Assessment of man-made impact of mining on the environment of the Baikal-Mongolian region

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Abstract. In the Baikal-Mongolian region the assessment of the environmental impact of mining is carried out for mining enterprises that search, explore, and extract various types of mineral raw materials, as well as carry out their primary processing, waste disposal and recultivation of wastelands. We proposed a research model, summarizing the investigation content and stages. Leading importance is attached to the cartographic method based on remote materials and geo-information technologies, which increases the reliability, visibility and efficiency of the results obtained. We developed a system of indicators, taking into account the peculiarities of mining industry and environment. The negative impact of mining production on specially protected natural territories is assessed, the role of the latter as nature reserves and barriers to the technogenic expansion is determined. The enterprises that have the strongest environmental impact were comprehensively evaluated, while integrating various aspects of interaction of natural complexes and mining. The evaluation is carried out in relation to landscapes and their components that are most responsible for the environmental state. The maps obtained make it possible to determine the acuteness of ecological situations and plan and implement environmental protection measures in a timely manner. Prospects for further research were identified, a special place in which is given to methods of geoinformation modeling and mapping.

1. Introduction
The mining industry is of great importance for the economy of the Baikal-Mongolian region. The share of this industry was 24.3% according to the data for 2017 [1, 2] in the gross domestic product of Mongolia, 26.2% in the gross regional product of the Irkutsk oblast, and 14.0% of the Transbaikal Territory. At the same time, mining is one of the most powerful factors of anthropogenic impact on the environment [3]. It is believed that when mining 1 million tons of iron and manganese ore, up to 600-650 hectares of land are disturbed, 1 million tons of coal – up to 45 hectares; when constructing trunk pipelines, each kilometer accounts for up to 4 hectares of wastelands. About 90% of the generated waste is associated with mining. In particular, the volumes of waste associated with the perennial alluvial gold mining in the Lensko-Bodaibinskii mining region reach 10.5 km³ of rock mass. During the extraction and enrichment of ores of ferrous and non-ferrous metals, more than 350 million m³ of waste are generated annually [4].

During the development of mineral deposits, there is a transformation of all components of a landscape; environmental damages are observed far beyond the limits of the mine workings. Negative
effects can occur over a long time. As a result, there is a degradation of forests, reduction of agricultural land and hunting grounds, and the management efficiency is being reduced.

New nature reserves of in the form of specially protected areas [5, 6] should be used and if necessary, be created according to the principles of polarized landscapes and location for compensation the effects of environmentally hazardous pollution centers. In this region, a large number of different types of specially protected natural territories perform this role.

Table 1. The influence degree of industrial production on the environment [3].

| Industry                     | Atmosphere | Surface Waters | Underground Water | Soil cover | Vegetation cover | Lithosphere | Landscape in general |
|------------------------------|------------|----------------|-------------------|------------|------------------|-------------|---------------------|
| Chemical and petrochemical   | St         | St             | Av                | Av         | Av               | In          | In                  |
| Metallurgical                | St         | St             | In                | Av         | Av               | Ab          | In                  |
| Pulp and paper               | Av         | St             | In                | In         | In               | Ab          | Ab                  |
| Fuel and energy              | St         | St             | In                | In         | In               | Ab          | In                  |
| Construction                 | In         | In             | In                | Av         | In               | In          | Av                  |
| Vehicles                     | Av         | Av             | In                | In         | In               | Ab          | In                  |
| Mining                       | Av         | St             | St                | St         | Av               | St          | St                  |

The relevance of the research increases in connection with the implementation of the trilateral agreement on the creation of the China-Mongolia-Russia transport economic corridor, signed by the leaders of the three countries in 2016. The implementation of the agreements envisages the intensification of economic activity, which will increase the impact on environment [7, 8].

Therefore, the environment impact assessment of mining and other industries of a large sensitive region, focused on the development of environmentally hazardous industries under environmental restrictions, is of great importance. These problems can be solved on the basis of cartographic methods.

2. Models and methods

We developed a research model and adopted it as a model for the assessment and mapping the anthropogenic impact of mining on the environment of the Baikal-Mongolian region. Our study examines three constituent entities of the Russian Federation - the Irkutsk oblast, the Republic of Buryatia and the Transbaikal Territory, as well as the aimags of Mongolia and the Tere-Kholskiykozhuun of the Republic of Tyva located within the catchment area of Lake Baikal (figure 1).

This paper demonstrates a cartographic method of research, which provides visualization of various information, which is spatially distributed. This makes it possible to objectively assess the state of the environment and the severity of environmental problems in the region that are caused by mining.

Maps are compiled in the ArcMap program based on the interpretation of high-resolution satellite images using the SASPlanet program. The base maps used here are minerals, mining, and landscapes and their stability [9, 10, 11 and oth.]. This article presents two maps: "Technogenic impact of mining on the environment" and "Structure of Wastelands". The main indicator here is the area of wastelands. For individual representative sites for the extraction of various types of raw materials, characterized by a high degree of areal and “deep” transformation of the subsoil, an additional assessment of the volumes of displaced rocks using Google Earth was made. For the same areas, an assessment of the impact of mining on landscapes and their components was made, as well as on specially protected natural territories.
3. Results
Maps are the main tool and the result of the study. In the research area, the assessment of anthropogenic impact is carried out for the subsurface sites in operation at a given time or earlier, as well as the areas of their location.

Figure 1. Research Model.
Currently, about 80% of the deposits in the region are being developed using the open method. This is caused by the peculiarities of the ore body and coal seam occurrence, their depth and the structure of the surrounding rocks. This method, compared with underground mining, is the most cost-effective, despite the great damage done to the environment. The open-pit method provides for the careers extension to a considerable depth, and dumps of overburden and host rocks occupy large areas. This is the basis for the use of wastelands and volumes of displaced masses as the leading indicators of the transformation of the geological environment and the ecological state of the territory as a whole. Gravity and erosion engineering and geological processes are intensively developing on the slopes of dumps and sides of quarries.

At different stages of open pit mining, heavy dust and gas pollution of the air environment occurs, associated with the production of blasting, excavation and loading operations, during transportation of raw materials and overburden, dumping and storage of waste rock. In some cases, there is wind transfer of pollutants. For example, as a result of mining of copper-molybdenum ores in the Erdenethovoo deposit, traces of ore transfer are found in the soil and snow cover at a distance of up to 100 km [12].

In the underground mining method, the main problem is the qualitative and quantitative groundwater depletion. The waters of the technogenic complex have elevated levels of pollutants compared to natural waters, which are represented by various toxic metals, phenols, petroleum products, exceeding the maximum permissible concentrations. As a result of geodynamic processes, dips and subsidence of soil are formed on the earth surface. Significant areas are occupied by dumps of overburden and host rocks and tailing dumps. Gas and dust emissions from underground mines, waste dumps, tailings, and mineral deposits are observed.

When developing oil and gas fields, the main sources of environmental disturbance are engineering infrastructure facilities, namely exploration and production well sites, field and trunk pipelines, oil and gas treatment plants, pumping stations, quarry construction materials, and industrial waste landfills. In emergency situations associated with well flow and pipeline rupture, a large amount of oil and brines flow to the surface, which leads to contamination of large areas. The greatest danger is represented by vapor explosions, fires in oil storages and in places of oil spill. This leads to chemical contamination of land cover over a large area. At the same time, such an impact has a predominantly superficial character and does not extend to great depth.

The map “Environmental Impact of Mining” shows the characteristics of lands disturbed during the extraction and processing of mineral raw materials (figure 2). To display areas of technogenic transformation, off-scale signs are used, the density of wastelands in administrative areas is a quantitative background.

To display this indicator on the map "Structure of Wastelands", we used a circular diagram, which shows the proportion of land disturbed during the extraction of a particular type of minerals. The size of the diagrams is determined by the total area of wastelands within the municipal districts (aimags). The color quantitative background presents the proportion of wastelands in administrative entities in relation to the total man-caused disturbance of the territory of the Baikal-Mongolian region (figure 3). In addition an assessment of the prospects for the development of mining production and its environmental consequences was made.

Technogenic impact caused by mining enterprises of the Baikal-Mongolian region, which have the strongest environmental impact (figure 4), was assessed, taking into account the properties of landscapes, the volume of displaced masses, the level of impact on environmental components, etc. The stability of landscapes is determined in relation to anthropogenic impact based on their environmental and resource significance [13, 14]. According to the impact degree, they are divided into five categories. The main indicators are environmental impact factors, such as the area of wastelands (extensive impact), and the depth of mining and the volume of displaced masses (intensive impact). Pollutant transfer processes are also taken into account. There are two types of transfer - biotic and abiotic. The first is associated with trophic chains in ecosystems. The second type of
migration can be mechanical, which occurs under the influence of soil (lithodynamic successions), water and wind flows and physico-chemical (geochemical scattering flows).

![Diagram showing the environmental impact of mining.]

**Figure 2.** Environmental Impact of Mining.

### 4. Discussion: ecological problems and their solutions

The main problem is, firstly, the high economic and social importance of mining, and, secondly, the risk of anthropogenic impact on natural complexes, taken under state protection.

Protected natural areas—nature reserves, national parks and game reserves, which protect natural and historical-cultural complexes, carry out environmental education and recreational activities, and monitor the current state of the environment are presented on the maps of the region. These territories occupy the largest share of the total area of Mongolia – 13.1% and the smallest in the Transbaikal
Territory (1.5%). In the Irkutsk oblast 2.4% of the territories were assigned to SPNTs and 6.9% in the Republic of Buryatia [16, 17]. In relation to mining, their main role is to protect unique natural landscapes, especially valuable and sensitive ecosystems to negative technological impact. This feature can be considered as prevented damage. From the standpoint of the polarized landscape, the specially protected natural territories are the nodes of the ecological framework that ensures the preservation of the wild gene pool.

Figure 3. Structure of Wastelands.

Within the Russian part of the Baikal-Mongolian region the Baikal natural territory has been allocated, consisting of three ecological zones. Lake Baikal is surrounded with the Central Ecological Zone, in the north-west of it there is a zone of atmospheric influence and in the south-east - a buffer
zone. Significant restrictions relating to the activities of the mining industry are legislated in the central zone; they prohibit extraction of crude oil and natural gas, radioactive and metal ores, exploration and development of new deposits that have not been previously affected by operational activities, and others.

Korshunovskoe iron ore deposit, Irkutsk region

Erdeneth-Ovoo Copper-Molybdenum Ore Deposit (Mongolia)

Tulukuyevskoye uranium deposit (Trans-Baikal Territory)

Kharanorskoe brown coal deposit (Transbaikal Territory)

Zaamar placer gold deposit site [15] (Mongolia, Tuv aimag, Tuul river)
To solve the problem of intensifying industrial production and ensuring environmental safety, it is necessary to use not only prohibitions of economic activity, but also wide application of modern environmentally oriented technologies based on the principles of full and integrated use of mineral raw materials. The introduction of a recycling system ensures maximum utilization of production waste with production of goods that are safe for human life [18]. Such an approach is focused on reducing the negative impact on the environment, cost of eliminating the consequences of an impact and is a reasonable compromise of economic development and environmental protection.

5. Conclusion

The research in the Baikal-Mongolian region allowed to identify and present on the maps various types of mining production and to quantify the environmental impact. The main indicators of this assessment are the areas of wasteland, and in key site the depth of mining and the volume of displaced masses, showing the nature of transformation of the lithosphere. Dynamics of extraction of raw materials is evaluated, including current state and opportunities. The commissioning of new enterprises or the closure of existing ones, increase or decrease in the production volumes and development pace of deposits will be accompanied by corresponding changes in the environment.

In the future, we intend to assess the impact in more detail, determined by the combination of areal and volume indicators. This will be achieved by creating and using 3D models of elevation and geological structure of mineral deposits.

Special attention should be paid to the study and mapping of pollutant transfers, lithochemical streams of field dispersion, migration of chemical elements within the hypergenes is zone, and formation of lithochemical halos of dispersion. The issues of compatibility of mining production and environmental protection, role of specially protected natural territories and technogenic destruction nodes in the formation of the ecological framework of the raw material regions require further consideration.

Integrated rational use of raw materials, the use of modern methods of its extraction and processing (enrichment) reduce the environmental impact and ensure the ecological and economic efficiency of production. Monitoring of the mining industry is a necessary condition for its sustainable development. This requires tracking the dynamics of mining, reproduction of the mineral resource base and restoration of ecological state. Technical and environmental safety management, territorial development with a high degree of reliability and efficiency are supported by the methods of geoinformational computer modeling and mapping, which use express methods for determining the environmental state and remote sensing data (interpretation of high-resolution satellite images).

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