (Landsat 2012-2017). The maps of minerals and mining industry were used as the basic ones [6, etc.]. The objects of environmental assessment and mapping are the areas of mining and municipal areas. To indicate the former on the map we used the signs. Considered are currently being developed, or previously developed deposits (except for common minerals), which, depending on the type of extracted raw materials, the method of extraction and the area of disturbed lands, are represented by cartographic signs of different color, shape and size. The method of quantitative background reflects man-made land transformations and other characteristics of the ecological state of the territory within the boundaries of administrative regions. These indicators have relative values and are estimated in points that allow us to compare them with each other and conduct an integral evaluation. The method of pie charts is used to display the percentage of each value in the total amount of indicators for the area. Diagrams provide visualization of data, supplement and improve the reliability of estimates.
3. Results and discussion
The ecological maps are the main result of our research. The following maps are considered.

3.1. The technogenic impact of the mining industry on the environment
This map is basic with the information that is used to compile subsequent maps (figure 2). Non-scale conventional signs reflect the nature of the disturbance, depending on the method of development, the type of extracted raw materials, and the extent of disturbance. As the leading indicator of anthropogenic impact on the environment, the amount of land disturbed in the process of mining has...
been adopted. For administrative districts, the quantitative background shows the density of disturbance, which is determined by the ratio of the total area of disturbed land in the district to the area of this district.

**Figure 2.** Technogenic impact of the mining industry on the environment
Nature of the impact on the environment: 1 - quarries, cuts, dumps (open mining method), 2 - dredge and hydraulic fields (open pit mining), 3 - mines, galleries, dumps (underground mining), 4 - wells (underground mining method), 5 - shafts, galleries, quarries, dumps (combined method), 6 - dumps, ditches, excavations (no data on the development method). The area of disturbed lands, km²: 7 - more than 10, 8 - 1-10, 9 - 0.1-1.0, 10 - less than 0.1. Kind of extracted raw materials: 11 - coal, brown, 12 - ferrous metals, 13 - non-ferrous metals, 14 - rare metals, 15 - gold, 16 - nonmetallic minerals, 17 - fluorite. Density of disturbed lands within municipal districts (aimaks), km²/thou.km²: 18 - more than 5 (5 points), 19 - 1-5 (4 points), 20 - 0.5-1.0 (3 points), 21 - 0.005-0.5 (2 points), 22 - no disturbance were detected (1 point). Borders: 23 - state, 24 - subjects of the Russian Federation, and aimaks, 25 - municipal districts.
The most significant land disturbance was formed as a result of the activities of coal mining enterprises in the Azeisk, Cheremkhovo, Kharanor, Gusinoozersk, Olon-Shibir, Mugun, and Baganur fields. Their development is accompanied by the formation of large quarries and dumps of overburden and enclosing rocks, reaching a volume of more than 200 million cubic meters.

Significant in terms of area, but relatively small in volume of displaced overburden rocks, extended linear sections of disturbed lands occur in river valleys due to the development of placer gold deposits. In the area under consideration, there are about twenty placer gold mining sites. Almost all of them are located in the river valleys in Mogochinskiy district, aimaks Selenge and Tuv. The largest areas of disturbed lands (about 40 km²), formed as a result of the work of drags and industrial equipment, were identified in the valleys of the Tuul river and its tributaries [7].

The work is often done right in the riverbeds and is accompanied by frequent discharges of dirty water, which leads to disturbance of aquatic ecosystems. This exacerbates the already complex problem of drinking water supply in Mongolia. In arid regions, under the influence of wind load and increasing gold mining, desertification of the territory also intensifies.

The analysis of the map shows that the territory experiences a significant man-caused strain on the part of mining enterprises, both current and in force in the past (on average, the density of violations of economic corridors is 0.662 km² / thousand km²). The highest values of this indicator were determined for the Selenginskii district of the Republic of Buryatia, and aimak Darkhan-Uul in Mongolia. Disturbance in the Tulun, Alar, Cheremkhovo districts of the Irkutsk region; Borzinskii, Petrovsk-Zabaiakalskiy, Mogochinskiy, Shilkinskii districts of the Transbaikal Territory are somewhat lower.

3.2. The structure of disturbed lands as a result of the activities of mining enterprises

The quantitative background shows the degree of land disturbance within the municipal area relative to the average for all economic corridors (figure 3). The highest values of this indicator are in Tulun, Mogochinskiy districts, as well as in the Tuv aimak.

The method of pie charts displays the area of technogenic deformations and the structure of disturbed lands in the districts (table 1).

**Table 1.** The share of lands damaged in the process of mining in economic corridors within the regions, %.

| Regions                      | Mongolia | Transbaikal region | Republic of Buryatia | Irkutsk region | Total |
|------------------------------|----------|--------------------|----------------------|----------------|-------|
| **Type of extracted raw material** |          |                    |                      |                |       |
| Coal stone and brown         | 32       | 30                 | 78                   | 83             | 46    |
| Black metals                 | 3        | -                  | -                    | -              | 1     |
| Non-ferrous metals           | -        | 14                 | -                    | -              | 5     |
| Rare metals                  | -        | 4                  | -                    | -              | 2     |
| Gold ore                     | 7        | 5                  | -                    | -              | 4     |
| Gold placer                  | 50       | 46                 | -                    | 13             | 36    |
| Non-metallic raw materials   | -        | -                  | 21                   | 4              | 3     |
| Fluorite                     | 8        | 1                  | 1                    | -              | 3     |
| **Toxicity of extracted raw materials** |          |                    |                      |                |       |
| Low                          | 21       |                    | 3                    | 2              |       |
| Moderate                     | 50       | 45                 | -                    | 13             | 36    |
| Increased                    | 35       | 30                 | 78                   | 84             | 48    |
| High                         | 15       | 20                 | 1                    | 12             |       |
| Very high                    | 5        |                    |                      |                | 2     |
Figure 3. The structure of disturbed land as a result of mining enterprises
Total area of disturbed lands in municipal districts (km): 1 - more than 30, 2 - 10-30, 3 - 3-10, 4 - 1-3, 5 - less than 1. Type of produced raw materials: 6 - coal, brown, 7 - ferrous metals, 8 - non-ferrous metals, 9 - gold ore, 10 - gold placer, 11 - rare metals, 12 - fluorite, 13 - non-metallic raw materials. Disturbance in the districts (aimaks) relative to the average along the corridor, km2 / km2: 14 - more than 5 (5 points), 15 - 1.5-5.0 (4 points), 16 - 0.5-1.5 (3 points), 17 - 0.005-0.5 (2 points), 18 - disturbances were not identified (1 point). Borders: 19 - state, 20 - subjects of the Russian Federation, aimaks, 21 - municipal districts.

The size of the diagrams is determined by the total area of disturbance. The maximum values of this indicator were recorded in Mogochinskii (mainly associated with the extraction of alluvial gold and, to a lesser extent, ore), Tulunskii (brown coal mining), Borzinskii (brown coal mining at present and tin in the past) municipal districts, as well as in the Tuv aimak (extraction of brown coal, iron, ore and placer gold, and tungsten). The shape of the diagrams reflects the structure of disturbed lands,
which is determined by the percentage of areas affected in the process of mining certain types of minerals, to the total area of disturbed land in the development of all types of minerals within the municipal area. The color of the segment corresponds to the type of extracted raw material.

**Figure 4.** Environmental risk assessment of mining industry activity in terms of toxicity of produced raw materials

Total area of disturbed lands in municipal districts (km): 1 - more than 30, 2 - 10-30, 3 - 3-10, 4 - 1-3, 5 - less than 1. Toxicity of the main and accompanying types of raw materials: 6 - low, 7 - moderate, 8 - high, 9 - high, 10 - very high. Toxicity in districts (aimaks), conventional units: 11 - more than 3.5 (5 points), 12 - 3.0-3.5 (4 points), 13 - 2.5-3.0 (3 points), 14 – 1.0-2.5 (2 points), 15 - no disturbance was detected (1 point). Borders: 16 - state, 17 - subjects of the Russian Federation and aimaks, 18 - municipal districts.
The largest disturbed areas were formed during coal mining (Mugunskii, Cheremkhovskii, Azeiskii, Tugnuskii, Kharanorskii, Baganuur and other sections), the second place is occupied by man-made landscapes that arose during the development of gold-bearing placers (the valleys of the rivers Ithaca, Kia, Kruchina, Davenda, Tuul, Sharyn-Gol, etc.

3.3. Assessment of the ecological hazard from mining enterprises activity in terms of the toxicity level of the extracted raw material

According to the degree of chemical impact on the natural environment, the raw materials and reagents used in its enrichment are divided into five toxicity classes: very high - rare metal and radioactive ores, antimony; high - ores of non-ferrous and precious metals, fluoride; increased - coal stone and brown, oil, iron ore, talc, salt; moderate - natural gas, alluvial gold, tungsten, tin, gypsum; low - non-metallic raw materials (mica, magnesite, perlite, zeolite) [8].

On the map (figure 4), the quantitative background method provides an ecological assessment of the areas by the criterion of toxicity. This assessment was determined by summing up the partial assessments obtained as a result of multiplying the toxicity class of the extracted raw materials and the weight indicators-the shares of the areas disturbed by the extraction of raw materials of this toxicity. The pie chart method represents the disturbance structure according to the indicated toxicity scale (see table 1). The size of the diagrams is determined by the total area of the disturbed territories within the municipal area. The size and color of the segments reflect the areas of man-caused disruptions that have occurred in the development of minerals of certain toxicity.

In the area under consideration, as a result of the extraction of raw materials of a very high toxicity level, 2% of the land was disturbed, and 12% of high toxicity level. Currently, enterprises for the extraction and processing of highly toxic raw materials in the Transbaikal Territory have been mothballed, but the accumulated production waste continues to have a negative impact on the environment, which is observed in Olovyaninskii and Shilkinsky districts.

The enterprises for the extraction and enrichment of raw materials of high toxicity are located in the Transbaikal region and Mongolia (active and mothballed mines for the extraction of molybdenum, tungsten, tin, ore gold, fluoride in Borzinskii, Chernyshevskii, Mogochinskii, Shilkinskii, Olovyaninskii districts, aimaks Selenge, Dundgov’ and Dornogov’). A significant contribution to pollution of the territory is made by the dumps and tailing dumps of closed mining enterprises of the Transbaikal Territory. To solve this problem, it is necessary to conduct an assessment of the impact of waste on the environment and the remediation of disturbed land.

3.4. The population and the disturbance of lands under the influence of the mining industry

Environmental damage during mining has a strong negative impact on the health, living conditions and economic activities of the local population (figure 5, 6).

On the first map (figure 5) the quantitative background shows the technogenic load: the ratio of the total area of disturbed lands per 1000 people. The maximum value of this indicator was revealed for Mogochinskii, Petrovsk-Zabaikalaskii, and Tulunskii districts. The method of pie charts shows the population in the districts (the size of the diagrams) and its structure (ratio of urban and rural population).

On the second map (figure 6), the quantitative background shows the technogenic load by the criterion of toxicity - the ratio of the total area of the land affected by the extraction of raw materials of high and very high toxicity by 1000 people. According to this indicator, the maximum burden falls on the residents of Mogochinskii and Chernyshevskii districts. Here the pie charts show the population in the regions and the share of the population of these areas in the total population of the Irkutsk region, the Republic of Buryatia, the Transbaikal Territory, and Mongolia within economic corridors.

Close to the settlements with mining and processing enterprises located here, dumps and tailing dumps most strongly affect the sanitary and hygienic conditions of the local population.

This situation is typical for the cities of Tulun and Cheremkhovo, having coal mines and dumps within their territories. The threat to ecological safety for the population of the Sherlovaya Gora
settlement was represented by a dusting layer of tail sediments in the tailing dump for ten years. At a distance of 1 km from the tailing dump, a very strong arsenic contamination of 57-300 mg/kg, a weak lead of 28-109 mg/kg and zinc 30-169 mg/kg was detected [9]. In Mongolia, as a result of large-scale mining of alluvial gold in river valleys, water became unsuitable for the swarming of livestock, which led to population migration.

Figure 5. Population and technogenic disturbance of lands
The population in the districts (aimaks), thousand people: 1 - more than 1000, 2 - 100-1000, 3 - 50-100, 4 - 30-50, 5 - 10-30. Population: 6 - urban, 7 - rural. Technogenic load on the population, km2/thou. people: 8 - more than 1.5 (5 points), 9 - 0.3-1.5 (4 points), 10 - 0.1-0.3 (3 points), 11 - 0.001-0.1 (2 points), 12 - no disturbance was detected (1 point). Borders: 13 - state, 14 - subjects of the Russian Federation and aimaks, 15 - municipal districts
Figure 6. Population and technogenic disturbance of lands by the criterion of toxicity
The population in the districts (aimaks), thousand people: 1 - more than 1000, 2 - 100-1000, 3 - 50-100, 4 - 30-50, 5 - 10-30. The ratio of the population of the region (6) and the region within the economic corridor (7). Technogenic load on the population by the criterion of toxicity, km2 / thou. people: 8 - more than 0.25 (5 points), 9 - 0.10-0.25 (4 points), 10 - 0.05-0.10 (3 points), 11 - 0.01-0.05 (2 points), 12 - no violations were detected (1 point). Borders: 13 - state, 14 - subjects of the Russian Federation and aimaks, 15 - municipal districts.

3.5. Integral assessment of technogenic transformation of lands
The assessment is carried out on the basis of the set of indicators adopted on the maps of various purposes considered above (figure 2-6). Indicators on the degree of environmental impact are assessed on a five-point scale according to the increase in the technogenic impact. Simple scores are summarized and translated into complex scores of the integral score over a range of values - also on a five-point scale (table 2).
The method of quantitative background is used to represent the total evaluation of anthropogenic impact. The method of pie charts is used to represent the spectrum of environmental indicators and their contribution to the integral assessment (figure 7).

**Figure 7.** Integral assessment of man-made impact
The total area of disturbed lands in municipal districts (km): 1 - more than 30, 2 - 10-30, 3 - 3-10, 4 - 1-3, 5 - less than 1. Indicators of integral assessment of the ecological state: 6 - density 7 - the disturbance density relative to the average along the corridor, 8 - man-caused load per 1000 people, 9 - toxicity in the areas, 10 - man-caused load per 1000 people by the criterion of toxicity. Integral assessment of the technogenic impact, the sum of simple scores: 11 - 19-21 (5 points - very high), 12 -15-18 (4 points high), 13 - 11-14 (3 points moderate), 14 - 9 10 (2 points - low), 15 - 5 (1 point - insignificant - no violations were detected). Borders: 16 - state, 17 - subjects of the Russian Federation and aimaks, 18 - municipal districts.
Table 2. Integral assessment of technogenic impact

| Representative municipal districts, aimaks | Estimation, scores |
|------------------------------------------|-------------------|
|                                          | * Dd | Dv | Dt | Tp | Tt | SSP | IA |
| Irkutsk                                   | 1    | 1  | 1  | 1  | 1  | 5   | I  |
| Kabanskii                                 | 2    | 2  | 2  | 2  | 1  | 9   | II |
| Tuv                                       | 3    | 3  | 2  | 4  | 2  | 14  | III|
| Darkhan-Uul                               | 5    | 5  | 3  | 3  | 1  | 17  | IV |
| Borzinskii                                | 4    | 5  | 4  | 4  | 4  | 21  | V  |

* Dd - density of disturbed lands; Dv – disturbance density relative to the average one along the corridor; Dt - degree of toxicity; Tp - technogenic load on population; Tt - technogenic load on population by the criterion of toxicity; SSP - the sum of simple points; IA - integral assessment

** Assessment of the anthropogenic impact degree: 1 (I) - insignificant, 2 (II) - low, 3 (III) - moderate, 4 (IV) - high, 5 (V) - very high.

Mogochinskii, Borzinskii and Shilkinskii districts of the Transbaikal Territory are highly technogenic disturbed. Irkutskii, Kuitunskii, Tarbagataiskii and other areas are considered environmentally safe, where mining operations (except for common ones) are not conducted.

4. Conclusion
The research is based on a model whose formalized image was used to solve problems of assessing the technogenic effect of mining on the environment within the economic corridors of Mongolia and the Baikal region. The model is revealed by a series of conjugated environmental maps of various topics related to the interaction of natural and man-made systems - a local assessment of the negative consequences of the development of specific mineral deposits and an area assessment of the state of the environment in administrative areas. In the series of maps, the first one, containing the information for compiling the subsequent maps is of the greatest importance, and the final one, which gives an integral assessment for the set of indicators.

The implementation of the project for the construction of transport and infrastructure corridors will contribute to strengthening the economic development of the adjacent territories. This will enable additional investments in innovative environmentally oriented technologies, and that is a prerequisite for the sustainable development of the transboundary region. Modernization of transport systems and expansion of mining production can lead not only to additional environmental loads, but also to increased dependence of Mongolia and Russia on raw materials exports, which will further complicate the environmental situation in these countries.

Prospects for further work are associated with the deepening of research to the second and third levels of remote regions, including in the research program all economic corridors, formed on their basis transport-infrastructure and mining complexes.

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