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Formation of Vegetation Cover and Soil Quality Indicators at the Mine Sites of a Gold-Bearing Deposit (the Case of Kara-Agash, Kazakhstan)

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Abstract: At present, the processes of natural recovery, vegetation coverage, and degraded lands of several coal, iron ore, uranium, and polymetallic mines and gold-bearing deposits are well-studied. The present study aims to identify opportunities to shape the soil layer and vegetation cover on reclaimed dumps/tailings of industrial waste and degraded land via artificial restoration. For this purpose, in July 2023, studies of overgrowth processes were conducted in the Kara-Agash gold-bearing field, Central Kazakhstan, which had been subjected to industrial impact. The deposit's territory has gold-bearing ore mining pits and primary processing areas, including leaching stacks. The processes of plant community formation at heap leaching sites and the technogenic impact caused by economic activity were investigated. Assessment of the floristic composition and density of the vegetation cover revealed a total of 47 species of higher vascular plants. General projective coverage in control plots on territory unaffected by economic activity reaches up to 80. The plant species that exhibit the most vigorous growth and initiate primary succession were identified. These species are endemics and can be used for artificial overgrowth of technogenically disturbed lands.

Keywords: Environmental Monitoring, Heap Leaching, Floristic Composition, Plant Population, Ionizing Radiation

Introduction

The processes of stable vegetative coverage forming on the surface of lands subjected to considerable technogenic impact are critical for the restoration of the environment in urban environments, agriculture, as well as mining, ore extraction and processing facilities located in natural deposits (Ospangaliyev *et al*. 2022; 2023; Nasiyev and Bekkaliyev, 2019; Nasiyev *et al*., 2023; Bugubaeva *et al*., 2023).

Research highlights the significance of soil layer development and vegetation cover establishment on rehabilitated dumps and tailings of industrial waste, as well as on degraded lands from various extraction and processing facilities (Kaldybaev *et al*., 2022), which represents one of the crucial conditions for the lands to be brought back into economic use (Valiyev *et al*., 2019; Adesipo *et al*., 2020; Velásquez Ramírez *et al*., 2021; Chamba-Eras *et al*., 2022).

The focus of our study is to investigate vegetation and soils in open-pit gold ore mining sites, including primary processing areas with heap cyanide leach stacks, waste stockpiles, and process pads.

Heap cyanide leaching technologies are extensively used in the mining industry to extract gold from low-grade ore (Timsina *et al*., 2022). It is important to stress that such production facilities have high environmental risks. Cyanide is highly toxic and can have severe negative effects on the environment. When cyanide spills or leaks occur, it can contaminate soil and water, posing risks to wildlife and human health. Cyanide exposure can lead to the death of aquatic organisms and disrupt ecosystems, making its management and disposal a significant environmental concern (Nugmanov *et al*. 2023).

Nevertheless, the formation of phytocenoses, soil remediation, and ecological processes in the heap cyanide leaching territories of gold mines have their features noted by several authors Adesipo *et al.* (2020); Chamba-Eras *et al*. (2022); Mamikhin *et al*. (2023). Researchers primarily observe that vegetation cover acts as an effective natural shield for the developing soil, protecting it from erosion. In addition, the first vegetation groups make a significant contribution to the formation of soil quality characteristics, including the accumulation of organic matter and the formation of the humus horizon (Nugmanov *et al*., 2022).

Therefore, an important and practically valuable task is to find endemic plant species able to inhabit deeply degraded lands of gold mines. Plant species forming primary successions are also actively involved in the formation of soil quality indicators (Nugmanov *et al*., 2022). For example, artificial planting with special plant species on degraded soils of gold mines can significantly improve soil quality indicators.

Studies are conducted to explore the processes of restoration and reclamation of degraded lands and phytocenoses, including uranium and coal deposits, in the Republic of Kazakhstan and the Russian Federation with the practical implementation of new research and assessment methods (Chibrik *et al*., 2014; Kupriyanov *et al*., 2021b; Bugubaeva *et al*., 2023; Konysbaeva *et al*., 2023). In particular, studies evaluate the processes of vegetation cover formation and the restoration of soil quality indicators in the course of reclamation of industrial waste dumps at uranium mines and coal field ash dumps (Valiev *et al*., 2018; Kupriyanov *et al*., 2021a; Bugubaeva *et al*., 2023).

Currently, the natural recovery processes of vegetation coverage and the restoration of degraded lands at various coal, iron ore, uranium, and polymetallic mines, along with gold-bearing deposits, are well-studied (Nasiyev *et al*., 2022; Mayrambekovich *et al*., 2014). However, there is a lack of research specifically addressing the formation of vegetation cover and soil quality indicators on reclaimed dumps/tailings of gold-bearing industrial waste and degraded lands in Central Kazakhstan. The present study aims to fill this gap by identifying opportunities for shaping the soil layer and vegetation cover on such reclaimed sites via artificial restoration.

Relying on previously accumulated experience, we expanded the research scope to previously unstudied industrial sites of gold-bearing ore deposits in Northern Kazakhstan.

The purpose of the study is to investigate the possibility of forming vegetation cover and soil quality indicators in technogenically disturbed areas of a gold-bearing deposit mine in Kazakhstan.

Given the practical importance of restoring vegetation cover (Yessimbek *et al*., 2022) and forming the soil layer in reclaimed areas of gold-bearing mines, we set the following research objectives:

1) To study agrochemical indicators of soils at the deposit and mine facilities, including soil sampling and laboratory control of key quality indicators
2) To conduct a floristic assessment of the vegetation cover and evaluate the intensity of overgrowth processes in areas disturbed by technological activities
3) To identify plant species that exhibit the most dynamic overgrowth and initiate primary succession in regions impacted by intensive economic activities

Scientific Novelty and Significance

This research is significant as it addresses the critical need for effective ecological restoration practices in regions heavily impacted by mining activities. The novelty of this study lies in its focus on the specific context of gold-bearing deposits in Central Kazakhstan, an area that has received less attention compared to other mining regions. This study offers valuable insights into the restoration potential and methods applicable to similar environments.

Materials and Methods

General Description of Studied Objects

The research work was conducted at the mine facilities of the Kara-Agash gold deposit (52 15'26 "N, 70 20'20 "E, July 2023, altitude 340 m above sea level), located in the Akmola region of the Republic of Kazakhstan, 7 km east of the Pushkino village and 17 km west of the Yeltai station (Fig. 1).

Fig. 1: Satellite image. The location of the mine is on the map of the Republic of Kazakhstan. Highlighted with a yellow circle

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The Kara-Agash deposit belongs to the deposits of Central Kazakhstan and is represented by quartz-vein geologic-economic type. The deposit is attached to Ordovician terrigenous volcanic rocks with an intrusion of granodiorite of the Stepnyak complex. Host rocks along the contact line are hornfelsed. The width of the hornfelsing zone is 10-50 m. Ore bodies are represented by quartz veins and streaks of the northeast range with a length from 50-170 m, a width of 0.01-0.8 m, and frequent wedging out and bulges. Rocks in the selvages of veins are beresitized. Composition of veins: Quartz (up to 70%), calcite, sericite, chlorite (up to 25%), pyrite, chalcopyrite, fahlore, gold. Area and linear weathering crust with a width of 60-75 m is widely developed.

According to the Committee of Geology and Subsoil Use of the Ministry of Industry and Infrastructural Development of the Republic of Kazakhstan, the development of the Kara-Agash gold-bearing deposit is being conducted by organizations holding contracts for territories covering a total area of 39.04 km² (Committee of Geology of the Ministry of Ecology, n.d.; Natsionalnaia geologicheskaia sluzhba, JSC, n.d.; Nedra. kz, n.d.). Gold-bearing ore is extracted using open-pit mining (Figs. 2-3). The maximum depth of the open pit is about 20 m (52°15'32"N, 70°21'08"E, 400 MASL).

Fig. 2: Satellite view of the Kara-Agash gold mine; 1. Site of primary processing of gold-bearing ore; 2. Gold ore pits

Fig. 3: Gold mine quarry

Fig. 4: Leach stacks and waste dumps

Southwest of the main pit, approximately 1 km, is the primary processing area for gold-bearing ore. The site includes heap leach stacks and waste dumps (Fig. 4).

Primary ore processing at the deposit is carried out by heap leaching per standard requirements, which include the following technological operations:

1) Site preparation for heap leaching
2) Ore preparation, which includes crushing, screening, blending of clay ores with rocky ores, and pelletizing of fine and fine fractions
3) Preparation of a waterproofing base, including the backfilling of clay and drainage layer, installation of collectors for productive solutions, etc.
4) Stacking of ore in stacks/heaps
5) Irrigation of the ore stack with cyanide solutions with the simultaneous process of gold leaching and drainage of solutions through the heap
6) Accumulation of gold-containing solutions and their sedimentation
7) Extraction of gold from solutions with subsequent melting of precipitates
8) Neutralization of the processed ore stacks (leach tailings) and reclamation of dumps and disturbed lands

Agroclimatic Conditions of the Kara-Agash Field. Soils of the Deposit

The Kara-Agash field is located on a flat plateau. Based on the agroclimatic zoning of the Akmola region, the field is situated in a slightly humid, moderately warm zone. It is characterized by a humidification coefficient of K = 0.8-1.0-1.2 and a sum of temperatures above 10°C ranging from 2,200-2,500°C.

The sunniest months in the region are May, June, and July, with an average of 9.9-10.6 h of sunlight per day. During this time, the average soil surface temperature in early May starts at 13°C, increases to 18°C by late May, and exceeds 21°C in July. The solar radiation resources in this region are ample for long-day plants, ensuring optimal crop viability (Baisholanov, 2017).

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The region receives a total annual precipitation of 400 mm, with 260-280 mm falling during the warm period. Moisture availability during the growing season is 0.90-0.98, which is sufficient but not stable. The region is not considered arid during the growing season, with an annual relative air humidity of 70%. Drought recurrence is less than 20%, occurring once every 5-8 years (Baisholanov, 2017).

The frost-free period in the air lasts for 110-120 days. On average, the soil surface temperature reaches 13°C in early May, 18°C by late May, and exceeds 21°C in July. The frost-free period for the soil is 102 days. The vegetation period in this region lasts 130-135 days (Baisholanov, 2017).

The soil of the field belongs to southern carbonate chernozems. Southern chernozems develop in arid steppes, are confined to elevated surfaces, and extend within the Akmola region from west to east. The Akkol district is mainly represented by southern chernozems. The thickness of the humus horizon of soils is approximately 45-47 cm.

The agroclimatic conditions of the Kara-Agash field, as well as soil composition, are favorable for the formation of a stable vegetation cover with high species diversity.

Assessment of Background Ionizing Radiation

To conduct additional research and ensure the general safety of the expedition participants, the level of ionizing radiation at the field facilities was assessed. The gamma radiation level was analyzed along the route, adhering to the requirements of regulatory standards and scientific recommendations (Artamonov *et al*., 2023; Kuatbaeva *et al*., 2023). Control of gamma radiation levels was performed in three main territories. These were the territory of leaching sites -1, the territory of quarries -2, and the control territory of forest and steppe not subjected to techno-genic and economic impact -3 (Fig. 5).

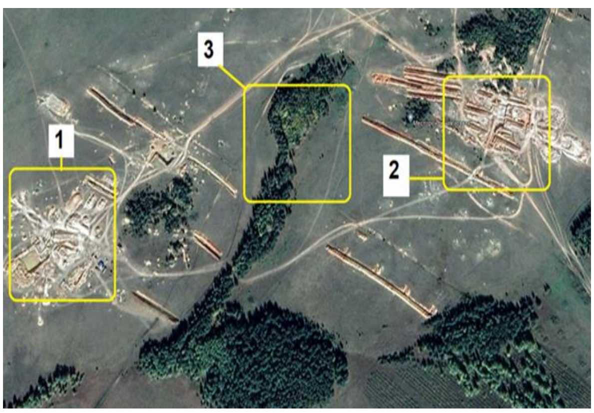

Fig. 5: Areas of gamma radiation level monitoring

The gamma radiation level was measured using a dosimeter-radiometer of the type MKS-AT6130, manufactured by "ATOMTEKH" RPUE and "MNIPI" OJSC, located in Minsk, Republic of Belarus. This device is officially approved as a measuring instrument in Kazakhstan and holds a valid certificate of state verification in accordance with ST RK 2.4-2018 standards. The analyzer was employed along the route to ensure compliance with both regulatory requirements and scientific guidelines for accurate and reliable radiation measurements.

Organization and Implementation of the Control of Agrochemical Indicators in Soil Samples

Soil and plant samples were taken in areas adjacent to leach stacks, waste dumps, and economic use areas (52°15'25"N, 70°20'22"E, 400 MASL) subjected to technogenic impact as a result of economic activity:

1) "Dump base" areas adjacent to leach piles and formed by processed rock
2) "Disturbed territory" plots located between dumps and formed partly by recycled rock and partly by mechanically impacted soil
3) "Boundary plot" plots located on the boundary of technical areas and lands not subjected to technogenic impact
4) "Control plot" natural areas of the field that have not been technologically impacted and are adjacent to the mine site (Fig. 6)

Studies of the agrochemical indicators of soil samples were carried out in an accredited laboratory to ensure accuracy and compliance with standardized testing procedures. The sampling and assessment of soil agrochemical indicators and toxicological indicators were guided by the regulatory requirements of the Republic of Kazakhstan having the force of state standards and by scientific recommendations.

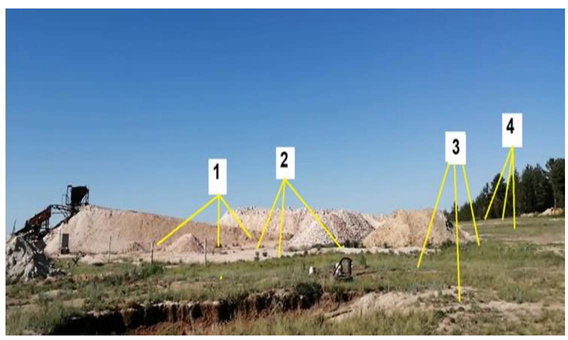

Fig. 6: Main sampling sites. "Dump base"-1, "disturbed territory"-2, "boundary plot"-3, "control plot"-4

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In the course of the study, one combined sample was taken from each analyzed area. The combined sample was made up of at least 25 point samples and had a mass of at least 2 kg. A special emphasis was placed on the assessment of such indicators as:

1) Soil acidity (pH)
2) Humus content according to GOST 26213-91
3) Mobile potassium and phosphorus content according to GOST 26205-91
4) Nitrate content according to GOST 26951-86
5) Electrical conductivity of saturated aqueous solution according to GOST 26423-85
6) Total dissolved solids according to GOST 26423-85
7) Heavy metal content according to ST RK 2.377-2015

When assessing the pH of the medium, water-soluble salts were extracted from the soil using distilled water at a 1: 5 soil-to-water ratio. The specific electrical conductivity of the water extract was then determined using a conductometer and a pH meter (Gosstandart of the USSR, 1985a). The organic matter (humus) content in the soil was analyzed using photometric and gravimetric methods, which involved oxidizing the organic matter with a solution of potassium bromic acid in sulfuric acid and subsequently determining the trivalent chromium equivalent to the organic matter content (Gosstandart of the USSR, 1991b). The nitrate content was measured using the ionometric method (Gosstandart of the USSR, 1986a). The determination of mobile phosphorus and potassium compounds was conducted using the Machigin method as modified by CINAO. This method involved extracting mobile phosphorus and potassium compounds from the soil with an ammonium carbonate solution, followed by the determination of phosphorus in the form of a blue phosphorus-molybdenum complex using a photoelectron colorimeter and potassium using a flame photometer (Gosstandart of the USSR, 1991a). Mobile sulfur was determined according to the CINAO method, which consists of extracting mobile sulfur from the soil with potassium chloride solution, precipitation of sulfates with barium chloride, and their subsequent turbidimetric determination in the form of barium sulfate according to the optical density of the suspension (Gosstandart of the USSR, 1985b). Determination of total dissolved solids and specific electrical conductivity was carried out according to GOST 26423-85 (Gosstandart of the USSR, 1985a). The methods of atomic absorption spectroscopy according to ST RK 2.377-2015 (Committee for Technical Regulation and Metrology of the Ministry of Investment and Development of the Republic of Kazakhstan, 2015) were used to determine the content of heavy metals, including manganese, copper, cadmium, nickel, mercury, lead, chromium, and zinc. The main analytical equipment used during the laboratory control included measuring instruments of the type MGA 915 (Russia, Lumex LLC), TDS meter (Korea, Hanna, Combo), pH meter/ionometer type Itan (Russia), spectrophotocolorimeter type KFK 3-01 (Russia) and flame photometer type PFA 378 (USA, UNICO). All measuring equipment had certificates of state verification valid in Kazakhstan.

Sampling for the Assessment of Floristic Composition and Vegetation Density

Sampling of plant and soil material by the expedition participants was conducted in early July 2022.

Samples were taken from both anthropogenically impacted and natural undisturbed sites (Fig. 7).

At the South Kara-Agash site, vegetation cover studies were conducted on the following plots:

1) At the base of leach stacks and waste dumps (pioneer overgrowth stage, 2 years)
2) The disturbed territory around stacks and dumps (group-overgrowth community)
3) Control plot on the territory unaffected by economic activity (Table 1)

Statistical Processing of Measurement Results

According to the results of statistical processing, the data were presented as an estimate of the measured value, specifically the arithmetic mean of corrected measurement results, along with the mean square deviation for the group of n measurement results. The primary software utilized for the statistical processing of these measurement results included standard Microsoft Office Excel packages, version 2016. These packages featured tools such as "data analysis" and "statistical functions," which were employed to analyze the data comprehensively. The use of these software tools ensured accurate statistical analysis and facilitated the computation of key metrics, including averages, deviations, and other relevant statistical parameters essential for interpreting the measurement results.

Fig. 7: Sampling of plant and soil material at the base of the leach stack and waste dumps

Table 1: General characterization of the floristic composition around the gold mining dump

Code	Coordinates	GPC, %	Dominant species	Number of species	Notes
PP-1	52°15'25"N, 70°20'22"E, 400 m.a.s.l.	3	*Bassia sedoides, Glycyrrhiza korshinskyi, Polygonum gracilius*	3	Pioneer grouping
PP-2	Same location	40	*Peucedanum morisonii, Chenopodium album, Phlomoides tuberosa*	25	Group-overgrowth community
PP-3	Same location	80	*Peucedanum morisonii, Stipa pennata*	29	Control, outside the industrial site

Notes: GPC-General Projective Cover, PP-Population in the Phytocenosis

Results

Assessment of Background Ionizing Radiation

The monitoring of gamma background ionizing radiation intensity on the soil or ground surface indicated that the values did not exceed the maximum permissible levels set by regulatory requirements (Table 2). The studies indicate that background ionizing radiation intensity is within 0.10-0.35 μSv/h, meeting regulatory requirements for environmental safety. The overall level of gamma radiation in plots located within the mining quarry is found to be elevated compared to radiation on the surface of leaching heaps and in the control forest plot. The average level of ionizing radiation at the bottom of quarries is higher than that in control plots. In any case, the observed levels of ionizing radiation have almost no effect on the formation of phytocenoses.

Agrochemical Assessment

The results of soil quality and fertility indicators control are presented in Table 3.

Dump soils have an alkaline reaction (pH more than 7.00). The hydrogen index pH corresponds to slightly alkaline and alkaline values. The analysis of soil samples revealed varying levels of organic matter (humus) and other agrochemical indicators. Specifically, soil samples were categorized into the first group based on their organic matter content, with levels below 2%, indicating the lowest humus content. In contrast, the boundary and control samples exhibited an average humus content, ranging from 4.2-5.7%, which aligns with the typical levels for average humus content in soils.

Regarding mobile potassium compounds, as determined by the Machigin method, the boundary samples showed average levels, while the control samples exhibited elevated levels. This differentiation suggests a variance in nutrient availability and potential soil fertility between these sample groups.

The Nitrate Nitrogen (N-NO_3) content was found to be low across all plots. This low level of nitrate nitrogen suggests limited immediate availability of this essential nutrient for plant uptake, which could impact plant growth and soil health if not addressed.

Overall, these findings provide a comprehensive understanding of the soil's nutrient status, informing potential soil management and fertilization strategies to enhance soil quality and productivity.

The content of mobile phosphorus compounds according to the Machigin method along the lines "dump base" → "disturbed territory" → "boundary plot" → "control plot" increases from very low to low values. It can be concluded that soil quality/fertility values increase along the line of "dump base" → "disturbed territory" → "boundary plot" → "control plot". Humus and potassium content in the "boundary" and "control" plots are sufficient for normal plant life, which contributes to the restoration of vegetation cover. Key indicators of potential soil fertility, such as humus, nitrogen, and phosphorus content, are relatively low on technogenically disturbed sites, making them unsuitable for the development of highly productive vegetation cover.

High values of standard deviation from the average estimation of the measured indicator values of samples from the "dump base" and "disturbed territory" sites can be attributed to intensive anthropogenic impact, including landscape change.

The analysis of soil samples to determine the gross content of heavy metals produced the following results (Table 4).

The gross content of heavy metals in the studied soil samples generally complies with the normative requirements.

Study of the Floristic Composition and Density of Vegetation Cover

A total of 47 species of higher vascular plants were found during the surveys (Table 5).

PP-1. Pioneer grouping at the base of the dump (52°15'25"N, 70°20'22"E)

The projective cover is extremely low (3%). The pioneers of overgrowth are Bassia sedoides, Glycyrrhiza korshinskyi, and Polygonum gracilius, which are usually characteristic of solonetzic and brackish soils.

PP-2. The group-overgrowth community is formed around the dump on clay erosions. Surrounding vegetation has a great impact on the formation of this community. Nevertheless, a major influence is also produced by anthropogenic salinization of the embryozem, as evidenced by the presence of species characteristic of solonetz and solonchak soils (Artemisia nitrosa, Eryngium planum, Kochia iranica, Limonium gmelinii, Palimbia turgaica). Importantly, these species were not found on the territory unaffected by economic activity.

Table 2: Indicators of ionizing radiation intensity, μSv/h

	Control location. Coordinates		
	Territory of leaching sites, 52°15'25"N, 70°20'22"E	Quarry territory, 52°15'31"N, 70°21'06"E	Forest and steppe control area, 52°15'26"N, 70°20'28"E
Number of measurements	0.20	0.25	0.10
Mean	0.25	0.33	0.15
SD	0.05	0.06	0.04

Table 3: Soil quality indicators

		Dump base (n = 10)		Disturbed territory (n = 10)		Boundary plot (n = 10)		Control plot (n = 10)	
No.	Soil quality indicators	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	pH	8.24	0.69	7.99	0.56	7.30	0.52	7.20	0.50
2	Organic matter, %	0.93	0.27	1.92	0.38	4.20	0.71	5.70	0.82
3	Nitrate nitrogen (N-NO3), mln-1	<2.00	0.10	<2.00	0.10	4.00	0.50	6.00	0.50
4	Mobile forms of sulfur, mln-1	399.50	34.10	319.50	27.50	340.00	29.10	320.00	22.20
5	Mobile phosphorus compounds, mln-1	7.00	0.88	13.00	1.67	14.00	1.28	15.00	1.31
6	Mobile potassium, mln-1	154.00	20.31	97.00	8.50	260.00	23.32	320.00	28.20
7	Total dissolved solids, ppm	793.00	64.50	1,543.00	109.70	670.00	34.30	660.00	34.50
8	Electrical conductivity, mS/cm	1.59	0.10	3.09	0.19	0.98	0.09	0.32	0.04

Table 4: Heavy metal content

		Content, mg/kg (ppm) Dump base (n = 10)		Disturbed territory (n = 10)		Boundary plot (n = 10)	
No.	Element	Mean	SD	Mean	SD	Mean	SD
1	Zn	35.210	8.02	7.680	3.24	7.320	1.20
2	Cu	18.850	0.09	17.590	0.45	16.890	0.09
3	Cd	0.258	0.06	0.102	0.04	0.102	0.04
4	Fe	14,852.000	3,546.14	7,457.000	1,735.09	6,876.000	898.00
5	Mn	510.000	91.92	155.000	28.26	162.000	33.40
6	Pb	10.560	1.33	11.060	1.55	9.040	1.20

Table 5: Floristic composition of vegetation cover around gold mine dumps

	PP-1	PP-2	PP-3
GPC, %	3	40	80
Allium flavescens Besser		+	
Eryngium planum L.			+
Palimbia turgaica Lipsky ex Woronow		+	
Peucedanum morisonii Besser ex Spreng		20	20
Achillea millefolium L.			+
Artemisia armeniaca Lam.		+	
Artemisia austriaca Jacq.			+
Artemisia latifolia Ledeb.		+	10
Artemisia nitrosa Weber		+	
Artemisia pontica L.			+
Echinops ritro L.			+
Galatella angustissima (Tausch) Novopokr		+	5
Galatella biflora (L.) Nees		+	5
Galatella villosa (L.) Rchb. f.		+	+
Inula salicina L.			+
Jurinea multiflora (L.) B.Fedtsch		+	
Trommsdorffia maculata (L.) Bernh			+
Campanula sibirica L.			+
Gypsophila altissima L.			+
Silene chlorantha (Willd.) Ehrh			+
Bassia sedoides (Pall.) Asch	1		
Chenopodium album L.		5	
Chenopodium urbicum L.		3	
Kochia iranica Bornm.		+	
Scabiosa ochroleuca L.			+
Astragalus sp.		+	
Glycyrrhiza korshinskyi Grig	1		
Glycyrrhiza uralensis Fisch			+
Medicago falcata L.			+
Iris halophila Pall.			+
Phlomoides tuberosa (L.) Moench		5	5
Salvia stepposa Des.-Shost		3	
Limonium gmelinii (Willd.) Kuntze		+	
Plantago media L.		+	5
Leymus racemosus (Lam.) Tzvel		3	
Poa pratensis L.			+
Stipa capillata L.		+	
Stipa pennata L.			20
Polygonum gracilius (Ledeb.) Klok	1		
Adonis wolgensis Steven		+	
Pulsatilla patens (L.) Mill			+
Filipendula vulgaris Moench		+	5
Potentilla argentea L.			+
Sanguisorba officinalis L.			+
Galium verum L.			+
Verbascum phoeniceum L.		+	
Veronica incana L.		+	
Veronica spicata L.		+	+
47 species in total	3	25	29

Notes: GPC-General Projective Cover, PP-Population in the Phytocenosis

Table 6: Indicators of GPC, PP, organic matter content, and the content of mobile potassium compounds

Indicator	Dump base	Disturbed territory	Boundary plot	Control plot	Stable plateau
GPC	3.00	40.00	40-80	80.0	100.0
PP	3.00	25.00	25-29	29.0	29.0
Organic matter, %	0.93	1.92	4.20	5.7	5.7
Mobile potassium, mg/kg	154.00	97.00	260.00	320.0	320.0

PP-3. Natural vegetation: Young pine forest, chestnut sandy loamy soil. Control is represented by mixed herbaceous-gramineous steppe with the predominance of *Peucedanum morisonii* and Stipa pennata. The species included in mixed grasses with a large proportion of projective cover are Artemisia latifolia, *Galatella angustissima, G. biflora*, Inula salicina, Phlomoides tuberosa, and Trommsdorffia maculate.

The number of PP species was found to increase with objective projective coverage (Fig. 8). The rise in GPC and the number of species follows the scheme "*Dump* base" → "*Disturbed* territory around the dump" → "*Control* plot", which is associated with improved soil quality and vegetation succession. Regression statistics show the following values: Multiple correlation R-0.92, R2-0.85, standard error-21.34.

It is also reasonable to assume that as GPC (%) approaches 100%, the number of species in the PP stabilizes at a certain level corresponding to the number of species in a stable phytocenosis following the scheme "dump base" → "disturbed territory around the dump" → "control plot" → "stable plateau". The "stable plateau" can be assigned a conditional GPC value of 100% and PP with the maximum number of species detected (Fig. 9).

The formation of organic matter/humus on stacks and dumps, as well as the accumulation of quality elements in the soil, including the mobile compounds of potassium and phosphorus, are at the beginning stages. There is a clear and logical dependence of GPC and PP both on the degree of anthropogenic impact and soil quality indicators, including organic matter and mobile potassium content (Table 6).

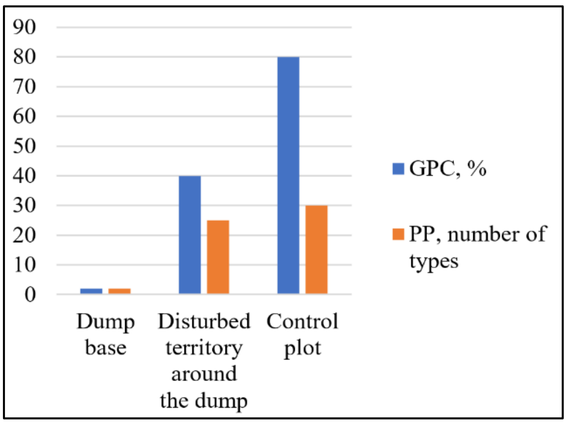

Fig. 8: Increase in the number of species with increasing GPC

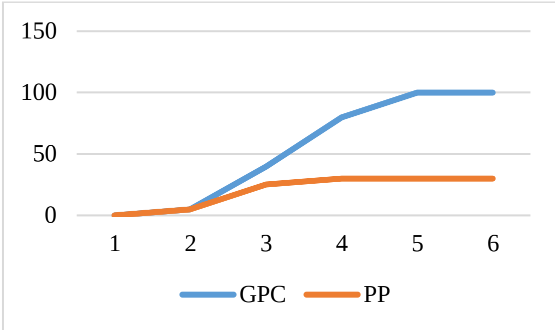

Fig. 9: Stabilization of the number of PP species with increasing GPC (%)

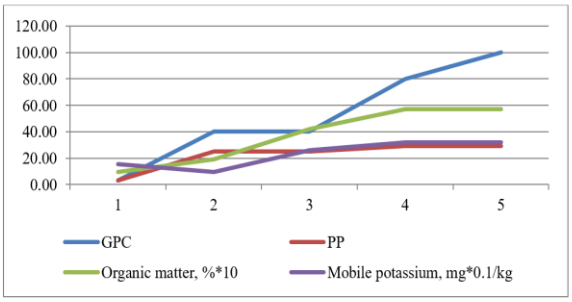

Fig. 10: Dependence of GPC and PP on organic matter content and mobile potassium compounds

It can also be assumed that an increase in the content of such vital components of soil quality as organic matter/humus and mobile potassium (Fig. 10, row 4) reinforces vegetation formation processes, including GPC (Fig. 10, row 1) and PP (Fig. 10, row 2).

Discussion

Our Results Provide Several Conclusions

First, methodological recommendations of the Republic of Kazakhstan on comprehensive agrochemical assessment of agricultural soil shall establish the following Threshold Limit Values (TLV) for the content of heavy metals: Zinc -100 mg/kg, copper-50 mg/kg, manganese-1,500 mg/kg, lead-30 mg/kg (Steinborn, 2004). The gross content of lead in the studied soil samples meets Kazakhstan's hygienic standards for habitat safety, which stipulate a maximum of 32 mg/kg (Gosstandart of the USSR, 1989). Cadmium content in soil samples is less than 0.30 mg/kg, which falls under the

TLV (Gosstandart of the USSR, 1986b). Additionally, the maximum gross content of iron in soil samples from reclaimed dumps is significantly lower than the recommended values, being about two to four times lower than the permissible limit of 38,000 mg/kg.

Second, an assessment of the vegetation cover of field plots found a total of 47 species of higher vascular plants. GPC on the control plots unaffected by economic activity reaches up to 80%. The intensity of ionizing radiation at the field objects is in the range of 0.10-0.35 μSv/h, which complies with radiation safety requirements and does not interfere with the formation of vegetation cover.

Third, it is important for practical purposes that our studies identify the species of pioneer overgrowth that provide primary succession. These are Bassia sedoides, Glycyrrhiza korshinskyi, and Polygonum gracilius, plants that are typically characteristic of solonetzic and brackish soils. In the areas of dumps with clay erosion, there develops a group-overgrowth community comprised of loam Artemisia nitrosa, Eryngium planum, Kochia iranica, Limonium gmelinii, and Palimbia turgaica, which are the species characteristic of solonetz and solonchak soils. Importantly, these species are not found on territory unaffected by economic activity. These species are endemic and can be used for artificial overgrowth of disturbed lands, subsequent fixation of soil structure from erosion, and formation of a humus horizon. The effectiveness of this approach is confirmed by other studies. For example, the use of Stylosanthes guianensis has already been investigated. At 470 days after sowing, the average plant height was 46.7 cm, with more than 50% rooting. The yields were 23.9 t/ha for biomass and 450 kg/ha for dry biomass and nitrogen. Significant improvements were observed in various soil parameters, including cation exchange capacity, which increased to 3.3-4.0 cmoL (+)/kg, soil organic matter content, which rose to 0.03-0.39%, and biomass, which improved to 0.03-0.15 mgC/g. Soil macrofauna expanded from 2-11 taxonomic groups, including ants, which are considered soil engineers. Moreover, *S. guianensis* increased soil carbon sequestration in affected areas by more than 1,650%, from 0.004-0.07 t C ha^{-1} (Velásquez Ramírez *et al*., 2021).

While the findings of this study provide valuable insights into the formation of vegetation cover and soil quality indicators at gold-bearing deposit sites, there are limitations that should be acknowledged. The study is limited to the Kara-Agash gold-bearing field in Central Kazakhstan. Therefore, the results may not be directly applicable to other gold mining regions with different climatic, geological, and ecological conditions.

Conclusion

Our assessment of the background ionizing radiation in the studied area, along with the agrochemical composition of the soil and the floristic composition and density of the vegetation cover, enabled us to evaluate the potential for forming vegetation cover and improving soil quality indicators. These findings contribute to enhancing the efficiency of restoration efforts in technogenically disturbed areas of gold-bearing deposit mines in Kazakhstan.

The research findings may be of use in the organization and conduct of environmental monitoring and assessment of the recultivation of vegetation cover and soils on the territories of mines of ore metal-containing mineral deposits subjected to intensive economic activity.

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Author's Contributions

All authors equally contributed in this study.

Ethics

The authors have no ethical issues to declare.

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