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Assessment of the elemental status of the young population in Solnechny, Khabarovsk krai, as part of mining environmental monitoring

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Abstract
Prolonged operation of the mining and processing plant in Solnechny District, Khabarovsk Krai, led to the formation of a technogenic mining system. Biogeochemical zones with elevated concentrations of chemical compounds, including heavy metals and arsenic, developed in the area. Monitoring revealed that soil samples taken at varying distances from the second tailings dump of the Solnechny Mining and Processing Plant (MPP), including within the settlement of Solnechny, contained heavy metals – Cu, Zn, Pb, and Hg – at levels exceeding the maximum permissible concentrations (MPCs) by factors of 1.4 to 12.36. Arsenic levels reached 571 times the MPC. Surface water bodies showed excess concentrations of Cr, Cu, Fe, and Zn, ranging from 2 to 110 times the MPC. No arsenic excess was found in water samples. The elemental status of a developing child reflects the health of the surrounding ecosystem. Hair samples from children under 14 years of age residing in the settlement of Solnechny were analyzed. Girls showed elevated levels of Hg, Cr, Pb, and Cu, along with reduced concentrations of the essential element Zn. Boys showed increased levels of Hg, Fe, Cr, Zn, and Cu. To reduce the spread of pollutants from tailings dumps, including those of the Solnechny plant, technical solutions have been proposed.

Keywords
mining, beneficiation, tin ore, waste, tailings dump, environment, technogenic pollution, soil and subsoil, water, sample, heavy metals, chromium (Cr), iron (Fe), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), tin (Sn), mercury (Hg), lead (Pb), spectrometry, spectrophotometer, child population, elemental status, land reclamation, waste containment, Khabarovsk Krai, settlement of Solnechny

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ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Научная статья

Исследование элементного статуса молодого населения посёлка Солнечный Хабаровского края в рамках горно-экологического мониторинга

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Аннотация
В Солнечном районе Хабаровского края в результате длительной работы горно-обогатительного комбината сформировалась горнопромышленная техногенная система. Здесь образовались биогеохимические зоны с высоким содержанием соединений химических элементов, в том числе тяжёлых металлов и мышьяка. Установлено, что в мониторинговых точках, расположенных на различном расстоянии от второго хвостохранилища Солнечного ГОКа, в том числе на территории посёлка Солнечный (Хабаров-

ский край), концентрации определяемых тяжёлых металлов в почвах превышают нормативные значения по Cu, Zn, Pb и Hg от 1,4 до 12,36 ПДК, содержание As составило 571 ПДК. В водных объектах отмечается превышение по Cr, Cu, Fe и Zn от 2 до 110 ПДК. Превышение содержания As в исследуемых пробах воды не обнаружено. Элементный статус в растущем организме человека является индикаторным показателем состояния экосистем, в связи с чем была проведена оценка элементного состава волос жителей посёлка Солнечный в возрасте до 14 лет. Показано, что особенностью элементного статуса для девочек в исследуемой группе являются высокие показатели содержания тяжёлых металлов Hg, Cr, Pb, Cu, а также пониженное содержание важного эссенциального элемента Zn. Для мальчиков отмечаются превышения по концентрациям Hg, Fe, Cr, Zn и Cu. В связи с этим предложены технические решения с целью снижения распространения загрязняющих веществ от хвостохранилищ, в том числе Солнечного ГОКа.

Ключевые слова

горное дело, обогащение, оловорудное сырье, отходы, хвостохранилище, окружающая среда, техногенное загрязнение, почва, грунт, вода, проба, тяжелые металлы, хром (Cr), железо (Fe), медь (Cu), цинк (Zn), мышьяк (As), кадмий (Cd), олово (Sn), ртуть (Hg), свинец (Pb), спектрометрия, спектрофотометр, детское население, элементный статус, рекультивация, консервация, Хабаровский край, поселок Солнечный

Финансирование

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Introduction

Since the early 1970s, intensive mineral resource development by mining enterprises in the Far Eastern Federal District has led to significant technogenic pollution of all environmental components [1, 2]. In the vicinity of mining operations, which have been affected to varying degrees by technogenic impact, biogeochemical zones have developed with elevated concentrations of chemical element compounds, including heavy metals and arsenic.

One such industry-forming enterprise of the past century was the Solnechny Mining and Processing Plant (MPP) in Khabarovsk Krai. During the economic transition of the 1990s, the plant failed to adapt and was declared bankrupt [3, 4].

The first tailings dump of the Solnechny Concentration Plant (SCP) is located about 100 meters from the settlement of Gorny, in the Silinka River valley, near its confluence with the Amut River. Tailings were deposited there from 1963 to 1997. The accumulated waste layer reaches a thickness of 20–25 meters. The dump covers an area of 20 hectares and contains 10.6 million tons of tailings. It is currently used for reprocessing by the SCP. The second tailings dump of the SCP lies across from the mining settlement of Solnechny. It covers 40.3 hectares and contains 24.09 million tons of accumulated waste. The former assets of the Solnechny MPP – including the Festiválnoye and Pereválnoye deposits – are currently managed by the Tin Ore Company, which has resumed tin and tungsten mining and continues to fill a third tailings dump. Meanwhile, GeoPromInvest LLC is actively reprocessing waste from the second dump and has constructed a new tailings storage facility behind it. Previous studies have shown that tailings dumps, containing vast quantities of waste, have a harmful impact on the environment and pose a serious threat to human health, biodiversity, and water bodies [5–7] due to the accumulation of toxic heavy metals in living organisms.

Hair is recognized as an informative and reliable biological material that reflects the environmental conditions as well as the presence of diseases and health deviations in the human body [8]. The chemical composition of hair reflects both the internal physiological state and the impact of various exogenous factors [9]. Due to the slow growth rate of hair, its analysis provides an average concentration of macro- and microelements over several months. According to A.Ye. Pobilat et al. [10, 11], monitoring trace element content in hair can address a wide range of scientific challenges, including the indication of environmental pollution and the assessment of harmful factors affecting human health.

The aim of this study is to assess the distribution of Pb, Hg, Cu, Cr, Fe, Zn, Cd, Sn, and As compounds using the elemental status of the child population in a mining settlement. Based on this aim, the following objectives were defined: 1. To analyze and systematize literature data on technogenic pollution of the ecosphere caused by waste from tin ore processing. 2. To assess the distribution of chemical elements in environmental components in the impact zone of the Solnechny tailings dump. 3. To investigate the

Fig. 1. Surface of the second tailings dump of the Solnechny Concentration Plant

elemental status of the population under the age of 14 in the settlement of Solnechny, Khabarovsk Krai, as part of mining-related environmental monitoring.
4. To develop proposals aimed at reducing the spread of technogenic pollution within the ecosystem.

The study focuses on technogenically impacted mining areas resulting from the operations of the Solnechny MPP, as well as the elemental composition of hair in children and adolescents residing in the mining settlement.

The second tailings dump of the Solnechny MPP is situated at elevations ranging from 286 to 303 meters, approximately 6.5 kilometers southwest of the confluence of the Kholdomi and Silinka rivers, directly opposite the second processing facility. The mining settlement of Solnechny lies on the opposite side of the valley, at a higher elevation (Fig. 1).

Methods

To characterize the technogenic conditions within the impact zone of the tailings dump, soil and ground samples were collected to determine the total content of heavy metals and arsenic in the vicinity of the second tailings dump of the Solnechny MPP. Sampling was conducted in accordance with GOST 17.4.3.01–2017[1].

Water samples were also collected from the impact zone of the second tailings dump, at various points within the Silinka River basin[2]. Element concentrations were determined using atomic absorption spectrometry, employing a Thermo Solaar M Series atomic absorption spectrophotometer and an Agilent 720 ICP-OES spectrometer.

Fig. 2 presents the map of soil and water sampling points within the impact zone of the second tailings dump.

Hair samples were collected from children and adolescents aged 3 to 14 (both boys and girls) residing in the settlement of Solnechny. The elemental status was determined for 45 children, including 20 boys and 25 girls under the age of 14. The mean age was 6.68 ± 2 years. Among them, boys aged 7 or younger accounted for 26.7%, girls of the same age group for 33.3%, boys aged 8–14 for 22.1%, and girls aged 8–14 for 17.9%. The sample included only permanent residents of the settlement. All hair samples were collected and prepared according to standard procedures for trace element determination in biological substrates[3], and were analyzed at the accredited Information and Analytical Center of the Institute of Tectonics and Geophysics, Far Eastern Branch of the Russian Academy of Sciences (Khabarovsk). The concentrations of the following elements were measured: Cr, Fe, Cu, Zn, As, Cd, Sn, Hg, and Pb. The data were processed using Microsoft Office software tools.

[1] GOST 17.4.3.01–2017. Interstate Standard. Nature Protection. Soils. General Requirements for Sampling.

[2] R 52.24.353–2012. Sampling of Surface Land Waters and Treated Wastewater.

[3] Guidelines for the Determination of Trace Elements in Diagnostic Biosubstrates by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Methodological Recommendations. Moscow: Federal Center for State Sanitary and Epidemiological Supervision, Ministry of Health of Russia; 2003. p. 22.

Results and discussion

Between 1969 and 2001, approximately 24.1 million tons of waste were deposited in the second tailings dump of the Solnechny MPP. As of 1990, the site contained the following amounts of recoverable metals: 46,392 tons of tin (average grade: 0.183%), 707,000 tons of copper (0.28%), 39,356 tons of zinc (0.156%), 47,853 tons of lead (0.188%), 6,742 tons of tungsten (0.015%), 5,874 tons of bismuth (0.013%), and 339 tons of silver (116 g/t), along with various rare elements and gold. According to previous assessments, the dewatered tailings are classified as highly hazardous in terms of toxicity[4] [2]. No land reclamation activities have been undertaken in the disturbed area, despite the requirements set forth by the Subsoil Law of the Russian Federation[5]. Based on our calculations, which considered the sampling depth (up to 20 cm), contamination level, area of polluted land, and applicable assessment coefficients, the total estimated environmental damage to the soil amounts to 19,306 rubles per square meter [13].

At monitoring points located at varying distances from the second tailings dump, the concentrations of heavy metals and arsenic in the 10–20 cm soil layer substantially exceeded regulatory thresholds (Table 1).

[4] Order of the Ministry of Natural Resources of Russia No. 238 of 08.07.2010 (as amended on 18.11.2021) “On Approval of the Methodology for Calculating the Amount of Damage Caused to Soils as an Environmental Protection Object.” Re-|gistered with the Ministry of Justice of Russia on 07.09.2010, No. 18364. URL: https://docs.cntd.ru/document/902227668

[5] On Subsoil. Law of the Russian Federation No. 2395-1 of 21.02.1992. Latest revision: 2024. Moscow: CENTRMAG; 2024. 136 p.

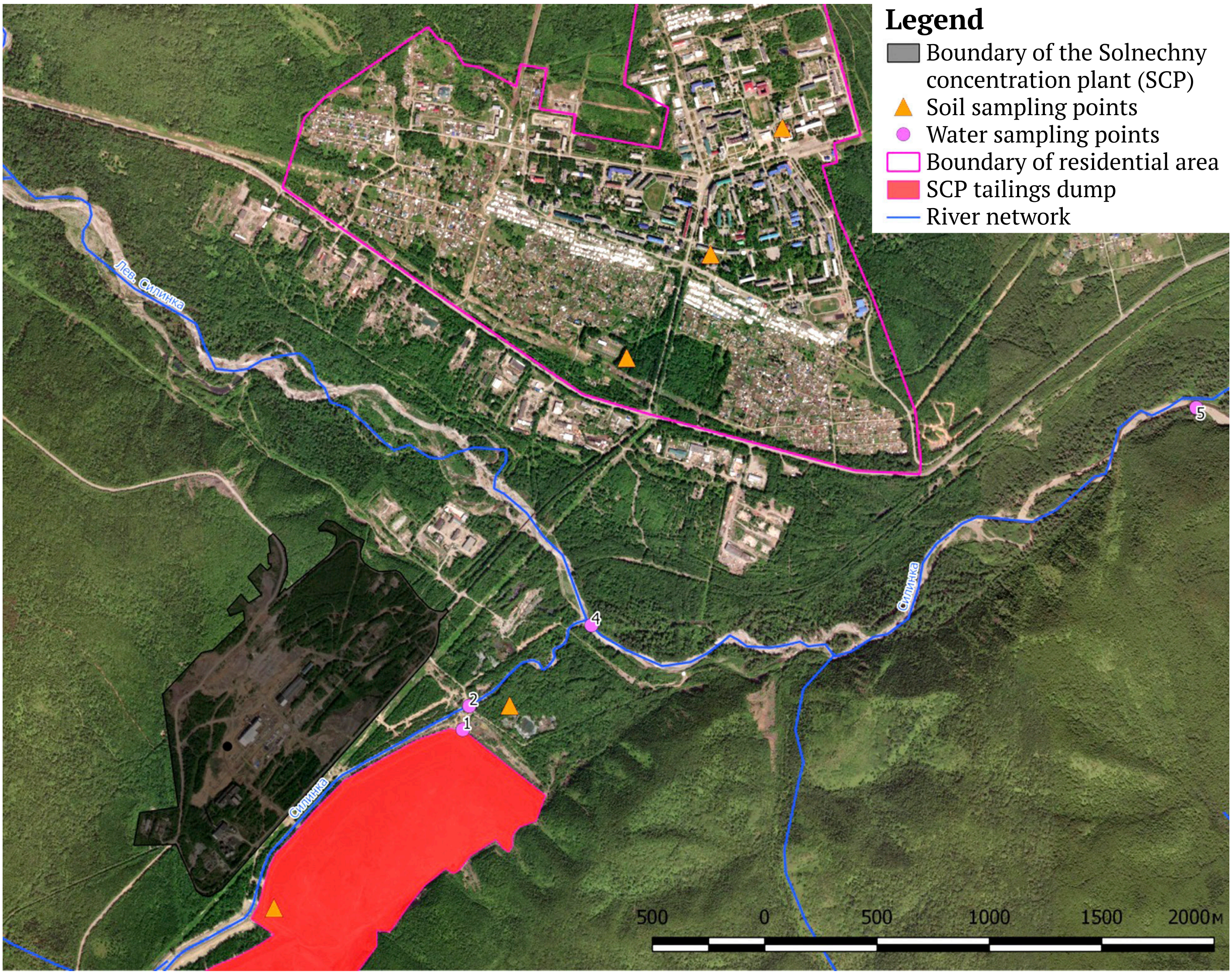

Fig. 2. Map of sampling points for soil and water in the vicinity of the second tailings dump of the Solnechny MPP

An unfavorable environmental situation was identified within the residential area located in close proximity to the site (1.5–3.0 km), where average concentrations exceeded regulatory limits by the following factors: Cu – 12.36 MPC, Zn – 2.73 MPC, Pb – 9.71 MPC, Hg – 1.40 MPC, and As – 569.09 MPC.

Water samples from both technogenic (T1) and natural sources (T2–T5) were collected (see Fig. 2) and analyzed for concentrations of the following elements: As, Cd, Co, Cr, Cu, Fe, Mn, Pb, Sn, and Zn. The analytical results are summarized in Table 2.

In natural waters downstream of the Silinka River, beyond the second tailings dump of the Solnechny MPP, concentrations of several elements exceeded the maximum allowable concentrations (MACs) for surface waters designated for fishery use: chromium exceeded MACs by 4 to 11.5 times, copper by 110 times, iron by 2 to 24.2 times, and zinc by 31 to 46 times. No exceedance of arsenic levels was detected in the water samples.

Thus, the residents of the Solnechny mining settlement live in an environment where contaminant levels in soil and soil substrate and water bodies exceed regulatory standards.

To identify regional geochemical characteristics of the natural environment, element ratios were calculated by comparing the concentrations of chemical elements in hair samples from the local child population with the average concentrations of these elements in hair by sex (see Fig. 3).

Table 1

Concentrations of selected heavy metals and arsenic in soil (10–20 cm depth) at various distances from the second tailings dump of the Solnechny MPP (mg/kg)

Elements	Zn	Cu	Pb	Hg	As
At the tailings dump	140.00	620.18	713.22	5.78	7792.60
0.3 km from tailings dump	168.30	749.79	282.74	2.29	2306.47
1.5 km from tailings dump	71.68	319.76	642.22	8.3	3254.48
2.5 km from tailings dump	264.16	643.56	195.37	0.3	105.12
3 km from tailings dump	119.62	260.91	36.31	0.22	54.95
Regulatory limit (MPC)	55. 5	33.0	30.0	2.1	2.0
Background level	60.46	38.78	81.5	0.58	42.49

Table 2

Concentrations of selected heavy metals and arsenic in water samples from the Silinka River basin at varying distances from the second tailings facility of the Solnechny MPP, mg/L

Sampling points	P. 1	P. 2	P. 3	P. 4	P. 5	MAC*, mg/L
As (total)	0.0180 ± 0.0076	0.0240 ± 0.0101	0.0090 ± 0.0038	0.0050 ± 0.0021	0.0050 ± 0.0021	0.05
Cd	0.20	< 0.01	< 0.01	< 0.01	< 0.01	0.005
Co	3.78	< 0.05	< 0.05	< 0.05	< 0.05	0.01
Cr (VI)	0.18	0.09	0.19	0.23	0.20	0.02
Cu	166.30	0.11	< 0.03	< 0.03	< 0.03	0.001
Fe (III)	292.90	2.42	0.38	0.20	0.20	0.1 (general)
Mn	104.79	2.22	0.42	0.28	0.37	0.01
Pb	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.006
Sn	0.0390 ± 0.0133	< 0.005	0.0090 ± 0.0031	0.0060 ± 0.0020	0.0110 ± 0.0037	0.112
Zn	51.09	0.46	0.37	0.35	0.31	0.01

* Order of the Ministry of Agriculture of Russia No. 552 of 13.12.2016 (as amended on 13.06.2024) “On Approval of Water Quality Standards for Water Bodies of Fisheries Importance, Including Maximum Permissible Concentration Limits for Harmful Substances in the Waters of Such Water Bodies”.

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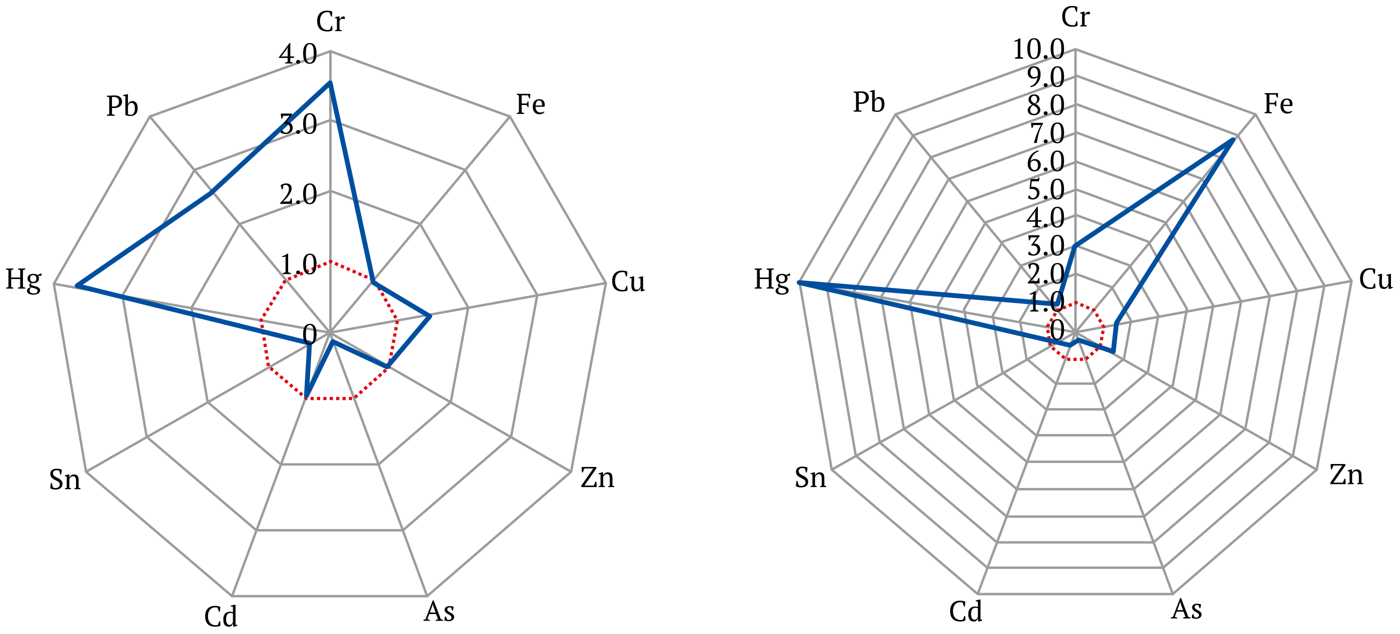

a ***b***

Fig. 3. Elemental composition of hair in the young population of Solnechny compared to average levels across Russia: *a* – girls; *b* – boys

The data obtained allowed us to identify the specific geochemical profile of hair samples from children and adolescents residing in the Solnechny mining settlement:

For girls: $Hg_{3.66} > Cr_{3.52} > Pb_{2.61} > Cu_{1.43} > Cd_{0.95} = Fe_{0.95} > Zn_{0.94} > Sn_{0.32} > As_{0.13}$;

For boys: $Hg_{9.81} > Fe_{8.75} > Cr_{2.95} > Zn_{1.54} > Cu_{1.45} > Pb_{1.06} > Sn_{0.87} > Cd_{0.57} > As_{0.33}$.

The elemental status of children in this study group is characterized by elevated levels of toxic metals such as Pb, Hg, and Cr. Notably, the Zn content in girls' hair was found to be close to the minimum reference range (124–320 μg/g).

To reduce the dissemination of pollutants in environmental components, the implementation of environmental management strategies using innovative technological solutions is recommended. Over the past 10 years, researchers at Pacific State University have proposed conducting reclamation or containment of tailings using substrates made from shredded spruce, larch, and birch bark, supplemented with a nitrogen-based activator and *Trichoderma* fungi[6]. These substrates have since been modified with additional components. In 2015, a Russian patent was granted for a tailings reclamation mixture incorporating phototrophic bacteria[7]. Other effective mixtures included additives such as biochar[8] and spent oyster mushroom mycelium[9]. The use of organic substrates derived from industrial by-products significantly reduces the cost associated with acquiring fertile soil, which is typically required for reclamation. In recent years, over one million tons of forestry and wood-processing waste have accumulated in the region. Therefore, reclamation or conservation of tailings surfaces using these materials is particularly relevant for Khabarovsk Krai. Further development and implementation of this technology are essential to reduce reclamation costs and prevent erosion processes.

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[6] Krupskaya L. T., Mayorova L. P., Orlov A. M. et al. Russian Federation Patent No. 2486733. Method for land reclamation of areas disturbed by toxic waste stored in a tailings dump under monsoon climate conditions. 2013.

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[9] Krupskaya L. T., Ishchenko E. A., Golubev D. A., et al. Russian Federation Patent No. 2707030, issued 21. November 2019. Composition for reducing dust load on the ecosphere and reclaiming the surface of a tailings dump. Appl. No. 2019114495 of 13 May 2019.

Conclusion

The results of this study, supported by a review of previous research, indicate that the second tailings dump of the Solnechny MPP is a significant source of technogenic pollution in the surrounding environment. Concentrations of heavy metals in soil samples exceeded maximum permissible concentrations (MPCs) as follows: Cu by 12.36 times, Zn by 2.73 times, Pb by 9.71 times, and Hg by 1.4 times. The average arsenic concentration in soil exceeded the MPC by a factor of 569.09. In surface water bodies, the highest exceedances were recorded for Cr, Cu, Fe, and Zn. Arsenic concentrations in water samples did not exceed regulatory limits.

An assessment of the elemental status of local residents under the age of 14, based on hair analysis by sex, revealed elevated concentrations of Hg, Pb, and Cr. A distinctive feature among girls was a reduced level of the essential element Zn, while boys exhibited elevated levels of Fe.

To mitigate the spread of pollutants from tailings dump, including the one operated by the Solnechny MPP, the study proposes the use of forest industry waste as an alternative substrate for reclamation, providing a cost-effective and sustainable solution.

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