Changes in vegetation cover as a result of anthropogenic and technogenic impact on arid ecosystems of the Ashchykol depression (Betpak-Dala): problems and prospects for the recultivation of uranium mines

Dmitry Faleyev*, *Olga* Fedorina, *Oles* Agapov, *Samat* Kairambaev, *Natalya* Bolshakova, and *Gulnur* Baibossunova

Institute of High Technologies LLP, Kazakhstan, Almaty. NAC KAZATOMPROM JSC

Abstract. The vegetation cover of arid ecosystems in the territory of uranium mines of NAC Kazatomprom JSC and adjacent territories (Ashchykol Depression, Betpak-Dala) is affected by both anthropogenic and technogenic factors. Anthropogenic, technogenic impact on vegetation and soil cover led to a significant reduction in species diversity and an increase in the proportion of weeds. The activity indicator of species is an important parameter of environmental monitoring and the effectiveness of recultivation. Some of the promising objects of recultivation are Haloxylon aphyllum, Calligonum aphyllum, which are widespread in the study area and tolerate not only anthropogenic but also technogenic impacts.

1 Introduction

Kazakhstan ranks first in the world in terms of uranium production and second place in its reserves. Uranium mining is carried out by NAC Kazatomprom JSC using the underground borehole leaching (UBL) method [1, 2]. This technology is the most environmentally friendly compared to open-pit or shaft uranium mining technologies. However, during uranium mining using the UBL, it is necessary to involve heavy construction and drilling equipment, equipment and maintenance of production infrastructure, which ultimately leads to the destruction of vegetation and soil cover.

Providing the environmental foundations for sustainable development and bearing responsibility for preserving a favorable environment in the region of presence, NAC Kazatomprom JSC pays due attention to environmental monitoring, in particular monitoring the state of vegetation, carries out measures to preserve and restore the biological diversity of technogenically disturbed areas [3-5]. At the same time, it is impossible to fully implement environmental protection measures without taking into account local natural and climatic conditions and a detailed study of biological diversity, in particular vegetation cover.

More than 70% of Kazakhstan's territory is represented by areas with an arid climate, which are characterized by a significant lack of moisture, high summer temperatures, low organic content in soils, and salinization. Here, plant life is characterized by a short growing season, low productivity of plant communities and ecosystems as a whole. Therefore, ecosystems of arid areas are especially vulnerable to the impact of anthropogenic and technogenic factors and take a long time to recover. The study of vegetation cover in areas subject to anthropogenic and technogenic impacts is one of the most important tasks of environmental monitoring, to identify the extent of damage to ecosystems and develop proposals for the recultivation of lands disturbed by uranium mining.

The aim of this study was to examine the vegetation cover as a result of anthropogenic and technogenic impact on arid ecosystems within the uranium mines of NAC Kazatomprom JSC and the zone of their possible impact (adjacent territories), in light of the problems and prospects of recultivation.

2 Materials and methods

The object of this study was the vegetation cover of arid ecosystems on the territory of uranium mines of NAC Kazatomprom JSC and adjacent territories, within a radius of 10 km from the mine. The study area was located in Southern Kazakhstan (near the village of Taikonur), in the area of the Ashchykol depression: at the junction of the extreme western spurs of the Moyynkum sands (Katynshokai sands) and the southwestern part of the Betpak-Dala clay desert.

* Corresponding author: ex_eko@mail.ru

The climate of the study area is sharply continental, arid. Summer is dry and hot, winter is moderately cold, with little snow. Snow cover is stable. Total precipitation is 100–150 mm per year (in some years – 200 mm). The hydrothermal regime is well reflected by the dryness index, which reaches 2.5–6 here. The winter continentality index is 10–40 [6]. The average annual temperature does not exceed 5 °C, the average January temperature is 12–14 °C, July 24–26 °C [7]. The vegetation period lasts 200–210 days [8].

In the western part of Betpak-Dala, Paleozoic rocks are submerged under a layer of horizontally lying Mesozoic and Paleogene loose sediments (sands, sandstones, clays, pebbles), which form a sheet plain with drainless depressions in the form of ravines and closed depressions [7]. Within the study area, various morphostructures are represented: lowland alluvial sandy plains, lowland and elevated eolian plains. Takyrs and salt marshes are common in the depressions.

The main characteristic of desert soils is low humus content, significant carbonate and gypsum content, frequent manifestation of solonetzic and saline soils [8]. Directly in the studied communities, the relief is mostly leveled or slightly hilly, in places a gently undulating plain. The altitude above sea level was about 150-170 m. Soils are gray-brown sandy loam, solonetz and brown solonetz.

The study area belongs to the Central North Turanian botanical-geographical subprovince. Here, the spatial structure of the vegetation cover is very heterogeneous. Perennial saltwort deserts predominate (56.4%). Wormwood deserts predominate on 15.6% of the area, and psammophytic shrub and saxaul deserts, confined to sandy massifs, occupy 8.3 and 18.7%, respectively [8].

The subzone of middle deserts, within the Betpak-Dala desert, is dominated by hemicryptophytic vegetation complexes with the prevalence of *Salsola arbusculiformis*, *Artemisia turanica*, *Anabasis salsa*, *Nanophiton erinaceum*, in some places only *Salsola arbusculiformis* communities participate in the complexes. On plains with loamy soils, plant community complexes of *Anabasis salsa* and *Artemisia terrae-albae* are widespread. The ratio of the components of the complexes can change, so *Artemisia terrae-albae* dominates on less saline soils. To the south, at the junction with the sandy deserts of Moyynkum and the Katynshokai sands, psammophytes such as saxaul appear in plant communities [8].

The anthropogenic impact of the study area is characterized by intensive livestock grazing and road degradation. Technogenic impact caused by uranium mining activities is characterized by damage to vegetation and soil cover: road and industrial construction, laying and maintaining various communications, drilling operations, moving heavy special equipment, moving soil during the planning of production sites, road works, etc.

In the study area, background plant communities are characterized by plant communities dominated by *Artemisia terrae-albae*, *Atriplex cana, Anabasis salsa*, *Nanophiton erinaceum*, ephemerals and ephemeroids, *Salsola arbusculiformis* and *S. orientale, Poa bulbosa*, with the participation of *Haloxylon aphyllum*, projective cover of 35-65%, the degree of damage to the plant cover is insignificant: 0-1 (out of 5 points). In areas with pronounced anthropogenic impact, the vegetation is characterized by ephemeral-herbaceous communities with the presence of *Haloxylon aphyllum* and *Tamarix ramosissima, Haloxylon aphyllum* - *Artemisia terrae-albae*, ephemeral-herbaceous communities, as well as sparse anthropogenic groupings of weedy ruderal species and undeveloped plant communities. The projective cover ranges from 0.1% to 60%, and the degree of vegetation cover disturbance is rated at 2–5 points In the conditions of technogenic transformation, unformed plant communities prevailed at the geotechnological testing grounds, the projective cover was 0.2–20%, the degree of damage to the vegetation cover reached 3–5 points.

The analysis was based on data on species composition and projective cover obtained at 31 sites; plant communities (grouped by the degree of anthropogenic/technogenic impact: background (control) – 14 plant communities, anthropogenic impact – 7, technogenic – 10). The research was conducted in April 2023. We analyzed the following parameters: species composition, species constancy, species activity.

To compare the species composition in the monitoring areas, the Dice index [9] was used, according to formula (1):

$$K = \frac{2c}{a+b} \quad (1)$$

where a, b – the number of species identified in each of the compared groups of plant communities; c – the number of species common to them.

Species activity is a complex indicator that shows the measure of the species' vital success in a given territory, one of the expressions of the "species weight" in a given flora [9, 10]. The calculation of species activity is performed using formula (2):

$$\mathrm{Act} = \sqrt{\frac{\mathrm{C}\times 100\%}{\mathrm{N}} \times \frac{\sum_{i=1}^{N} \mathrm{A_i}}{\mathrm{N}}} = 10 \times \frac{\sqrt{\mathrm{C}\times \mathrm{A}_\Sigma}}{\mathrm{N}}\% \quad (2)$$

where Act - is the estimated activity of the taxon for the monitoring area in percent (0÷100%); N - is the number of survey plots; C - is the constancy of the taxon – the absolute number of survey plots where the taxon is registered; Ai - is the projective cover of the taxon on the i-th survey plot; AΣ - is the sum of the projective covers of the taxon on all survey plots [10].

Results and discussion

During the study, 31 plant communities were examined. 90 plant species belonging to 57 genera and 25 families were identified. The greatest systematic diversity was found in plant communities of background sites - 71 species belonging to 54 genera and 22 families. Anthropogenic, technogenic impact on vegetation and soil cover led to a significant reduction in species diversity: 30 and 29 species, 28 and 24 genera, 12 and 13 families, respectively. In particular, anthropogenic and technogenic impact contributed to an increase in the proportion of ruderal plant species: in background plant communities their number reached 15 species (21.1% of the total number of species), with anthropogenic impact - 9 species (30.0%), with technogenic - 8 species (27.6%).

The highest activity of species (31.3 – 7.9) in the formation of background plant communities was demonstrated by *Artemisia terrae-albae* – 31.3; *Poa bulbosa* – 19.0; *Ceratocephalus orthoceras* – 19.0; *Salsola orientale* – 18.8; *Anabasis salsa* – 16.8; *Lepidium perfoliatum* – 10.6; *Nanophiton erinaceum* – 9.7 and *Salsola arbusculiformis* – 7.9 (Table). Among these species, the majority are native vegetation and take an active part in the formation of natural plant communities, which may indicate a low degree of damage to plant communities by anthropogenic factors. Under conditions of anthropogenic, technogenic impact, there is a noticeable decrease in the activity of these species, some of them even drop out of the processes of plant community formation. Thus, the species activity of *Artemisia terrae-albae* under anthropogenic impact decreases almost 5 times, under technogenic impact - 10 times; the species activity of *Poa bulbosa* under anthropogenic impact decreases 3 times, under technogenic degradation this species drops out of the process of formation of vegetation cover.

The similarity of the floristic composition in plant communities with different degrees of anthropogenic, technogenic impact calculated on the basis of the Dice index showed a low degree of similarity of the floristic composition between plant communities: 0.38 - background - anthropogenic impact, 0.34 - anthropogenic - technogenic impact, 0.22 - background - anthropogenic impact, which is obviously associated with the high level of anthropogenic, technogenic transformation, leading to the disappearance of many species of flora and their replacement with ruderal species.

Thus, our studies have shown that the vegetation cover of arid ecosystems in the territory of uranium mines of NAC Kazatomprom JSC and adjacent territories (Ashchykol Depression, Betpak-Dala) is affected by both anthropogenic and technogenic factors. The greatest systematic diversity was found in plant communities of background (control) sites. Anthropogenic, technogenic impact on vegetation and soil cover led to a significant reduction in species diversity and an increase in the proportion of weeds.

The most active species in the formation of background plant communities were Artemisia terrae-albae, Poa bulbosa, Ceratocephalus orthoceras, Salsola orientale, Anabasis salsa, Lepidium perfoliatum, Nanophiton erinaceum, Salsola arbusculiformis. Among these species, most are characteristic, native vegetation and take an active part in the formation of natural plant communities, which may indicate a low degree of damage to plant communities by anthropogenic factors. Under anthropogenic, technogenic impact, there is a steady decrease in the activity of these species, some of them even drop out of the processes of formation of plant communities. Recultivation of disturbed territories, according to the requirements of the legislation in the liquidation of the consequences of subsoil use, requires the restoration of vegetation cover, species diversity and the structure of plant communities to their natural state. The activity indicator of species is an important parameter of environmental monitoring and the effectiveness of recultivation.

Table. Vegetation of uranium mines of NAC Kazatomprom JSC and adjacent territories (Ashchykol Depression, Betpak-Dala) and its species activity

Family	Specie	Species activity			Economic importance
		Back-ground (control)	Anthropo-genic impact	Techno-genic impact	
1	2	3	4	5	6
Asteraceae	*Artemisia terrae-albae*	31,3	5,6	3,5	fodder, essential oils
Poaceae	*Poa bulbosa*	19,0	5,6	0,0	fodder
Ranunculaceae	*Ceratocephalus orthoceras*	19,0	12,9	8,3	weed, poisonous
Chenopodiaceae	*Salsola orientalis*	18,8	0,0	1,7	fodder
Chenopodiaceae	*Anabasis salsa*	16,8	0,8	1,0	fodder
Brassicaceae	*Lepidium perfoliatum*	10,6	14,1	2,2	halophyte
Chenopodiaceae	*Nanophyton erinaceum*	9,7	0,5	0,0	fodder
Chenopodiaceae	*Salsola arbusculiformis*	7,9	0,0	0,0	fodder
Poaceae	*Bromus tectorum*	7,3	0,0	0,0	fodder
Brassicaceae	*Alyssum desertorum*	7,2	3,4	3,2	fodder
Poaceae	*Eremopyrum triticeum*	6,5	0,0	4,2	weed
Cyperaceae	*Carex subphysodes*	6,4	0,0	0,0	fodder
Poaceae	*Eragrostis minor*	5,5	0,0	0,0	weed
Brassicaceae	*Syrenia siliculosa*	5,4	0,0	0,0	endemic
Chenopodiaceae	*Atriplex cana*	5,4	4,8	0,0	fodder
Papaveraceae	*Papaver pavoninum*	4,6	10,4	1,7	poisonous
Liliaceae	*Tulipa patens*	3,9	0,0	0,3	decorative
1	2	3	4	5	6
Poaceae	*Eremopyrum orientale*	3,0	5,6	0,0	fodder

Poaceae	*Aeluropus littoralis*	3,0	0,0	0,0	fodder
Cyperaceae	*Carex pachystylis*	2,9	0,0	0,0	fodder
Poaceae	*Phragmites australis*	2,7	0,0	0,0	weed, fodder, food
Brassicaceae	*Erysimum sisymbrioides*	2,6	0,0	0,0	weed, тех., medical
Asteraceae	*Artemisia turanica*	2,5	1,2	1,9	fodder
Apiaceae	*Ferula assa-foetida*	2,5	0,0	1,1	medical, medical, spice
Poaceae	*Aristida pennata*	2,4	0,0	0,0	-
Chenopodiaceae	*Climacoptera brachiata*	2,2	0,0	3,7	fodder
Liliaceae	*Tulipa alberti*	2,2	0,0	0,3	endemic, Red Book of the RK
Polygonaceae	*Rheum tataricum*	2,1	0,0	0,0	fodder, tannin
Амариллисовые	*Ixiolirion tataricum*	2,1	0,0	0,0	decorative, medical, food
Chenopodiaceae	*Calligonum aphyllum*	1,9	0,0	2,7	fodder, тех., food, fuel
Chenopodiaceae	*Haloxylon aphyllum*	1,9	5,9	16,0	fuel, fodder
Chenopodiaceae	*Chenopodium album*	1,7	5,3	0,0	fodder, food, medical, dye
Chenopodiaceae	*Salsola sp.*	1,7	0,0	0,0	-
Chenopodiaceae	*Salsola pestifer*	1,7	0,0	2,2	fodder, сол., weed
Apiaceae	*Ferula tatarica*	1,6	0,0	0,0	weed
Poaceae	*Bromus sp.*	1,5	0,0	0,0	-
Chenopodiaceae	*Halocharis sp.*	1,5	0,0	0,0	-
Fabaceae	*Astragalus sp.*	1,5	0,0	0,0	-
Crassulaceae	*Sedum purpureum*	1,2	0,0	0,0	weed, food, decorative, medical
Ranunculaceae	*Ranunculus aser*	1,2	0,0	0,0	weed, poisonous
Ranunculaceae	*Delphinium songoricum*	1,2	0,0	0,0	medical, poisonous
Fabaceae	*Alhagi pseudoalhagi*	1,2	0,0	5,3	fodder, medical, food
Boraginaceae	*Arnebia decumbens*	1,2	0,0	0,0	-
Boraginaceae	*Lappula semiglabra*	0,9	1,7	0,0	-
Cyperaceae	*Carex supina*	0,8	0,0	0,0	fodder
Tamaricaceae	*Tamarix ramosissima*	0,8	4,5	0,0	decorative, tannin
Asteraceae	*Acroptilon repens*	0,8	1,7	1,7	weed, poisonous
Asteraceae	*Cardaria repens*	0,8	0,0	0,0	weed
Papaveraceae	*Roemeria hybrida*	0,8	0,0	0,0	-
Papaveraceae	*Roemeria refracta*	0,5	0,4	0,0	weed, poisonous, medical
Brassicaceae	*Sisimbrium officinale*	0,5	0,0	0,0	medical, fodder, weed
Geraniaceae	*Geranium pratense*	0,5	0,4	0,0	medical, medical, fodder, dye
Asteracea	*Sonchus arvensis*	0,5	0,0	0,0	weed, fodder, medical
Liliaceae	*Tulipa biebersteiniana*	0,3	0,0	0,0	-
Chenopodiaceae	*Ceratocarpus arenarius*	0,3	0,0	0,0	weed, fodder
Brassicaceae	*Sisimbrium altissimum*	0,3	0,0	0,0	weed
Apiaceae	*Ferula songorica*	0,3	0,0	0,0	medical, poisonous
Rosaceae	*Rosa persica*	0,3	0,8	3,0	weed, fodder
Asteraceae	*Cousinia sirdariensis*	0,3	0,0	0,0	endemic
Amaranthaceae	*Kalidium caspicum*	0,3	0,0	0,0	poisonous, insecticidal, halophyte, technical
Zygophyllaceae	*Peganum harmala*	0,0	12,2	0,0	weed, poisonous, medical
Fabaceae	*Goebelia alopecuroides*	0,0	4,2	0,0	weed, insecticidal, medical
Fabaceae	*Astragalus paucijugus*	0,0	1,8	0,0	fodder
Ulmaceae	*Ulmus pumila*	0,0	1,7	0,0	decorative
Brassicaceae	*Malcolmia africana*	0,0	1,7	1,2	-
Asteraceae	*Taraxacum officinale*	0,0	1,7	0,0	weed, medical, food, medical
Fabaceae	*Trigonella arcuata*	0,0	1,2	0,0	weed
Chenopodiaceae	*Ceratocarpus utriculosus*	0,0	0,8	8,8	weed, fodder
Alliaceae	*Allium sp.*	0,0	0,4	0,0	-
Polygonaceae	*Polygonum aviculare*	0,0	0,0	2,4	weed, medical
Chenopodiaceae	*Suaeda altissima*	0,0	0,0	2,4	weed, fodder, halophyte
Chenopodiaceae	*Salsola paulseni*	0,0	0,0	2,4	fodder
Chenopodiaceae	*Climacoptera lanata*	0,0	0,0	1,0	fodder, halophyte
Boraginaceae	*Heliotropium arguzioides*	0,0	0,0	1,0	-
Polygonaceae	*Atraphaxis spinosa*	0,0	0,0	0,7	-
Chenopodiaceae	*Corispermum lehmannianum*	0,0	0,0	0,7	-
Tamaricaceae	*Tamarix hispida*	0,0	0,0	0,3	decorative

Some of the promising objects of recultivation are *Haloxylon aphyllum*, *Calligonum aphyllum*, which are widespread in the study area and tolerate not only anthropogenic but also technogenic impacts. *H. aphyllum*, *C. aphyllum* are often found in the territories of uranium mines, which is an example of a balanced approach to engineering and construction work and the possibility of faster restoration of technogenically disturbed lands. These species can be recommended for recultivation work (creation of phytogenic fields).

Further study of changes in vegetation cover as a result of the anthropogenic and technogenic impact of UBL uranium on arid ecosystems will significantly expand our understanding of the degree and mechanisms of the impact of technogenic human activities on the environment, optimize methods of recultivation and rehabilitation of technogenically disturbed areas in the process of uranium mining activities, carried out in accordance with environmental legislation of Kazakhstan.

References

1. E.N. Panova, E.A. Aubakirov, L.S. Ibraeva Comprehensive study of drill cuttings from one of the enterprises of NAC KAZATOMPROM JSC. Bulletin of KazNRTU. Chemical and metallurgical sciences. 6, 85–94 (2021)
2. I.P. Poezzhaev, K.D. Polinovsky, O.A. Gorbatenko and others. Geotechnology of uranium: textbook (Almaty: Kazakh universities, 2017)
3. S.K. Kairambaev, Yu.G. Permenev, N.A. Bolshakova, D.G. Faleev, O.A. Fedorina, G.E. Baybosunova. Monitoring of the vegetation cover of the territories of uranium mining mines of NAC Kazatomprom JSC. Development of the uranium and rare metal industry. XI International Scientific and Practical Conference. (Almaty May 16-18, 2024) - Almaty: Kazatomprom: KBTU. 168–174 (2024)
4. Y.G. Permenev, S.K. Kairambaev, D.G. Faleev, O.A. Agapov, O.A. Fedorina, Zh.T. Mukhanbetzhanov Remediation of territories of Southern Kazakhstan exposed to uranium mining activities: problems and prospects. // Development of the uranium and rare metal industry. XI International Scientific and Practical Conference. (Almaty May 16-18, 2024) - Almaty: Kazatomprom: KBTU. 186–190 (2024)
5. M.M. Iskakov, Y.G. Permenev, E.N. Panova, O.A. Agapov Implementation of the ESAP roadmap as a tool for sustainable development of the company. // Development of the uranium and rare metal industry. XI International Scientific and Practical Conference. (Almaty May 16-18, 2024). 164-167 (Almaty: Kazatomprom: KBTU, 2024)
6. I.A. Beresneva Climates of the arid zone of Asia. 287 (Moscow, Nauka, 2006)
7. Kazakhstan: National Encyclopedia; Ch. ed. B. Ayagan. 1, 560 (Almaty: Kazakh encyclopedia, 2004)
8. N.I. Akzhigitova, Z.-V. Brekle, G. Winkler et al. Botanical geography of Kazakhstan and Central Asia (within the desert region) (St. Petersburg, 2003)
9. B.A. Yurtsev Flora Suntar-Khayat. (Leningrad,.Nauka, 1968)
10. A.N. Kupriyanov, S.S. Kazmina, A.A. Zverev Changes in the floristic composition of plant communities of the Karakan Range near coal mines. Bulletin of Tomsk State University. Biology. 43, 66–88 (2018).