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Original Article

Improving the level of water quality and plant species diversity in the reservoir accumulating natural effluents from the reclaimed uranium-containing industrial waste dump

Melhoria do nível de qualidade da água e da diversidade de espécies vegetais no reservatório que acumula efluentes naturais de depósito de resíduos industriais com urânio recuperado

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Abstract

Due to the need to achieve the principles of sustainable development and to understand the processes of formation of phytocenoses in areas that were adversely affected by the industrial impact, this study assessed the condition of the Grachevsky uranium mine (Kazakhstan), which underwent conservation procedures about 25 years ago. The purpose is to determine the level of water quality and phytocenosis of the shores of the reservoir accumulating natural effluents from reclaimed dumps and anthropogenic sites of a uranium mine, as well as quality indicators and toxicology. The assessment included a qualitative research method (analysis of documents) to determine agro-climatic conditions and empirical methods of collecting information. The authors studied the intensity of ionizing radiation of the gamma background of the water surface of the reservoir (and sections of the shoreline and territories adjacent to the reservoir), and hydrochemical parameters of the waters of the reservoir, and performed a description of the botanical diversity. The vegetation cover of the sections of the reservoir shore is at different stages of syngenesis and is represented by pioneer groupings, group thicket communities, and diffuse communities. Favorable ecological conditions for the settlement and development of plants develop within the shores of the reservoir. The intensity levels of ionizing radiation do not exceed the maximum permissible levels and practically do not affect the formation of phytocenoses. An anthropogenically modified dry meadow with the participation of plants typical of the steppe zone has been formed on the floodplain terrace. Concerning the indicators of quality and toxicology of this reservoir, the water can be used for household and drinking purposes under the condition of prior water treatment. It can be concluded that a high level of natural purification of the reservoir waters occurred within twenty years after the reclamation of the uranium mine.

Keywords: reclamation, floral composition, uranium deposit, ecotone, ionizing radiation.

Resumo

Devido à necessidade de alcançar os princípios do desenvolvimento sustentável e de compreender os processos de formação de fitocenoses em áreas que foram negativamente afetadas pelo impacto industrial, este estudo avaliou o estado da mina de urânio de Grachevsky (Cazaquistão), que foi submetida a procedimentos de conservação há cerca de 25 anos. O objetivo é determinar o nível de qualidade da água e fitocenose das margens do reservatório que acumula efluentes naturais provenientes de depósitos recuperados e sítios antrópicos de uma mina de urânio, bem como indicadores de qualidade e toxicologia. A avaliação incluiu um método de investigação qualitativa (análise de documentos) para determinar as condições agroclimáticas e métodos empíricos de coleta de informação. Os autores estudaram a intensidade da radiação ionizante do fundo gama da superfície da água do reservatório (e seções da linha de costa e territórios adjacentes ao reservatório), bem como os parâmetros hidroquímicos das águas do reservatório, e fizeram uma descrição da diversidade botânica. A cobertura vegetal da seções da margem do reservatório encontra-se em diferentes estádios de singênese e é representada por agrupamentos pioneiros, comunidades de arbustos agrupados e comunidades difusas. Nas margens do resevatório desenvolvem-se condições

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ecológicas favoráveis à fixação e desenvolvimento das plantas. Os níveis de intensidade da radiação ionizante não ultrapassam os níveis máximos admissíveis e praticamente não afetam a formação de fitocenoses. No terraço da planície de inundação formou-se um prado seco modificado antropogenicamente com a participação de plantas típicas da zona de estepe. Em relação aos indicadores de qualidade e toxicologia deste reservatório, a água pode ser utilizada para fins domésticos e de consumo, desde que seja objeto de um tratamento prévio. Pode concluir-se que ocorreu um elevado nível de purificação natural das águas do reservatório nos vinte anos seguintes à recuperação da mina de urânio.

Palavras-chave: recuperação, composição floral, depósito de urânio, ecótono, radiação ionizante.

1. Introduction

Assessment of the ecological state and carrying out work on the reclamation of mining areas and degraded lands is an urgent task aimed at ensuring environmental safety and reusing lands subjected to catastrophic anthropogenic impacts (Mukhomedyarova et al., 2023). Researchers are actively working in the field of studying and implementing mechanisms for environmental monitoring and reclamation of industrial waste from enterprises engaged in the extraction and primary processing of various ore raw materials, coal, and uranium-containing ores (Kupriyanov et al., 2021; Zaretskaya, 2022).

Strategies for developing approaches for the reclamation and restoration of vegetation cover in the territory of spent mines include the stages of studying the formation of natural phytocenoses as a result of self-overgrowth and subsequent syngenesis, which allows us to identify the main patterns of such processes (Mamikhin et al., 2023; Nugmanov et al., 2022a). Understanding the fundamental patterns allows us to assess further the factors that are most important for the formation of plant communities (Akhmetov et al., 2023; Yessimbek et al., 2022) and identify the most promising species for reclamation and bioremediation activities (Belousova et al., 2021; Dukenov et al., 2023a).

Researchers note that the scientific literature (Baidalina et al., 2023; Nugmanov et al., 2022b) contains a limited amount of data on the issues of geobotanical research of the processes of formation of plant communities and assessment of the floral composition of the plant community on lands subjected to strong anthropogenic influence of uranium-containing waste from uranium mines, and the return of reclaimed uranium mines territories to economic circulation (Bugubaeva, 2022; Bugubaeva et al., 2023; Chen et al., 2020). An important aspect of such studies is the comparison of the data obtained with information about the vegetation of natural phytocenoses, which is important for assessing the impact of negative factors on phytocenoses and identifying species that can potentially play the greatest role in the processes of reclamation and remediation (Barnekow et al., 2019; Zanina and Smirnova, 2020). At the same time, the patterns of phytocenosis formation processes may vary depending on the climatic zone and the type of deposit (Dukenov et al., 2023b; Ivanova et al., 2023; Osintseva, 2023). This underlines the importance of considering agro-climatic factors in the formation of vegetation cover (Aipeisova et al., 2023; Shaimerdenova et al., 2023).

In the Republic of Kazakhstan, special attention is paid to the issues of reclamation of the territories of decommissioned uranium mines (Kazakhstan, 2001). This is especially important if these territories are associated with aquatic vegetation.

According to B.F. Sviridenko (Sviridenko & Sviridenko, 2014) , about 300 species of algae, mosses, and vascular plants are found in the reservoirs of Northern Kazakhstan.

The presence of a large group of Pleistocene relics in the lakes of Northern Kazakhstan, currently isolated from the main area, can serve as an indicator of the geological age and evidence of a close connection with the Boreal regions of the Holarctic region. Higher charophytes play a significant part in the vegetation of reservoirs. Among vascular plants, *Phragmites australis, Typha angustifolia, T. latyfolia, T. laxmannii, Scirpus lacustris, S. tabernaemontani, Bolboschoenus maritimus, Eleocharis palustris, Carex acuta, C. atherodes, C. omskiana, C. riparia, C. rhynchophysa, C. vesicaria, Equisetum fluviatile, Nymphaea candida, Nuphar lutea, Potamogeton crispus, P. lucens, P. pectinatus, P. perfoliatus, P praelongus, P. pusillus, Myriophyllum spicatum, Urticularia vulgaris, and Ceratophyllum demersum* have the greatest partial activity in Northern Kazakhstan. (RGP "Kazgidromet", 2022; Sabylina et al., 2020). Therefore, the focus of our research is aimed at investigating the issues of water quality in reservoirs adjacent to anthropogenic sites. To do this, it is necessary to study hydrochemical indicators and indicators of water quality in reservoirs (Neverov et al., 2023; Shevchenko et al., 2023), which accumulate effluents formed as a result of exposure to natural precipitation (rain, snow) on the surface of reclaimed uranium-containing industrial waste dumps and anthropogenic sites of reclaimed uranium mines adjacent to the reservoir.

We set a goal to determine the level of water quality and phytocenosis of the shores of the reservoir accumulating the natural effluents from reclaimed uranium mine dumps and anthropogenic sites, as well as indicators of water quality and toxicology. To date, detailed data on the processes of overgrowth of the shores of reservoirs accumulating radioactive effluents have been gathered in a minimum amount. Obtaining such data is important both for understanding the fundamental patterns of such a process and for using it to develop methods for the reclamation of the territory of uranium mines within the framework of existing strategies for reclamation and phytoremediation of anthropogenic landscapes.

During the study, the following tasks were set and detailed:

1) study of the potential impact of agro-climatic parameters and humidity regimes on the formation of vegetation cover;
2) assessment of the values of the level of ionizing radiation on the surface of the water of the reservoir, the shoreline

of the reservoir, and the territories directly adjacent to the reservoir;
3) the study of the main hydrochemical and qualitative indicators of the reservoir, which is a reservoir of effluents formed as a result of the impact of natural precipitation (rain, snow) on the surface of reclaimed uranium-containing industrial waste dumps and anthropogenic sites of reclaimed uranium mines adjacent to the reservoir, as well as the study of the possibility of using the waters of the reservoir in the economy;
4) conducting a study of phytocenoses and species composition of vegetation cover of the shoreline of the reservoir, as well as territories directly adjacent to the reservoir;
5) investigation of the processes of overgrowth of the reservoir shore;
6) identification of plant species that provide the most dynamic overgrowth and form the primary succession.

2. Materials and Methods

2.1. General description of the study objects

The object of the study was a reservoir located on the territory of the reclaimed mine of the Grachevsky uranium deposit (53o 18’45”N, 68o 01’10”E), located in the northern part of the Republic of Kazakhstan (Figure 1). The study of the processes of phytocenosis of the reservoir shore was conducted in 2023.

The studied reservoir of the Grachevsky uranium deposit (53o 18’43”N, 68o 01’18”E) is a reservoir of natural surface runoff from precipitation (rain, snow) from reclaimed dumps and anthropogenic sites of the uranium mine (Figure 2).

Uranium mining at this mine was carried out from 1965 to 1998. Further, the mine was sealed off and underwent measures to eliminate the mining site and reclaim the lands of the mine territory. Therefore, at the first stage of the study, it was necessary to determine the level of radiation safety of the territory (BaigeNews.kz, 2022; Berezhnaya, 2020; Novikov, 2020).

The reservoir has an area of 0.01 km^2 and is adjacent to the eastern part of the reclaimed industrial uranium-containing waste dump with an area of 0.05 km^2, located in the southeastern part of the Grachevsky mine (Figure 3). There are sites around the reservoir that were previously part of the territory of the production complex. The perimeter of the reservoir, including the drying part, is about 0.52 km. The northern part of the reservoir is shallow and dries up in summer (Figure 3).

2.2. Agro-climatic conditions of the deposit

The mine is located in a forest-steppe zone and, by agro-climatic zoning, is located in a moderately humid, moderately warm region of Northern Kazakhstan. The main element of the relief of the region is a plain with isolated hills or groups of hills scattered over its surface.

According to the agro-climatic zoning of the North Kazakhstan region, the deposit is located in a moderately humid moderately warm zone and is characterized by a moisture coefficient K = 1.0-1.2 and a sum of temperatures above 10°C in the range of 2,000-2,300°C. The annual amount of total solar radiation (MQ) ranges from 5,900-6,100 MJ/m2 under clear skies and from 4,100-4,600 MJ/m under average cloudy conditions. In this scenario, about

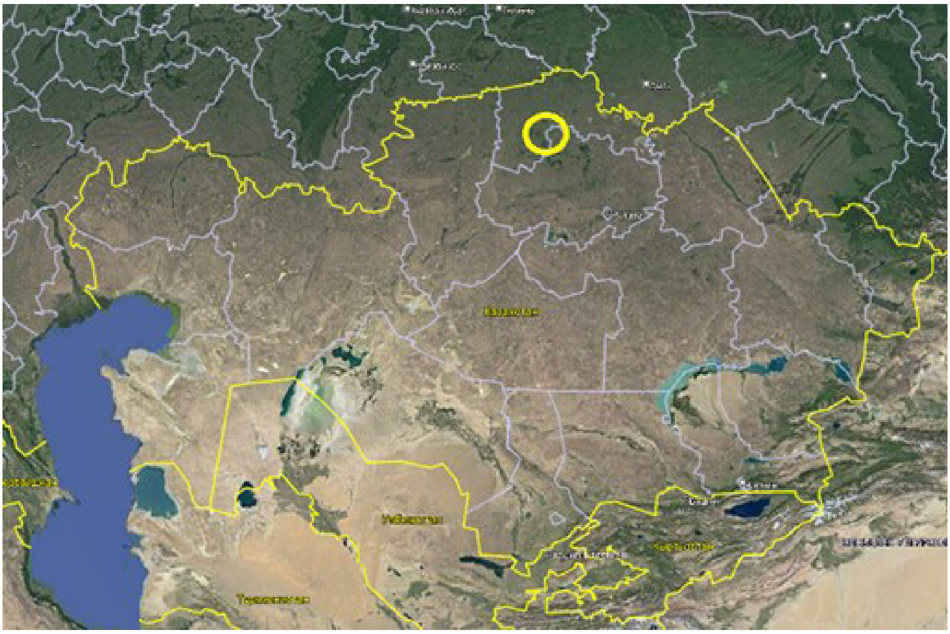

Figure 1. Satellite view of the location of the Grachevsky uranium deposit in Kazakhstan. The Grachevsky deposit is marked with a yellow circle.

Figure 2. General view of the reservoir.

Figure 3. Satellite view of the reservoir and waste dump. The reclaimed waste dump is highlighted with a yellow circle. The reservoir is located in the image to the right of the dump and its borders are also highlighted in yellow.

72% of the possible total radiation reaches the Earth's surface. The sunniest months are May, June, and July when the average sun shines during the day for 9.9-10.6 hours. The solar radiation resources in this region are sufficient for long-day plants and optimal crop life (Baisholanov, 2017).

The climate of the region is continental. The average temperature for July is 19.1°C, and the average for January is -14.9°C. In the region, the climatic spring begins on April 3-6. The duration of the climatic seasons in days is 53 in spring, 90 in summer, and 61 in autumn. The frost-free period in the air lasts 120-130 days. The average air temperatures for May, June, July, August, and September, respectively, are 12.5°C, 18.1°C, 19.1°C, 17.1°C, and 10.9°C. On average, the soil surface warms up to 12°C in the first decade of May, up to 17°C in the third decade, and exceeds 20°C in June. The annual precipitation is 420 mm. The total precipitation for the warm period of the year is 280-300 mm. The region is considered as not arid during the growing season. The annual relative humidity is 72%. The recurrence of drought is 41-60% with a probability of once in 2-3 years (Baisholanov, 2017).

The soils in the area of the deposit are classified as ordinary chernozems. The mechanical composition of the soils corresponds to medium-loamy and light-loamy soils.

2.3. Assessment of the ionizing radiation background

During the research, the level of intensity of ionizing radiation of the gamma background of the water surface of the reservoir, sections of the shoreline, and territories adjacent to the reservoir at a distance of no more than 10 meters from the shore were assessed. The assessment of the level of ionizing radiation was carried out considering the basic requirements of regulatory documents and scientific recommendations (Kazakhstan, 2020). The control of the intensity level of ionizing radiation also ensured the personal safety of the participants of the working team.

When measuring the level of ionizing radiation, a dosimeter of the MKS-AT6130 type was used (manufactured by NP UP ATOMTECH, MNIPI JSC, Republic of Belarus, Minsk). This measuring instrument has been approved as a measuring instrument in Kazakhstan and holds a valid International System of Units (SI system) state verification certificate (Chashkov et al., 2019; Kazakhstan, 2018).

2.4. Assessment of hydrochemical parameters of water in the reservoir

When conducting water quality control of the reservoir, we followed the provisions of the requirements for the unified system of classification of water quality in water bodies of the Republic of Kazakhstan (Mukatova et al., 2021; Rosstandart, 2019).

During the control of water samples, individual most significant indicators were monitored, including control of the reaction of the medium pH, total mineralization, suspended solids, control of the content of metal ions (iron, calcium, magnesium, manganese, lead, zinc, cadmium) and anions (common sulfates, common phosphates, chlorides). Sampling was carried out following the regulatory requirements (Republic of Kazakhstan, 2003a, b). The control of the content of the indicators was carried out according to approved measurement methods designed to control the content of indicators in minimum concentrations, including the control of chemical components in drinking water. During the study, we used standardized laboratory analytical equipment of the appropriate accuracy class, including photocolorimeters, spectrophotometers, measuring burettes, and pH meters.

The reaction of the pH medium was monitored using a standard pH meter according to the instructions. The total mineralization was determined following the recommendations of weight methods for determining the dry residue content of suspended solids by the gravimetric method (Gosstandart of the USSR, 1972e; Rosgidromet, 2020). The permanganate oxidability index was determined by the oxidation of organic and inorganic substances with potassium permanganate in a sulfuric acid medium during heating, followed by the addition of an oxalate ion or oxalic acid solution, followed by titration of its excess with a solution of potassium permanganate (Rosstandart, 2013). The content of calcium and magnesium was determined by the titrometric method (Gosstandart of the USSR, 1978; Rosgidromet, 2018). The maximum permissible concentration (MPC) of calcium and magnesium in natural waters used for fishing according to RD 52.24.470-2014 corresponds to no more than 180 mg/l of calcium and no more than 40 mg/l of magnesium (Rosgidromet, 2014). The total iron concentration was determined by the interaction of iron ions in an alkaline medium with sulfosalicylic acid to form a yellow-colored complex compound followed by spectrophotometry (Gosstandart of the USSR, 1972a). Zinc was determined by a method based on the formation of a red-colored zinc compound with dithizone with further extraction of zinc dithizonate into a layer of carbon tetrachloride (at pH 4.5-4.8) followed by spectrophotometry (Gosstandart of the USSR, 1972f). The determination of lead was carried out by a method based on the formation (at pH 7.0-7.3) of the lead compound with sulfarsazen (plumbo), colored yellow and orange, followed by colorimetry (Gosstandart of the USSR, 1972f). Copper was determined by a method based on the interaction of divalent copper ions with sodium diethyldithiocarbamate in a weak ammonia solution to form copper diethyldithiocarbamate, colored yellow and brown, followed by colorimetry (Gosstandart of the USSR, 1972c). Manganese was determined by a method based on the oxidation of manganese compounds to the MpO4 ion in an acidic medium with ammonium or potassium persulfate in the presence of silver as a catalyst, while pink staining appears (Gosstandart of the USSR, 1972d). The sulfate anion was determined by a method based on the titration of sulfate ions with a solution of barium chloride (Rosstandart, 2012). The chloride anion was determined by a method based on the precipitation of chlorine ion in a neutral or slightly alkaline medium with silver nitrate in the presence of potassium chromate as an indicator (Gosstandart of the USSR, 1972b). The determination of polyphosphates was carried out by a method based on the hydrolysis of polyphosphates converting to orthophosphates, with the formation of a blue-colored phosphorous-molybdenum complex, and subsequent photometric determination of the resulting colored compound (Rosstandart, 2014a). The determination of nitrates was carried out by a method based on photometric determination of the nitrate content using sodium salicylate (Rosstandart, 2014b).

The analysis of the obtained hydrochemical parameters of the reservoir was carried out considering scientific studies of reservoirs in Northern Kazakhstan carried out by various groups of researchers (RGP "Kazgidromet"; Sabylina et al., 2020).

2.5. Botanical description

For this work, standard geobotanical descriptions were carried out according to accepted methods on an area of 100 m^2. The general and particular projective coverage of each type was determined. The practical recommendations on the organization and conduct of botanical studies of reclaimed territories and uranium-containing waste dumps/tailings were considered. They are described in detail in the guidelines published by the International Atomic Energy Agency (IAEA) in 2019 (Barnekow et al., 2019).

The studies were carried out in the supralithoral area (the hygrophyte area) (CP-1), on the coastal part (mesophyte area) (CP-2), in the upper part of the slope (meso-xerophyte area) (CP-3) and an anthropogenically modified dry meadow (CP-4). The stages of syngenesis were determined according to Shennikov.

The aquatic vegetation of Northern Kazakhstan has been studied by several researchers, including L.A. Demchenko, V.M. Katanskaya, B.F. Sviridenko, S.A. Nikolaenko, O.E. Tokar, and V.P. Lezin (Bugubaeva et al., 2023). According to B.F. Sviridenko, about 300 species of algae, mosses, and vascular plants are found in the reservoirs of Northern Kazakhstan.

The presence of a large group of Pleistocene relics in the lakes of Northern Kazakhstan, currently isolated from the main area, can serve as an indicator of the geological age and evidence of a close connection with the Boreal regions of the Holarctic region. Higher charophytes play a significant part in the vegetation of reservoirs.

When conducting research, one needs to keep in mind that among vascular plants, *Phragmites australis*, *Typha angustifolia*, *T. latyfolia*, *T. laxmannii*, *Scirpus lacustris*, *S. tabernaemontani*, *Bolboschoenus maritimus*, *Eleocharis palustris*, *Carex acuta*, *C. atherodes*, *C. omskiana*, *C. riparia*, *C. rhynchophysa*, *C. vesicaria*, *Equisetum fluviatile*, *Nymphaea candida*, *Nuphar lutea*, *Potamogeton crispus*, *P. lucens*, *P. pectinatus*, *P. perfoliatus*, *P praelongus*, *P. pusillus*, *Myriophyllum spicatum*, *Urticularia vulgaris*, and *Ceratophyllum demersum* have the greatest partial activity in Northern Kazakhstan (Bugubaeva et al., 2023).

2.6. Statistical processing of measurement results

Statistical processing of measurement results was carried out following scientific recommendations, standardized measurement methods, and regulatory documents, including methods of processing results (Mamikhin and Shcheglov, 2020). The main methods used were variance, correlation, and regression analyses of the data. GOST R 8.736-2011 is quite universal when measuring the level of ionizing radiation and indicators of physico-chemical control and it establishes the main provisions of methods for processing the results of these measurements and calculating errors in estimating the measured value. According to the results of statistical processing, the result was displayed as an estimate of the measured value (the arithmetic mean of the corrected measurement results) and the average square deviation of the group containing n measurement results. As the main software tool for statistical processing of measurement results, we used standard Microsoft Office Excel packages of the 2016 version, including Data Analysis and Statistical Functions.

3. Results

3.1. Assessment of the ionizing radiation background

The obtained results do not exceed the maximum permissible values established by regulatory requirements (Table 1). The average intensity of the background ionizing radiation was 20-40 µgSv/hour, which corresponds to the regulatory requirements for environmental safety. The distribution of values of the intensity level of residual ionizing radiation is uniform. There were no deviations from the maximum permissible values, which corresponds to the regulatory requirements for environmental safety. This level of ionizing radiation has practically no effect on the formation of phytocenoses.

3.2. Results of the assessment of the hydrochemical parameters of the waters of the reservoir

During laboratory control of reservoir water samples, the obtained values of quality and toxicology indicators complied with sanitary and toxicological requirements (Table 2).

Using the classification of waters by the amount of mineralization and by the amount of ions contained in the water, this reservoir can be classified as freshwater. The content of heavy metals, including lead and copper, is within the MPC. The permanganate oxidizability is low, which indicates a low content of organic substances. The ratio of calcium and magnesium is close to 3:1.

According to the unified classification system for water quality in water bodies, by the results of these measurements, this reservoir can be assigned to the second quality class. The water of this class is suitable for all categories of water use, except household and drinking purposes. Simple water treatment methods are required for use for household and drinking purposes. It can be concluded that a high level of natural purification of the reservoir waters occurred within twenty years after the reclamation of the uranium mine.

3.3. Assessment of the species composition and projective coverage of the shores of the reservoir and adjacent areas of the Grachevsky mine

The studied areas differed significantly in their overall projective coverage (OPC) (Figure 4). It was the smallest in the supralithoral area (CP-1), and the largest in the coastal part (CP-2).

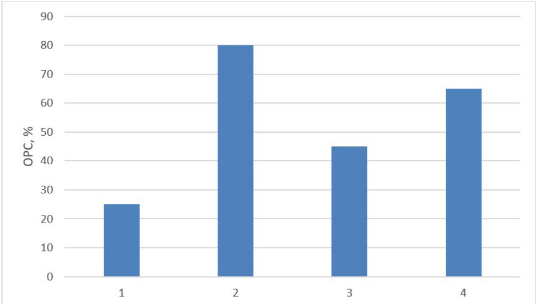

Figure 4. OPC in the studied ecotopes, %.

Table 1. Values of the intensity of ionizing radiation, µSv/hour.

No.	Place of control measurement	Number of measurements	Average	Standard deviation
1	Water surface	10	0.22	0.04
2	Shoreline	20	0.29	0.05
3	Surrounding area up to 10 meters	30	0.35	0.06

The territory adjacent to the reservoir is characterized by a steppe type of vegetation, meadow saxifrage and feather grass steppes are common here (with a predominance of Silaum silaem species (meadow saxifrage, Umbelliferae family) and Stipa zalesskii (Zalessky's feather grass, Gramineae family)).

In total, 49 plant species were identified during the research, which belonged to 18 families (Table 3). It should

Table 2. Hydrochemical parameters of the reservoir

No.	Control indicator	Units of measurement	Value of the indicator	Standards (MPC), no more than	
1	pH	pH units	7.2	6.5-8.5	1
2	Total mineralization (dry residue)	mg/l	410	1,000 (1,500)	1
3	Permanganate oxidizability	mg/l	2.8	5.0	
4	Calcium	mg/l	12.4	150	1
5	Magnesium	mg/l	4.1	40	1
6	Iron (total)	mg/l	<0.1	0.3 (1.0)	1
7	Zinc	mg/l	0.4	5.0	2
8	Copper (total)	µg/l	0.05	1.0	1
9	Manganese (total)	mg/l	0.05	0.1 (0.5)	2
10	Lead (total)	mg/l	<0.001	0.03	1
11	Sulfates	mg/l	290	500	2
12	Chlorides	mg/l	31	350	1
13	Phosphates, total content	mg/l	0.26	3.5	2
14	Nitrates	mg/l	0.04	45	1

Notes: mg/l is milligrams per liter; MPC is the maximum permissible concentration.

Table 3. Representation of species of the identified families in the studied areas (number of species).

Family	Number of species representing the family				
	CP-1	CP-2	CP-3	CP-4	Total
Asteraceae	3	6	5	8	15
Amaranthaceae	1	0	0	0	1
Leguminosae	1	2	5	7	10
Boraginaceae	0	0	1	0	1
Caryophyllaceae	0	0	0	1	1
Gentianaceae	0	0	1	1	1
Polygonaceae	2	1	1	1	4
Lythraceae	1	1	0	0	1
Gramineae	2	2	1	2	4
Umbelliferae	0	0	1	1	1
Salicaceae	0	1	0	0	1
Brassicaceae	0	0	0	1	1
Ranunculaceae	2	0	0	0	2
Euphorbiaceae	0	0	1	1	1
Typhaceae	1	1	0	0	1
Juncaceae	1	1	0	0	2
Asparagoideae	0	0	0	1	1
Alismataceae	1	0	0	0	1
Number of species (total)	14	15	17	24	49

be noted that the largest number of identified species belonged to the *Asteraceae*, *Leguminosae*, *Polygonaceae*, and *Gramineae* families (Tables 3 and 4).

Tables 5-7 present the species composition of the studied phytocenoses, the dominant species of the studied areas, as well as the representation of the studied species in the studied areas.

4. Discussion

An analysis of the previous work shows that the processes of formation of phytocenoses in the areas where mining enterprises used to be located depend on the climate of a particular area and on the characteristics of the deposit itself. In our study, the indicators of moisture supply, humidity, and precipitation of the Grachevsky mine are favorable for the formation of vegetation cover. The conducted assessment of the background of ionizing radiation revealed no deviations from the maximum permissible values. This meets the regulatory requirements for environmental safety (Yernazarova et al., 2023). This level of ionizing radiation has practically no effect on the formation of phytocenoses.

The results of the assessment of the hydrochemical parameters of the water in the reservoir show that,

Table 4. The representation of the identified families in the studied areas.

Representation of families in the areas	CP-1	CP-2	CP-3	CP-4
Asteraceae	+	+	+	+
Amaranthaceae	+	-	-	-
Leguminosae	+	+	+	+
Boraginaceae	-	-	+	-
Caryophyllaceae	-	-	-	+
Gentianaceae	-	-	+	+
Polygonaceae	+	+	+	+
Lythraceae	+	+	-	-
Gramineae	+	+	+	+
Umbelliferae	-	-	+	+
Salicaceae	-	+	-	-
Brassicaceae	-	-	-	+
Ranunculaceae	+	-	-	-
Euphorbiaceae	-	-	+	+
Typhaceae	+	+	-	-
Juncaceae	+	+	-	-
Asparagoideae	-	-	-	+
Alismataceae	+	-	-	-

Note. "+" means that the family is represented in the phytocenosis of the studied area; "-" means that the family is not represented in the phytocenosis of the studied area.

Table 5. General characteristics of the floral composition of the reservoir shore.

Cenopopulation	Ecotope	Dominants	Number of species
CP-1	Supralithoral area (hygrophyte area):	*Agrostis gigantea, Alisma gramineum, Chenopodium rubrum, Puccinellia distans, Taraxacum officinale*	14
CP-2	Coastal part (mesophyte area)	*Calamagrostis epigeios, Tussilago farfara, Typha angustifolia*	15
CP-3	The upper part of the slope (meso-xerophyte area)	*Artemisia absinthium, Calamagrostis epigeios, Euphorbia uralensis*	17
CP-4	Above-floodplain terrace (anthropogenic-modified dry meadow)	*Calamagrostis epigeios, Festuca valesiaca, Lathyrus tuberosus, Medicago falcata*	24

Table 6. Projective coverage (%) of the shores of the reservoir formed by the species from cenopopulations.

Family	Species name	CP-1	CP-2	CP-3	CP-4
Asteraceae	*Achillea kasakstanica* Kupr. et Kulemin	-	-	-	+
	Achillea nobilis L.	-	-	-	+
	Artemisia absinthium L.	-	-	5	+
	Artemisia dracunculus L.	-	-	-	+
	Bidens tripartita L.	-	+	-	-
	Centaurea scabiosa L.	-	-	+	+
	Cichorium intybus L.	-	-	+	-
	Cirsium setosum (Willd.) Besser	-	+	-	-
	Conyza canadensis (L.) Cronquist.	-	+	-	-
	Erigeron acris L.	-	-	-	+
	Lactuca serriola L.	-	+	-	-
	Picris hieracioides L.	-	-	-	+
	Taraxacum officinale F.H.Wigg.	5	-	+	3
	Tephroseris palustris (L.) Reichenb.	+	3	-	-
	Tussilago farfara L.	+	10	+	-
Amaranthaceae	*Chenopodium rubrum* L.	5	-	-	-
Leguminosae	*Astragalus onobrychis* L.	-	-	+	-
	Astragalus sulcatus L.	-	-	-	+
	Lathyrus pratensis L.	-	+	+	5
	Lathyrus tuberosus L.	-	-	+	3
	Lupinaster pentaphyllus Moench	-	-	-	+
	Medicago falcata L.	-	-	+	3
	Medicago lupulina L.	+	+	-	-
	Onobrychis arenaria (Kit.) DC.	-	-	-	+
	Oxytropis pilosa (L.) DC.	-	-	-	+
	Vicia tenuifolia Roth	-	-	+	-
Boraginaceae	*Lappula microcarpa* (Ledeb.) Guerke	-	-	+	-
Caryophyllaceae	*Gypsophila altissima* L.	-	-	-	+
Gentianaceae	*Gentiana macrophylla* Pall.	-	-	+	3
Polygonaceae	*Persicaria hydropiper* (L.) Spach	+	-	-	-
	Polygonum aviculare L.	-	-	+	-
	Polygonum gracilius (Ledeb.) Klok.	+	-	-	+
	Rumex stenophyllus Ledeb.	-	+	-	-
Lythraceae	*Lythrum salicaria* L.	+	+	-	-
Gramineae	*Agrostis gigantea* Roth	5	3	-	-
	Calamagrostis epigeios (L.) Roth	-	10	30	30
	Festuca valesiaca Gaudin	-	-	-	10
	Puccinellia distans (Jacq.) Parl.	5	-	-	-
Umbelliferae	*Seseli libanotis* (L.) W. D. J. Koch.	-	-	+	3
Salicaceae	*Salix triandra* L.	-	+	-	-
Brassicaceae	*Erysimum cheiranthoides* L.	-	-	-	+
Ranunculaceae	*Batrachium circinatum* (Sibth.) Spach +	+	-	-	-
	Ranunculus sceleratus L.	+	-	-	-
Euphorbiaceae	*Euphorbia uralensis* Fisch. ex Link.	-	-	5	+
Typhaceae	*Typha laxmannii* Lepech.	+	50	-	-
Juncaceae	*Juncus gerardii* Loisel.	-	+	-	-
	Juncus nastanthus V.I.Krecz. & Gontsch.	+	-	-	-
Asparagoideae	*Asparagus officinalis* L.	-	-	-	+
Alismataceae	*Alisma gramineum* Lej.	5	-	-	-

Note: 1) the numeric value indicates the percentage of OPC for a species; 2); "+" means the single presence of the species in the cenopopulation; 3) "-" (an empty cell) means the absence of the species in the cenopopulation.

Table 7. Projective coverage (%) of the shores of the reservoir formed by the species from cenopopulations.

Family	Species name	CP-1	CP-2	CP-3	CP-4	Representation in the studied ecotopes, number	Dominance in ecotopes
Asteraceae	*Achillea kasakstanica* Kupr. et Kulemin				+	1	-
	Achillea nobilis L.				+	1	-
	Artemisia absinthium L.			5	+	2	CP-3
	Artemisia dracunculus L.				+	1	-
	Bidens tripartita L.		+			1	-
	Centaurea scabiosa L.			+	+	2	-
	Cichorium intybus L.			+		1	-
	Cirsium setosum (Willd.) Besser		+			1	-
	Conyza canadensis (L.) Cronquist.		+			1	-
	Erigeron acris L.				+	1	-
	Lactuca serriola L.		+			1	-
	Picris hieracioides L.				+	1	-
	Taraxacum officinale F.H.Wigg.	5		+	3	3	CP-1, CP-4
	Tephroseris palustris (L.) Reichenb.	+	3			2	CP-2
	Tussilago farfara L.	+	10	+		3	CP-2
Amaranthaceae	*Chenopodium rubrum* L.	5				1	CP-1
Leguminosae	*Astragalus onobrychis* L.			+		1	-
	Astragalus sulcatus L.				+	1	-
	Lathyrus pratensis L.		+	+	5	3	CP-4
	Lathyrus tuberosus L.			+	3	2	CP-4
	Lupinaster pentaphyllus Moench				+	1	-
	Medicago falcata L.			+	3	2	CP-4
	Medicago lupulina L.	+	+			2	-
	Onobrychis arenaria (Kit.) DC.				+	1	-
	Oxytropis pilosa (L.) DC.				+	1	-
	Vicia tenuifolia Roth			+		1	-
Boraginaceae	*Lappula microcarpa* (Ledeb.) Guerke			+		1	-
Caryophyllaceae	*Gypsophila altissima* L.				+	1	-
Gentianaceae	*Gentiana macrophylla* Pall.			+	3	2	CP-4
Polygonaceae	*Persicaria hydropiper* (L.) Spach	+				1	-
	Polygonum aviculare L.			+		1	-
	Polygonum gracilius (Ledeb.) Klok.	+			+	2	-
	Rumex stenophyllus Ledeb.		+			1	-
Lythraceae	*Lythrum salicaria* L.	+	+			2	-
Gramineae	*Agrostis gigantea* Roth	5	3			2	CP-1, CP-2
	Calamagrostis epigeios (L.) Roth		10	30	30	3	CP-2, CP-3, CP-4
	Festuca valesiaca Gaudin				10	1	CP-4
	Puccinellia distans (Jacq.) Parl.	5				1	CP-1
Umbelliferae	*Seseli libanotis* (L.) W. D. J. Koch.			+	3	2	CP-4
Salicaceae	*Salix triandra* L.		+			1	-
Brassicaceae	*Erysimum cheiranthoides* L.				+	1	-
Ranunculaceae	*Batrachium circinatum* (Sibth.) Spach +	+				1	-
	Ranunculus sceleratus L.	+				1	-
Euphorbiaceae	*Euphorbia uralensis* Fisch. ex Link.			5	+	2	CP-3
Typhaceae	*Typha laxmannii* Lepech.	+	50			2	CP-2
Juncaceae	*Juncus gerardii* Loisel.		+			1	-
	Juncus nastanthus V.I.Krecz. & Gontsch.	+				1	-
Asparagoideae	*Asparagus officinalis* L.				+	1	-
Alismataceae	*Alisma gramineum* Lej.	5				1	CP-1

Note: 1) the numeric value indicates the percentage of OPC for a species; 2); "+" means the single presence of the species in the cenopopulation; 3) "-" (an empty cell) means the absence of the species in the cenopopulation.

according to the unified classification system of water quality in water bodies, the reservoir can be attributed to the second quality class. The water of this class is suitable for all categories of water use, except household and drinking purposes. Simple water treatment methods are required for use for household and drinking purposes (Osintseva and Ishutin, 2023). It can be concluded that a high level of natural purification of the reservoir waters occurred within 20 years after the reclamation of the uranium mine.

According to the results of the study, we propose to differentiate the species composition of the vegetation cover and the degree of projective coverage by the humidity regime. In the hygrophyte area (supralittoral area resulting from the drying of the reservoir) (CP-1), 14 species were noted, most of them, like *Agrostis gigantea, Alisma gramineum, Puccinellia distans, Lythrum salicaria, Juncus nastanthus*, are species more characteristic of the coastline of freshwater lakes than for the overgrowth of dump shoreline. However, ruderal species such as *Chenopodium rubrum, Taraxacum officinale, and Tussilago farfara* are also noted here. The projective coverage is 25%. A pioneer community is formed with a predominance of single or juvenile plant species, characteristic of many freshwater reservoirs, and named a floodplain ephemeretum by G.S. Taran.

Above the water cutoff in the mesophyte area (CP-2), the maximum projective coverage was noted (80%), which is associated with good soil moisture. The undisputed dominants are three species: *Calamagrostis epigeios, Tussilago farfara,* and *Typha laxmannii*, whose projective coverage in total equals 70% of 80% of the OPC. The finding of species of the genus *Typha* L. is quite typical for the coastal area, but this species is rare in northern Kazakhstan (Sultangazina et al., 2020). The basis of the herbage is made up of perennial long-rhizomatous plants, which is typical for the group-thicket community of overgrowth of dumps.

On the upper part of the slope, the meso-xerophyte area (CP-3) forms a community in which *Calamagrostis epigeios* is dominant, forming significant spots with a projective coverage of 30%. Many weed species are also noted here, like *Artemisia absinthium, Centaurea scabiosa, Cichorium intybus*, *Taraxacum officinale,* and *Lappula microcarpa.* There are rare characteristic species for the dry meadows of central and Northern Kazakhstan, such as *Astragalus onobrychis, Lathyrus pratensis, Medicago falcata,* and *Vicia tenuifolia*, which is typical for a complex diffuse community.

The anthropogenically modified dry meadow (CP-4) was formed on the site of the former bunchgrass steppe. It should be noted that *Festuca valesiaca* (10%) and steppe grasses have a large abundance, represented by *Lathyrus tuberosus, Medicago falcata, Oxytropis pilosa, Astragalus sulcatus*, and other species characteristic of the meadow steppes of the steppe and forest-steppe zone of Kazakhstan (Sultangazina et al., 2020). Ruderal species are also numerous, like *Artemisia absinthium, Centaurea scabiosa, Taraxacum officinale, Erigeron acris*, etc.

Most species were identified in only one cenopopulation, whereas the species *Taraxacum officinale*, *Tussilago farfara*, *Lathyrus pratensis,* and *Calamagrostis epigeios* were represented in three cenopopulations at once. *Calamagrostis epigeios* (bush grass) dominated three cenopopulations at once (CP 2-3).

Interpreting the results obtained, we have come to the conclusion that the shore of the studied reservoir, in general, is a favorable ecotope for plant settlement and plant development, and the observed pattern can serve as an illustration of the most likely type of overgrowth of the shoreline territories of reservoirs located in the territories of uranium mines and forming a water volume due to moisture of natural origin (precipitation, etc.) at low levels of background radiation (Yesmagulova et al., 2023). The study of the processes of overgrowth of the reservoir shore fits into the classical scheme of syngenesis, which includes the processes of formation of a pioneer community (floodplain ephemeretum) along the drying shore, a group-thicket community on the lake shore, a diffuse community on the slope and an anthropogenically modified dry meadow on the floodplain terrace with the participation of plants typical of the steppe zone.

5. Conclusions

The studied reservoir is a natural reservoir of effluents formed as a result of exposure to precipitation of natural origin (rain, snow) and groundwater discharge to the surface of reclaimed industrial waste dumps and anthropogenic sites of the former uranium mine of the Grachevsky deposit adjacent to the reservoir. The results of this work show that after the conservation of a uranium mine, phytocenoses typical of the mine location region can form on its territory, which allows us to consider the autochthonous flora as a source of species promising for planning measures for phytoremediation and reclamation of uranium ore dumps and overburden rocks. The obtained research results make it possible to identify the dominant plant species, which can serve as a basis for further research, namely, to determine the phytoremediation potential of the species of the studied phytocenosis, to determine the possibility of accelerating the processes of self-growth, as well as for their use in the formation of artificially introduced populations.

The study of the territories of mines in a state of conservation will contribute to further deepening the understanding of the process of formation of phytocenoses in territories that were adversely affected by uranium mining.

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