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Impact of technogenic dust pollution from the closed mining enterprise in the Amur Region on the ecosphere and human health

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Abstract
Environmental protection is a complex ecological and economic problem, including the need to develop and implement a number of environmental protection measures to mitigate the negative impact of mining waste on all natural environment components and human health. In this regard, the study purpose was to assess the impact of Pb, Cd, Cr, and As compounds on the environment and health of the population of the Solnechny miner's village. Based on the purpose, the following tasks were set: 1) review and systematization of literature data on the problem of technogenic dust pollution; 2) assessment of the mining industrial system as a source of ecosystem pollution with toxic elements within the closed mining enterprises impact areas; 3) development of proposals for mitigating the impact of mining activities on ecosystems and human health. The paper presents the findings of the study of the elemental status of children and adolescents living within the closed town-forming enterprise JSC Solnechny GOK impact area. The relationship between the level of technogenic pollution of the natural environment and the changes in the elemental status of the children was shown. A feature of the elemental status of the children in the study group was high content of heavy metals, including Pb, Cr, and As. Our research confirmed the data that a growing child's body actively adsorbs compounds of toxic chemical elements. Deficiency and imbalance of microelements in the body can cause ecologically-related diseases in the child population. Individual and population carcinogenic risks (*CR*) caused by the As, Pb, and Cr pollution were calculated. In accordance with the acceptance criteria for the risk caused by exposure to the pollutants, the individual carcinogenic risk CR (Cr) = $1{,}05 \cdot 10^{-3}$ belongs to the fourth range and is unacceptable neither for the population, nor for occupational groups. This is De manifestis risk, and when it is reached, it is necessary to carry out emergency curative measures to mitigate it. The individual risks CR (As) = $7{,}05 \cdot 10^{-4}$ also exceed the acceptable level for the population. This level of pollution is subject to permanent monitoring, requires development and implementation of planned curative measures to improve the indicators of the human environment, one of which is the organization of the environmental monitoring system in the study area.

Key words
mining, environmental monitoring, waste, heavy metal, compounds, population risk, Amur Region

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ТЕХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Научная статья

Воздействие техногенного пылевого загрязнения на экосферу и здоровье человека закрытого горного предприятия Приамурья

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Аннотация
Проблема защиты окружающей среды представляет собой сложную эколого-экономическую задачу, включающую необходимость разработки и реализации ряда природоохранных мероприятий,

обеспечивающих минимизацию негативного влияния отходов горного производства на все природные составляющие и здоровье человека. В связи с этим целью исследования является оценка влияния соединений Pb, Cd, Cr и As на окружающую среду и здоровье населения горняцкого поселка Солнечный. Исходя из цели определены следующие задачи: 1) анализ и систематизация литературных данных по проблеме техногенного пылевого загрязнения; 2) оценка горнопромышленной техногенной системы как источника загрязнения экосистем токсичными элементами в границах влияния закрытых горнорудных предприятий; 3) разработка предложений по снижению влияния горного техногенеза на состояние экосистемы и здоровье человека. В статье изложены результаты исследований по изучению элементного статуса детей и подростков, проживающих в границах влияния закрытого градообразующего предприятия ОАО «Солнечный ГОК». Показана связь изменений в элементном статусе детей с уровнем техногенного загрязнения среды обитания. Особенностью элементного статуса детей в исследуемой группе является высокий показатель содержания тяжелых металлов, в том числе Pb, Cr и мышьяка. Наши исследования подтверждают данные о том, что детский растущий организм активно адсорбирует соединения токсичных химических элементов. Рассчитаны индивидуальные и популяционные канцерогенные риски по As, Pb, Cr. В соответствии с критериями приемлемости риска, обусловленного воздействием загрязняющих веществ, индивидуальный канцерогенный риск *CR* (Cr) = $1{,}05 \cdot 10^{-3}$ относится к четвертому диапазону и является неприемлемым ни для населения, ни для профессиональных групп. Это De manifestis Risk, и при его достижении необходимо проведение экстренных оздоровительных мероприятий по его снижению. Индивидуальный риск *CR* (As) = $7{,}05 \cdot 10^{-4}$ превышает приемлемое значение для населения. Данный уровень загрязнения подлежит постоянному контролю, требует разработки и проведения плановых оздоровительных мероприятий по улучшению показателей среды обитания, одним из которых является организация системы экологического мониторинга в исследуемом районе.

Ключевые слова
горное дело, экологический мониторинг, отходы, тяжелые металлы, популяционный риск, Приамурье

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Introduction

Long-term research experience of Russian and foreign scientists testifies to the negative impact of mining and processing complexes, both operating and closed [1–4], on the natural environment and humans. Environmental pollution by heavy metal compounds (Cr, Cd, Pb and As) in mining areas, where mining and agriculture coexist, is a major worldwide concern [5–16]. The studies of foreign scientists in South Africa, Mexico, and China have shown high levels of soil, crops and microbial communities pollution with metals [5–9]. Xu Zhang et al., having analyzed the features of migration of Fe, Mn, Cr, Pb, emphasized high contents of these elements in soils and plants, noting their high phytotoxicity and significant deterioration of water quality due the pollution. Bioavailable forms of heavy metals pose great environmental risks, ultimately threatening human health [8]. Karaca O. et al. note that heavy metal pollution can affect biodiversity and economic well-being of the study region [6]. Ying-NanHuang et al. note that children are more sensitive than adults to the impacts of metals Cd and Cr, as reflected in the HI and CR values, exceeding the permissible levels [5, 9].

Recently, in the Far Eastern Federal District (FEFD), including in the Amur region, mining enterprises, including tin ore producing ones, have been closed, which has led to serious environmental problems. For instance, Solnechny Mining and Processing Complex (hereinafter Solnechny GOK or the GOK), closed to date, for many years was one of the largest mining enterprises in the Far East. The tin ore deposit in the central part of the Khabarovsk Territory was exploited by the GOK for decades, starting from the middle of the past century. After the mining termination and the mining enterprise closure, the past mining activity negative impact on the natural environment and the surrounding area can continue for a long time.

The main types of such impacts include disfigurement of the landscape and deterioration of soil and vegetation cover, changes in the condition and composition of groundwater and surface water, decrease in biodiversity, and the release of hazardous substances onto the day surface.

Currently, there is a need to organize a comprehensive environmental monitoring of ecosystem changes, as well as to predict environmental impact of technogenic objects for development of measures aimed at reducing the negative consequences caused by long-term mining activities and eliminating the cumulative harm to natural environment (waste of mineral processing) in the tin ore mining areas of the Far East, including in the Amur region. In this regard, the study purpose was to assess the impact of Pb, Cd, Cr and As compounds on the natural environment and health of the population of the Solnechny miner's village for ensuring environmental safety. Proceeding from this purpose, the following tasks were defined: 1) review and systematization of literature data on the problem of technogenic dust pollution; 2) assessment of the mining industrial system as a source of the ecosystem pollution with compounds of toxic elements within the closed mining enterprises impact areas; 3) development of proposals to reduce the impact of mining activities/consequences on the ecosystem and human health.

Research Subject and Methods

The study subjects were natural and technogenic ecosystems formed in the past century due to the activities of the Solnechny Mining and Processing Complex. The tin ore processing waste is a potential source of the technogenic pollution. For quantitative analysis of the samples (the tin ore processing waste, soils, vegetation, biological material), the ICP/AAS (inductively coupled argon plasma atomic absorption spectroscopy) method was used.

A mass spectrometer (ICP-MS Elan 9000, Canada) was used for measuring the quantitative contents of heavy metals and arsenic compounds [17]. According to the Guidelines for assessing the risk to public health when exposed to natural environment polluting chemicals [18], to determine the values of population carcinogenic risks (PCR), reflecting the additional number of cases of malignant neoplasms that can arise throughout life due to exposure to the factor under study, the calculation is performed using formula:

$$PCR = CR \cdot POP, \tag{1}$$

where *CR* – is an individual carcinogenic risk, *POP* – is the study population number, people.

The calculation of the additional probability of developing cancer in an individual throughout his life (*CR*) was carried out by formula:

$$CR = LADD \cdot SF, \tag{2}$$

where *LADD* is lifetime average daily dose of an element, mg/(kg · day); SF is carcinogenic potential factor, (kg · day)/mg.

Lifetime average daily dose of an element intake into a human body is calculated by formula:

$$LADD = \frac{((Ca \cdot Tout \cdot Vout) + (Ch \cdot Tin \cdot Vin)) \cdot EF \cdot ED}{BW \cdot AT \cdot 365}, \tag{3}$$

where *Ca* – is a substance concentration in the atmospheric air, mg/m^3; *Tout* – is time spent outdoors, h/day; *Vout* – is outdoor breathing rate, m^3/h; *Ch* – is a substance concentration in the room air, mg/m^3; *Tin* – is time spent indoors, h/day; Vin – is indoor breathing rate, m^3/h; EF – is exposure frequency, days/year; *ED* – is exposure duration, years; *BW* – is a human body weight, kg; *AT* – is exposure averaging period, years.

Findings and Discussion

The specificity of the extraction and processing of tin ore at the mining enterprise under study consisted in the extraction and processing of huge volume of rock mass, of which only a small part was used, whereas the rest was accumulated in the form of technogenic waste, so-called tailings, placed in the special structure, tailings storage facility (TSF). This hydraulic engineering facility was designed and put into operation in 1969. In the process of ore mining and processing, new technogenic landforms not characteristic of this territory were formed. During the GOK operation, the TSF has accumulated about 16 million m^3 of waste [1]. In 2001, in connection with the enterprise operation termination, the TSF of the central processing plant of Solnechny GOK was drained, but its surface, contrary to the legislation of the Russian Federation (according to which the subsoil user was obliged to conserve the man-made object and reclaim the disturbed lands), was not reclaimed in a timely manner.

Migration of chemical elements and their compounds as a result of complex physicochemical processes of transformation of minerals contained in waste, occurring in the near-surface part of the lithosphere under conditions of increased aeration is one of the main causes of ecosphere pollution. At present, the TSF of the closed Solnechny GOK is a great source of dust release and intensive technogenic environmental pollution with toxic elements [2, 3]. On the surface and within the tailings, especially in dry periods, blossom, thin crusts and films of technogenic minerals (sulfates, carbonates, silicates, arsenates, etc.) originate [1]. As a result of the processes of hypergenesis and technogenesis, highly mineralized solutions, containing large amounts of heavy metal compounds, are formed in mining waste [4]. They enter surface water and groundwater and migrate over long distances, polluting natural environment components [3, 4].

At the present stage, the role of technogenic environmental pollution in genesis of a number of human diseases has been insufficiently studied. It should be noted that the Solnechny miner's village is located 3 km from the TSF. The population lives in conditions of stable exceeding permissible levels of the pollutants contents, including in atmospheric air [3, 4].

Numerous studies indicate that the child population is more sensitive to the impact of unfavorable environmental factors [5, 9, 10].

Studies in the field of the impact of tin ore mining and processing industry on natural environment components indicate that the problem of the ecosphere pollution is one of the most urgent, especially within the impact areas of closed mining enterprises of the Far Eastern Federal District. The issues of environmental protection are a complex ecological and economic task, including the need to develop and implement a number of environmental protection measures to minimize the negative impact of mining waste on all natural environment components and humans [4], including implementation of environmental monitoring. It is aimed at solving the problems outlined in the Federal Law No. 7 "On environmental protection" [19]. In accordance with Federal Law No. 7, the objectives of environmental monitoring include: 1) monitoring environmental condition, including areas where sources of anthropogenic impact are located; 2) monitoring the impact of anthropogenic sources on the environment; 3) providing the government, legal entities and individuals with reliable information required to prevent and (or) mitigate the adverse consequences of changing environmental condition. In this regard, there is a need to create and develop environmental monitoring system in the study area.

Within the framework of environmental monitoring, multi-year research allowed determining contents of heavy metal compounds in the tailings, soils, vegetation, snow cover, human biological material (hair). The tailings assay confirmed the presence of high contents of heavy metal compounds in them, including the most hazardous ones, such as chromium (Cr), arsenic (As), cadmium (Cd) and lead (Pb) (in accordance with current classifications). Significant amount of gases is released from the tailings body into the air near the tailings surface. Air pollution here can be classified as extremely high. The aerosol concentration turned out to be 80 times above the baseline. The weighted average concentrations of heavy metal compounds in the snow cover in winter seasons were as follows (mg/dm^3): Pb – 0,001; Cd – 0,002; Cr – 0,001.

Contents of As, Cr, Pb compounds in the soils and vegetation exceeded MPCs. In addition, the soil cover is an accumulator of the technogenic pollutants. Soils react slowly to changes in the environment, but they fix and accumulate toxic elements. Within the TSF impact area, accumulation of Pb, Cr, Cd compounds by plants was recorded, mainly in the leaves and roots of the plants.

Assaying hair samples taken from children aged 3 to 14 years living in the Solnechny miner's village for As, Cr, Cd, Pb indicated the following regional features of the elemental status (content of the elements in hairs) in the studied group of children:

– the girls demonstrated an excess of 3.5 times for Cr and 2.61 times for Pb, respectively, in comparison with the averaged data for Russia [20]. In increasing order of the excess, these elements should be positioned as follows: Pb < Cr. The contents of As (0.015 mg/kg) and Cd (0.103 mg/kg) did not exceed the corresponding average values in Russia;

– for the boys, only average Russian Cr content was exceeded by 1.54 times. At the same time, the contents of As (0.015 mg/kg) and Cd (0.103 mg/kg) did not exceed the corresponding average values.

The feature of the elemental status of children in the study group was increased contents of toxic Pb, Cr and As. Our research confirmed the data that a growing child's body actively adsorbs toxic elements. Diseases can be caused both by surplus/deficiency and imbalance of microelements in a body [21–24].

In the course of analyzing the impact of the As, Cr, Pb compounds as carcinogenic factors upon inhalation into a human body [18] in the Solnechny village, the following data on the values of the individual and population risks were obtained (Table 1).

Table 1

Individual and population carcinogenic risks for the Solnechny village inhabitants

Element	Content in air, mg/m^3	*SF*, (kg · day)/mg	LADD, mg/(kg · day)	CR	PCR
As	0.0032	15	$4.7 \cdot 10^{-5}$	$7.05 \cdot 10^{-4}$	9
Cr	0.0017	42	$2.5 \cdot 10^{-5}$	$1.05 \cdot 10^{-3}$	12
Pb	0.0028	0.042	$4.2 \cdot 10^{-5}$	$1.76 \cdot 10^{-6}$	< 1

In accordance with the acceptance criteria for the risk due to exposure to the pollutants, the individual carcinogenic risk *CR* (Cr) = $1.05 \cdot 10^{-3}$ belongs to the fourth range (the individual risk throughout life being equal to or more than $1 \cdot 10^{-3}$), and it is unacceptable neither for population nor for occupational groups. This range is referred to as De manifestis risk, and when it is reached, it is necessary to give recommendations for decision-makers on carrying out emergency curative measures to mitigate the risk. For arsenic (*CR* = $7.05 \cdot 10^{-4}$) the population risks exceed the acceptable values for the population. The individual carcinogenic risk caused by lead compounds is acceptable (*CR* = $1.76 \cdot 10^{-6}$). To mitigate the negative impact of TSF, containing toxic waste, on ecosphere, special process design solutions have been proposed, the novelty of which the novelty of which was confirmed by patents of the Russian Federation (2017, 2019) [25, 26].

Conclusion

The study findings indicated that the environmental condition within the impact area of the closed tin ore enterprise Solnechny GOK in the Amur Region should be assessed as critical.

Improving the situation within the closed tin ore enterprise impact area is possible with establishing an environmental monitoring center in the study area, the main task of which shall be providing an integrated approach to monitoring of the contents of toxic elements in the biosphere components; organizing an effective system for collecting, processing and transmitting the monitoring results, as well as forecasting. The new methods have been created aimed at ensuring environmental safety of ore processing waste, the novelty of which was confirmed by patents (2017, 2019) [25, 26].

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