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## Assessment of Technogenic System Impact on Ecosphere Using GIS-Technologies (on the Example of Dalpolimetall Mining Enterprise)

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# Assessment of Technogenic System Impact on Ecosphere Using GIS-Technologies (on the Example of Dalpolimetall Mining Enterprise)

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**Abstract.** The results of experimental studies for Dalpolimetall object (in the Primorsky Krai), which is the only enterprise in the region producing lead and zinc concentrates, are presented in the article. It was established that the wastes of mineral materials processing, stored in large amounts in tailings, contribute to the ecosphere intensive pollution. It is obvious that the wastes (Class 2 of hazard – high-hazard) on the Earth's surface are more actively exposed to oxidation, dissolution, transformation into other mineral forms and aqueous solutions, that significantly worsens the environmental situation in the region under research. In this regard, the problem of the assessment of their impact on the environment and human health is very relevant. Accordingly, the main aim was to create a scientific basis and methodology for assessing the present state of technogenic systems as the real objects of a potential threat of ecological disasters and to develop the technology of its reduction or elimination. The results of long-term researches of the problem of technogenic system impact on ecosphere using GIS-technologies within its borders have allowed to reveal the patterns of technogenic pollution of the biosphere components, to develop the principles of pollutants migration from tailings to environmental objects, including the human body. The geoinformation approach has allowed to detect in the air basin 10 or more times excess of heavy metal compounds in dust, in soils – from 2 to 25 times, in water – up to 20 times and in vegetation – in 35-45 times. The obtained results have been taken as a basis of the proposed method of ensuring ecological safety of technogenic system in the region under study. the novelty of it was confirmed by the RF Patent.

## 1. Introduction

In the Dalnegorsky District of the Primorsky Krai the development of polymetallic raw materials began in the 1930-1940s. The situation is complicated by the fact that in town of Dalnegorsk different mining enterprises are located: Bor Mining and Chemical Company, Dalpolimetall Mining and Metallurgical Works, with its structural units: tailing dump and mining and processing plant. Moreover, assessing the overall state of mining production, it should be recognized, that it is not rational. The level of complex use of mineral materials is extremely low. And, as a result, huge volumes of wastes, mineral processing including, are accumulated here. Mining operations increase in the Far Eastern Federal District and Dalnegorsky District, in particular, contributed to a large-scale



negative change in all biosphere components. There occurred an intensive environment pollution by toxic metal compounds, as a result, natural-mining technogenic systems formed, which led to the emergence of environmentally-induced diseases of the Dalnegorsk population. In this regard, the main aim of the research was to create a scientific basis and methodology for assessing the current state of technogenic systems as real objects of potential threat of environmental disasters to develop the technology of accumulated environmental damage elimination. The following tasks were defined: 1. To analyze and summarize literary data on the problem of assessment of ecosphere technogenic objects impact; 2. Ecological-geochemical assessment of technogenic systems as a source of environment pollution and their impact on environment and health of population in the mining settlement using GIS-technologies; 3. Development of proposals on ensuring ecological safety of natural-mining technogenic systems.

## **2. Objects and methods of research**

The natural-mining systems formed by the previous economic activity of the Dalpolimetall mining enterprise were the object of research. The methodological basis of the study was the doctrine of academician V. I. Vernadsky on the biosphere and noosphere [1] and the basic provisions set out in the Program and Methodology of Technogenic Biogeocenosis Study [2]. A complex of methods, including both experimental and laboratory studies was used. Among the main methods are: modern instrumental and traditional physical-chemical and chemical methods, generalization of theoretical and experimental researches, zoning, biological methods, scientific forecasting, computer statistical processing. The main and governing system-complex approach was applied in the research process. The methods of GIS-technology cartographic modeling were used. The assessment of technogenic impact on the environment was made [3, 4] on the basis of geo-information monitoring using information models. This technique includes a method of remote sensing, allowing to monitor changes regularly using high-precision equipment of different spatial and spectral resolution [4, 5]. The Landsat 7, 8 system space images, scale 1:10000 – 1:100000, in various spectra are the research information database. Field and laboratory data processing (heavy metals and arsenic content in soils, vegetation, air, etc.) was performed using the free cross-platform Quantum GIS geo-information system, and the Ecologist Program (Version 4.0).

For the first time the authors applied the method of express assessment of the biosphere components state using the Growth Test and Pollen Sterility test-systems [6] in the conditions of mining enterprise in the Dalnegosky District. A number of indicators have been calculated to assess the environmental status of environmental objects [7]: a concentration coefficient (Kc), a total pollution index (Zc), a biological accumulation coefficient (BAC). The work was carried out in the MS Word text editor. All the results of the research were processed in the MS Excel program. Pictures and maps were processed with the Photoshop, Ms Office Picture Manager, Paint, Ms Visio programs. The illustrative material is prepared using MS Power Point and Quantum GIS 2.6.1 programs.

## **3. Results and discussion**

The accumulated great experience of information gathering and analysis for the problem of mineral processing wastes impact testifies that there is no synthesis of this knowledge, allowing to approach to the assessment of their impact on ecosystems [8-10]. Therefore, the existing methods of assessment of technogenic impact on the environment cannot provide its full-scale protection. Only the methods of bioindication using higher plants as the test objects will allow to assess objectively the technogenesis associated with mining [6]. At the present stage the problem of complex assessment of technogenic pollution impact on ecosystems and health of the population of mining settlements using GIS-technologies is practically not studied [3-5]. Annually at the mining and processing plant located in the town of Dalnegorsk, millions of tons of ore are being processed. To ensure the work of Dalpolimetall mining and processing plants 2 tailing dumps were constructed: an "old" one – 300 thous m<sup>2</sup> and volume of stacked tailings – 7.2 mln. t, and a "new" one – 525 thous. m<sup>2</sup> with a planned volume of 40 mln. t which has been filled by 25 mln. t. Naturally, the boundary of tailings is a hill

slope. As a result of long-lasting and vigorous activity of lead-zinc mining industry in the territory of the Dalnegorsky District, the systems of mining works were left behind: ditches, quarries, galleries and dumps of substandard ores and barren rocks, as well as tailing dumps, which contributed to the formation of a large-scale (hundreds of square kilometers) natural-mining technogenic system. Accumulated huge volumes of processing wastes is of the greatest risk and hazard for all living matter. The hazard class of mineral processing wastes is 2 – highly dangerous. It is established, that here the main ore minerals are sphalerite and galena, accessory minerals – chalcopyrite, arsenopyrite, pyrite, pyrrhotite, etc. Chemical composition of wastes is characterized as follows: Zn – 0.27- 0.29 %; Pb – 0.11- 0.18; Cu – 0.01-0.03; Fe – 4.37-4.60; Ag – 5-6 g/t. It should be noted that ore-bearing rocks with sulphide impregnation are present in the wastes. Intensification of their oxidation processes with formation of sulphate solutions is caused by that the rocks here are in crushed state that provides their loose structure in the tailing dump body. As a result, toxic elements pass into mobile state and are transported into a natural hydrographic network.

Geochemical and mineralogical characteristics of tails, as well as the duration and changing conditions of their storage (wet, water-closed on the top – at initial stages, and dry, open to wind erosion – at present), dust and gases emission, actual sulphide content, the migration of arsenic, zinc and copper compounds (several hundred times exceeding the background and Clark), suggest that dump wastes are a powerful negative factor of intense impact on environmental objects.

Thus, at present the tailing dump is in an active formation stage. It accumulates a large number of toxic chemical elements. Being toxic, they can obviously have a negative impact on environmental objects and biota.

The calculation of dust emission from the tailings surface of the Central Processing Plant (CPP) and Krasnorechenskaya Processing Plant (KPP), made in accordance with the "Methodical manual., 2001", allows to characterize quantitatively and qualitatively the pollutants emission into the atmosphere (table).

**Table 1.** Characteristics of pollutant emission into atmosphere from the Central tailings dump (CPP) and a new tailings dump (KPP).

| Tailings dump | Pollutant   | Maximum single emission, g/sec | Annual emission, t/year |
|---------------|---|--------------------------------|-------------------------|
| CCP           | Inorganic dust containing 70-20% of silicon dioxide (code 2908) | 93.245266                      | 42.774628               |
| KCP           | Inorganic dust containing 70-20% of silicon dioxide (code 2908) | 927.79039                      | 425.60755               |

The gas survey performed by transversal profiles to determine a degree of air pollution by suspended solids, sulphur dioxide, sulphate aerosols and nitrogen oxide shows that the greatest amount of toxic dust contained in the various compounds of heavy metals (HM) was found in the area of the mining and processing plant, as well as near the tailing dump. Its maximum concentration, reaching 86 MACs, was identified near the mining and processing plant. The average concentration at the whole territory of the investigated object 38 times exceeded the norm. The high level of dust pollution was observed in the territory of the kindergarten No 33 (Fig. 1), the secondary school No 21, constituting 55 MACs. It was revealed that the concentration of sulphates in aerosols was 78 times higher than the background value (near the mining and processing plant). In other points the maximum concentrations 18 - 37 times exceeded the background. Wind spreading of the fine sulphide mass, hypergene and technogenic minerals from the tailings body surface contributed to the air basin intensive pollution in the residential areas in Dalnegorsk, especially those located near the mining and processing plant, including the kindergarten No 33 and the school No 21 (Fig. 1).

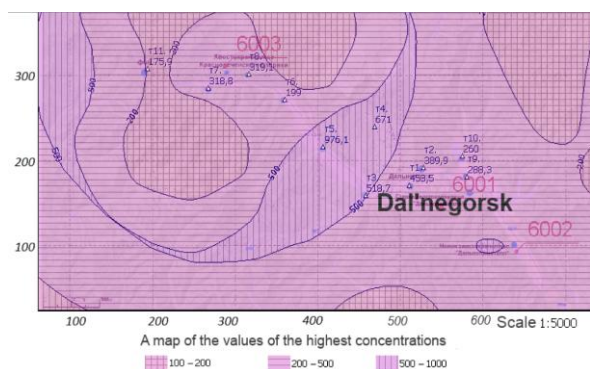
The results obtained allow to assert that air basin pollution by mineral processing wastes within the limits of technogenic system impact in Dalnegorsk considering toxic dust, heavy metals and sulfate-

ions aerosols, refers to an extremely high level. Figure 1 presents the digital cartographic model of majorant for substances and summation groups in the atmosphere within the locality of Dalnegorsk, the Primorsky Krai.

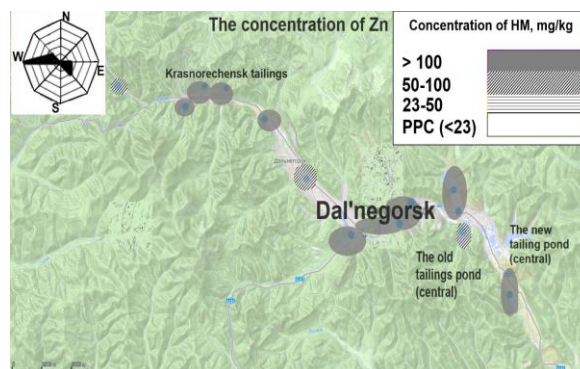
The large volume of sulfur and other gases emits into ground-level air from a body of the tailing dump.

Thus, the tailings are a dangerous source of atmospheric air pollution, especially in summer, when the winds have south, south-east and south-west directions, when aerogenic flow is directed towards the residential community of Dalnegorsk. The study of a snow cover within the boundaries of the technogenic system impact, as an indicator of technogenic pollution, allowed to establish that in all samples the concentration of pollutants (P) in the snow cover 3 - 16 times exceeds MAC and reference site.

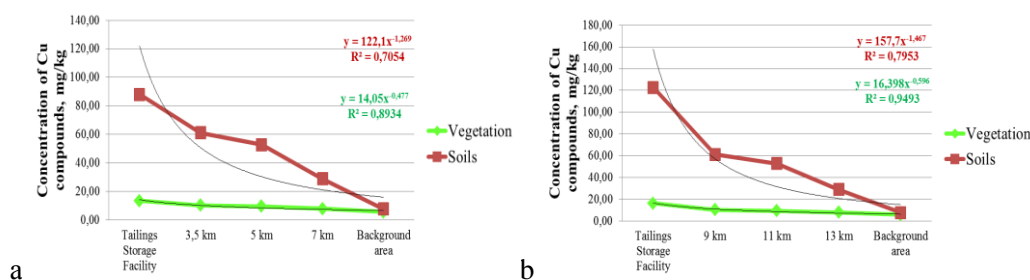
Polluting substances contained in wastes, including heavy metals compounds (HM), in large quantities are carried out from technogenic system by mine, slurry, pore waters in surface and ground waters, that has contributed to geochemical background changes of the study area. Undoubtedly, an intensive pollution of the soils of adjacent areas occurs. High concentrations of gross forms of heavy metal compounds are found in the soils of the Dalpolimataill tailings waste zone, several times exceeding the background content and MAC. The excess of MAC in soils for zinc, copper, manganese, lead, cobalt, antimony and other compounds has been determined (Fig. 2). The soil cover is a deposit of technogenic pollution. Our research shows that in the soils, confined to the tailings and ore processing plant, namely, in their upper level, the significant accumulation of toxic elements compounds such as Zn, Cu, Pb, etc were revealed. It was established that the gross contents of Zn, Pb, Cu in technogenic soils exceed MAC (in 1.6-13 times) and their background values (in 2 – 25 times). The anomalous amounts of Zn, Cu, Pb compounds are fixed not only in the upper layer of soil (0-10 cm), but also at the 10-20 cm depth. As the distance from the technogenic source increases, the pollution level decreases. Undoubtedly, the intensity of HM migration in technogenic soils depends on the organic matter content. According to migration ability the heavy metal compounds form a following series in technogenic soils: Zn > Cr, Pb > As > Cu (Fig. 3).



**Figure 1.** Digital cartographic model of majorant for substances and summation groups in the atmosphere within Dalnegorsk populated locality, the Primorsky Krai.



**Figure 2.** Cartographic model of Zn compounds in technogenic soils (Krasnorechensky tailing dump).



**Figure 3.** Cu compounds content in vegetation of the studied area of old (a) and new (b) tailing dump of CCP, mg/kg.

Calculation of the total soil pollution index ( $Z_c$ ), performed by N.A. Chernykh et al. [160], shows that its greatest value is characteristic of those soil samples, which are selected near to the source of pollution (tailing dump or ore-processing plant), and with increase of distance the level of technogenic soils pollution decreases. Similar results have been obtained for the concentration factor ( $K_c$ ).

Within the boundaries of technogenic system (Dalpolimetall tailing dump) there is the accumulation of a wide spectrum of toxic chemical compounds not only in soils, but also in vegetation: in roots, bark and leaves of trees, as well as in herbaceous plants, berries and mushrooms. The latter migrate by a chain: wastes – snow cover – air – soil – vegetation – human. Especially high content of HM compounds was found in needles and branches of Ajan spruce, exceeding such content in background areas. With increasing the distance from the source of toxicants, the concentration of heavy metal compounds, for example, in the fir branches, is naturally reduced. It was found that in the vegetation growing near the tailing dump, the content of Pb and Cd compounds, 3 - 7 times exceeds the normative data.

It was revealed, that the higher vegetation accumulates HM compounds (Zn, Pb, Cd, etc.), in quantities 1.5 to 8 times exceeding regional-background values.

Study of agricultural products, growing in the suburban areas located near the tailings pond showed, that the concentration of lead compounds in the potato tubers was 2-3 mcg/g in the most samples, the hygienic standard being 0.5 mg/kg. The concentration of lead ions in potatoes, collected at a distance of 3 km from the mining and processing plant, varies from 0.08 to 23.93 mcg/g and in 27 of 30 samples it exceeds MAC (0.5 mcg/g). At the most part of the territory, the content of lead compounds in potatoes exceeds 1 mcg/g and is increasing up to 3 or more mcg/g in the west and south-west part of Dalnegorsk. It was revealed that in potatoes and cucumbers, the excess of cadmium compounds relative to the MAC was in 10 and 13 times higher, respectively.

Thus, our research shows that mining technogenesis contributes to the degradation of not only the soil cover, as the main pollutants deposit, but vegetation also. The studies of surface watercourses and groundwaters within the impact of Dalnegorsky district tailing dumps showed their intensive pollution by compounds of toxic chemical elements: zinc, copper, lead, iron, nickel, cobalt, manganese, arsenic, their content 1.6 to 20 and more times higher than the background values.

In accordance with the standards of drinking water quality, it should be noted that the content of compounds such as lead and arsenic in the studied water from the wells near the sources of pollution is 2.6 and 20 times higher than the water quality target, respectively. In the public water supply source for the population of Dalnegorsk, the dry residue content did not exceed 1000 mg/l, sulfates – 500 mg/l, chlorides – 350 mg/l, the total hardness is 7 mg-eq/l.

Undoubtedly, the unfavorable ecological situation in the studied region causes the morbidity growth of the Dalnegorsk population (respiratory organs, carcinology, etc.). Almost all inhabitants live constantly in the area of high technogenic risk. The studies have revealed that the content of lead, zinc and other heavy metals compounds in biological material of children under 14 years from Dalnegorsk was 1.4-2 and more times higher than, for example, in the Non-Black and the Central non-black soil

zones and other areas of Russia. It was revealed that there is a direct correlation between the ecological conditions of living in a miners settlement or a town and significant growth of environmentally conditioned diseases in the area of study.

Thus, the natural-mining technogenic system formed by the Dalpolimetall mining enterprise negatively affects the ecosphere and health of the Dalnegorsky District population in the Primorsky Krai.

On the basis of these researches the methods of toxic wastes negative impact decrease on the environment objects were developed, aimed at ecological safety of natural-mining technogenic system, their novelty is confirmed by the Patents of the Russian Federation [11-12].

#### 4. Conclusion

The assessment of technogenic system impact on ecosphere, based on GIS-technologies (on the example of Dalpolimetall mining enterprise), has allowed to study the regularities of technogenic environment pollution, to reveal the peculiarities of heavy metal compounds and arsenic migration from wastes to ecosphere, a method to reduce their negative impact on environmental objects was suggested.

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