

ЭКОЛОГИЧЕСКАЯ ОЦЕНКА ПОСЛЕДСТВИЙ ДОБЫЧИ БОКСИТОВ В КАЗАХСТАНЕ

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Аннотация: Приведены исследования по накоплению отходов от функционирования бокситодобывающей промышленности. В частности, рассмотрена проблема управления промышленными отходами, такими как отвалы некондиционного боксита, которые были накоплены в результате деятельности Тургайского боксито-рудного управления. Приведены статистические данные по характеристике отвалов бокситодобычи. Изучен и проанализирован химический состав отвалов бокситодобычи, рассмотрено влияние образовавшихся отвалов некондиционных бокситов на окружающую среду. Рассмотрены и изучены экологические риски, связанные с образовавшимися отвалами бокситодобычи. Приведены аналитические исследования негативного антропогенного влияния отвалов бокситодобычи, в частности, влияния их химического состава на загрязнение почвы, поверхностных вод, атмосферы, а также непосредственного влияния токсичных веществ на здоровье человека. В результате проведенных исследований, с целью минимизации воздействия отвалов некондиционного боксита на окружающую природную среду и здоровье населения предложен целый ряд мероприятий по снижению антропогенного воздействия накопленных отходов бокситодобычи. По результатам проведенного анализа сформулированы выводы о необходимости дальнейших физико-химических исследований накопленных отвалов бокситодобычи с последующей разработкой экологической технологии их переработки.

Ключевые слова: горнодобывающая промышленность, отвалы некондиционных бокситов, отходы, воздействие на здоровье населения, защита и охрана окружающей среды, промышленная безопасность.

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Environmental assessment of the consequences of bauxite mining in Kazakhstan

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Abstract: This article presents studies on the accumulation of waste from the functioning of the bauxite mining industry. In particular, the problem of industrial waste management, such as dumps of substandard bauxite, which were accumulated as a result of the activities of the Turgai Bauxite Ore Management (TBOM), is considered. Statistical data on the characteristics of bauxite mining dumps are presented. The chemical composition of bauxite mining dumps has been studied and analyzed, and the impact of the resulting dumps of substandard bauxite on the environment has been considered. The environmental risks associated with the formed bauxite mining dumps are considered and studied. Analytical studies of the negative anthropogenic impact of bauxite mining dumps, in particular, the effect of their chemical composition on soil pollution, surface waters, and the atmosphere, as well as the direct effect of toxic substances on human health, are presented. As a result of the research, in order to minimize the impact of substandard bauxite dumps on the environment and public health, a number of measures have been proposed to reduce the anthropogenic impact of accumulated bauxite mining waste. Based on the results of the analysis, conclusions are formulated about the need for further research in the form of physico-chemical studies of accumulated bauxite mining dumps with the subsequent development of an ecological technology for their processing.

Key words: mining industry, dumps of substandard bauxite, waste, public health effects, environmental protection and industrial safety.

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Introduction

Recently, the problem of industrial waste management in Kazakhstan has acquired the status of one of the most urgent environmental problems [1]. The increase in production volumes and accelerated urbanization covering the country's territories make it possible to significantly increase the amount of waste [2, 3]. This, in turn, leads to serious environmental challenges, as well as has a significant negative impact on the economic sphere [4, 5]. For an objective understanding of the scale of the problem, it is necessary to take into account not only the total amount of waste already accumulated, but also to analyze current trends in their formation. This characteristic allows you to identify important aspects that require attention and develop effective solutions to minimize them [6–8].

In Kazakhstan, industry is represented by a number of industries that generate in-

dustrial waste, the annual accumulation of which contributes to an increase in the total volume of waste produced in the country. The largest contribution to such educational waste is made by the main sectors of the economy, including the mining sector [1–3], metallurgy [9–11], the chemical industry [12–14], the energy complex [15–17] the production of building materials [18–20] and the construction sector [21–23]. Each of these industries provides an overview of various production processes that are accompanied by the formation of various types of waste, which directly requires further ways to address issues related to their disposal, recycling and reduction of negative impacts [24, 25].

The largest amount of waste in Kazakhstan is accounted for by mining enterprises, which occupy a leading position among all industries in terms of waste volume. Typical examples of such waste are rock

dumps, slags, metal residues, as well as various chemical compounds formed during the extraction and processing of raw materials. According to 2020 data, about 60% of all waste produced in the country is accounted for by the mining and metallurgical industries. This indicates the significant impact of these sectors on the environment and requires the development and modern technologies to minimize their impact [26–28].

According to the Ministry of Environment, Geology and Natural Resources of the Republic of Kazakhstan, the volume of accumulated waste in the country continues to be accounted for annually. At the end of 2022, the total volume of waste exceeded 2.5 billion tons, reflecting the scale of the problem. This indicator reflects both hazardous and non-hazardous types of waste, including the diversity of their nature and the need for an integrated management approach. For a more detailed analysis, you can refer to the data presented in table 1, which provides information on the distribution of waste by its categories and hazard levels.

According to reports, the proportion of waste is still steadily increasing, which is directly related to the active development of the mining and metallurgical industries, as well as the growing demand for resources. Some of the most dangerous types of waste include harmful chemicals, including heavy metals such as Pb, Cd, and Hg,

which contribute to posing a toxic threat to public health and the environment. In addition, radioactive waste generated during the extraction and processing of uranium ore is particularly dangerous, which makes the management of such waste one of the priorities. [1, 25, 29].

Thus, based on the above analysis, the purpose of these studies is the need to develop a number of recommendations to reduce the anthropogenic impact of landfills from mining bauxite, a man-made waste from the mining industry.

Results and discussion

The problem of industrial waste in Kazakhstan

Kazakhstan, being a country with a developed mining and manufacturing industry, is facing a large-scale problem of the formation and accumulation of industrial waste. The activities of these industries make an additional contribution to the total volume of waste, which necessitates their management. For a deeper understanding of the situation, the scale of accumulation and annual generation of waste can be referred to the data presented in table 2, which reflects the main quantitative indicators.

These data allow us to assess the dynamics and scope of problems, as well as identify the main directions for developing environmental strategies to reduce the formation of landfills [25, 29].

Table 1

Amount of accumulated waste in Kazakhstan in recent years (in millions of tons)

Количество накопленных отходов в Казахстане за последние годы (млн т)

Year	Total waste	Accumulated hazardous waste	Accumulated non-hazardous waste
2018	2.1	0.4	1.7
2019	2.3	0.5	1.8
2020	2.4	0.6	1.8
2021	2.5	0.7	1.8
2022	2.6	0.8	1.8

Table 2

Accumulation and annual generation of waste in region.
According to the Committee on Statistics of the Republic of Kazakhstan (2023)
Накопление и ежегодное образование отходов в регионе.
По данным Комитета по статистике Республики Казахстан (2023 год)

Type of waste	Volume of accumulated waste (million tons)	Annual growth (million tons)
Mining waste	25 000	1200
Industrial solid waste	1600	80
Hazardous chemical waste	300	10
Solid household waste (MSW)	120	5

Turgai Bauxite Ore Management, located near the city of Arkalyk, has played an important role in the economy of Kazakhstan for many years, being one of the largest bauxite producers in the country. Currently, bauxite mining at this enterprise has been suspended. However, long-term production activity has left behind significant amounts of substandard bauxite dumps, which are the cause of serious environmental problems [30–32]. These waste dumps contain harmful substances, including chemical compounds that have a negative impact on the environment [32, 33]. They create unfavorable conditions for the health of the local population located in different regions from these dumps, which allows for the application of measures for reclamation and reduction of environmental consequences [33–34].

Dumps of substandard bauxite, formed over many years of bauxite mining, pose

a serious environmental problem. Such dumps develop in the process of separating rocks that are unsuitable or unsuitable for further use. The Turgai field, which significantly influenced the development of the mining and metallurgical industry in Kazakhstan, has become an enterprise of large-scale accumulation of bauxite mining dumps, which necessitates the study and exploration of accumulated dumps. The dumps located near the city of Arkalyk contain a number of side components, among which oxides of iron, calcium, aluminum and silicon are present. In addition, they contain traces of dangerous substances that pose a potential danger to the environment and human health. Detailed information on the composition of these wastes is given in table 3, which makes it possible to assess the degree of their impact on the environment (According to the data of the Ministry of Ecology and Natural Re-

Table 3

Composition of dumps (waste) from bauxite mining of Turgai bauxite Ore Management
Состав отвалов (отходов) от добычи бокситов Тургайского боксито-рудного управления

Substance	Waste content (%)
Aluminum oxide	10–12
Iron oxide	7–15
Silicon oxide	45–50
Toxic metals	0.5–1
Mercury	0.02
Arsenic	0.05

Table 4

The influence of chemical compounds and elements present in landfills on water, plants, soil, biocenoses, animals and humans

Влияние химических соединений и элементов, имеющихся в отвалах на воду, растения, почву, биоценозы, животных и человека

Substance	Environmental impact
Aluminum oxide	Reduced water quality, plant toxicity
Iron (Fe)	Deterioration of soil quality, impact on acidity
Silicon (Si)	Increased soil acidity, a threat to agriculture
Toxic metals	Water and soil pollution, threats to the biocenosis
Arsenic and mercury	High toxicity to animals and humans

sources of the Republic of Kazakhstan for 2022).

In addition, landfills have a negative impact on the health of the population located near their locations. Exposure to harmful substances contained in landfills can lead or contribute to the development of a number of adverse health consequences, including exacerbation and the appearance of chronic diseases in the population located near the landfills. Thus, accumulated bauxite mining dumps are a catalyst for socio-ecological and economic problems that require timely response [32–34].

The impact of substandard bauxite dumps on the environment

One of the main environmental risks associated with substandard bauxite dumps is environmental pollution (table 4).

Such waste contains toxic substances that can enter groundwater and the atmosphere, contributing to pollution of water bodies and deterioration of air quality [29, 34].

1. Soil pollution: Due to dust emissions and the infiltration of toxic substances into the soil, changes occur in the chemical composition of the soil, which leads to a decrease in its fertility and deterioration of plant growth conditions.

2. Pollution of water bodies: Rainwater that passes through the dump can leach toxic substances such as heavy metals into

groundwater and surface waters, leading to their contamination and poisoning of aquatic ecosystems.

3. Air pollution: Under the influence of wind, the smallest dust particles containing oxides of various metals rise as dust from landfills, contributing to air pollution. This significantly worsens the air quality in the surrounding areas and negatively affects the ecological situation of the region.

According to the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan as of 2023, in the soils of Arkalyk, the average index of a number of toxic elements was 0.29–0.35 mg/kg for cadmium; 18.34–31.71 mg/kg for lead; 0.84–3.15 mg/kg for copper; 0.97–2.83 mg/kg for chromium; 13.16–23.00 mg/kg for zinc.

The impact of substandard bauxite dumps on public health

According to data on the impact of toxic substances on public health from environmental agencies in Kazakhstan for 2022, environmental pollution caused by substandard bauxite dumps has a direct impact on the health of the population living in nearby areas, in particular in Arkalyk (table 5).

The main risks include:

1. Respiratory diseases: Dust rising from contact with landfills can provoke the development of respiratory system diseases,

Table 5

Effects of toxic substances on human health**Влияние токсичных веществ на здоровье человека**

Substance	Possible health effects
Aluminum oxides	Irritation of the respiratory tract, deterioration of the lungs
Mercury	Poisoning, damage to the nervous system and kidneys
Arsenic (As)	Cancers, diseases of the heart and blood vessels
Cadmium	Kidney damage, osteoporosis, liver disorders
Iron (Fe)	Acid-base balance disorders, anemia

including asthma, chronic bronchitis, allergic condition and other forms of diseases caused by air pollution and its poor quality.

2. Toxic effects of heavy metals: Highly toxic components contained in bauxite mining waste, including iron, silicon, cadmium, mercury, and arsenic, can accumulate in various animal and human body environments, leading to poisoning, nervous system disorders, kidney and liver dysfunctions, especially with prolonged exposure to polluted water and air.

3. Oncological diseases: Some dangerous substances, including arsenic, have carcinogenic properties, which increases the risk of cancer in people who live in polluted areas for a long time.

4. Reproductive disorders: Some heavy metals can affect human reproductive function, causing infertility or developmental abnormalities in newborns.

Problems and challenges of mining waste accumulation and processing

1. Waste accumulation:

- More than 90% of waste in Kazakhstan is related to the mining industry, including tailings, landfills and dust.

- A large amount of waste remains unused, which leads to their accumulation in landfills and landfills.

2. Insufficient processing:

- The level of waste recycling remains low: less than 15% of industrial waste is recycled or recycled.

- Existing recycling technologies often do not meet modern requirements.

In particular, in order to minimize the impact of bauxite-forming landfills on human health and the environment, we have proposed the following series of measures and measures to reduce the anthropogenic impact of bauxite mining dumps accumulated over the years of operation of the Turgai bauxite mining department (Arkalyk, Kazakhstan):

- Systemic environmental control: It is necessary to carry out regular monitoring of the air, water and soil conditions in the area of the Turgayskoye field and the city of Arkalyk to assess the level of pollution and take timely measures. The use of modern monitoring technologies will help to detect excess of the maximum permissible concentrations of toxic substances in time.

- Waste recycling: The development and implementation of waste recycling technologies, such as the use of bauxite waste in production processes, will reduce landfill volumes.

- Green technologies: The introduction of advanced environmentally friendly technologies in the process of mining and processing bauxite will minimize the impact on nature

- Reclamation and restoration of ecosystems: To carry out reclamation of lands polluted with waste, using plants capable of purifying the soil from toxic substances.

- Development of the recycling infrastructure: Construction of modern proces-

sing plants. Creation of technologies aimed at recycling dumps from bauxite mining.

- Stricter control over the management of waste dumps: The introduction of strict standards for storage and disposal. Strengthening environmental monitoring at storage sites and in landfills.

- Economic incentives: Subsidies and tax incentives for landfill recycling companies. Introduction of a system of "green" financing for environmental projects.

- Raising public awareness: Conducting campaigns to promote recycling. Involving citizens in environmental initiatives.

Conclusions

As a result of the conducted research on the formation of dumps from bauxite mining in the mining industry of Kazakhstan and their impact on the region, the following conclusions can be drawn:

- the problem of industrial waste in Kazakhstan requires an integrated approach, including the introduction of new technologies, stricter environmental controls and active interaction between the government, business and society. Timely solution of this problem will reduce environmental

risks and ensure the sustainable development of the country;

- the long-term activities of the Turgai bauxite Ore Management contributed to the accumulation of dumps from bauxite mining and had a significant impact on the environment and the health of the region's population;

- the dumps formed as a result of bauxite mining cause soil, water and air pollution, provoking serious environmental and health risks. Their elimination requires comprehensive support, including environmental monitoring, waste recycling, and the introduction of environmentally sound integrated technologies;

- one of the main steps in the disposal of landfills formed as a result of bauxite mining at TBR is to conduct primary studies of their physico-chemical properties, which make it possible to determine their composition and choose optimal methods of processing and disposal.

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