International Journal of Agriculture and Biosciences 2025 14(2): 289-300.
https://doi.org/10.47278/journal.ijab/2025.007

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Granulometric and Chemical Composition of Bottom Sediments in North Kazakhstan's Water Reservoirs: Implications for Soil and Water Management

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ABSTRACT

Bottom sediments play a crucial role in the environmental and agricultural management of freshwater reservoirs, acting as repositories for organic matter, chemical elements, and potential pollutants. This study investigates the chemical and granulometric composition of bottom sediments in the Verkhnetobolskoe and Karatomarskoe reservoirs in North Kazakhstan, focusing on the relationships between sediment particle sizes, organic matter, and heavy metal content. Sediment and water samples were collected during winter under ice-covered conditions using specialized sampling equipment and analyzed with advanced spectrometric and analytical methods. The study reveals significant correlations between fine-grained sediment fractions (<0.16mm) and the accumulation of organic matter and heavy metals, including cobalt, arsenic, and chromium, which exceeded permissible concentration limits. These findings underscore the ecological importance of fine sediment fractions as adsorptive sites for pollutants. The study concludes with methodological recommendations for sediment quality assessment and provides baseline data for environmental monitoring and agricultural planning in temperate freshwater ecosystems.

Keywords: Bottom sediments; Clay soils; Granulometric composition; Organic matter content; Heavy element

Article History
Article # 24-1033
Received: 10-Dec-24
Revised: 24-Dec-24
Accepted: 28-Dec-24
Online First: 15-Jan-25

INTRODUCTION

Organizing and assessing the safety indicators of water bodies are important and strategic tasks from an environmental and economic point of view. According to the normative definition, bottom sediments are deposits and solid particles formed and deposited on the bottom of a water body due to in-water physicochemical and biochemical processes occurring with substances of natural and technical origin (Ismukhanova et al., 2022). According to the guidelines for Monitoring and Assessment of Transboundary Rivers of the Working Group of the United Nations Economic Commission for Europe on Monitoring and Assessment under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, it is recommended to monitor and assess the quality of sediments (deposits) if contaminated sediments may harm human health and worsen the sanitary state of the environment (Voigt et al., 2017). Granulometry refers to analyzing the distribution, composition, and texture of particles/granules in different sedimentary environments based on their size ranges (Kanbetov et al., 2024).

Bottom sediments are unique objects of interphase interaction and accumulation of toxic and beneficial substances. They are the product of heterogeneous phase and chemical equilibrium and have been formed for decades. This ensures the formation of a unique physicochemical composition and indicators different from the bottom relief's waters and adjacent solid mineral rocks (Tomilina et al., 2018a; Bugubaeva et al., 2022, 2023a, 2023b). From an ecological point of view, the study of bottom sediments helps to analyze the accumulation of

Cite this Article as: Yskak A, Chashkov V, Nugmanov A, Joldassov A, Paramonova T, Kurmangaliyeva D and Nurseitova A, 2025. Granulometric and chemical composition of bottom sediments in North Kazakhstan's water reservoirs: implications for soil and water management. International Journal of Agriculture and Biosciences 14(2): 289-300. https://doi.org/10.47278/journal.ijab/2025.007

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radio nuclides, heavy metals and elements and the formation of qualitative indicators. Bottom sediments are powerful adsorbents of chemical elements and substances. The bottom sediments and reservoir waters are phases of different aggregate states and have different physicochemical properties. Reservoir waters are solutions with a multicomponent chemical composition directly affecting the reservoir bottom sediments. Water is a natural carrier and transporter of many chemicals and particles of sedimentary rocks. Water and bottom sediment influence each other and physicochemical parameters (Yanin, 2019). Over the years, research into the granulometric and chemical composition of bottom sediments in various aquatic ecosystems has gained significant momentum, driven by the pressing need for sustainable soil and water management strategies. These studies have focused on highlighting the interactions between sediment composition, pollution, and ecological impacts. This body of research highlights the role of bottom sediments as both reservoirs of environmental contaminants and indicators of ecosystem health (Ismukhanova et al., 2022). Recent studies (Yakovlev et al., 2021; Castro et al., 2021) have shown the relationship between bottom sediments and the long-term effects of anthropogenic activities. (Castro et al., 2021) in their study on an urban river detected the presence of heavy metals in the studies of sediment clusters. The study by (Yakovlev et al., 2021) showed the presence of radionuclides in the Pechora River estuary when studying regions associated with oil and gas activities. These studies support the need for granulometric analysis in predicting contaminant behaviors. Similarly, (Expósito et al., 2021; Lifshits et al., 2021) provided valuable insights into the chemical composition of bottom sediments. Their study revealed that the majority of the sediment composition consisted of industrial waste, microplastics, effluent discharges, hydrocarbons from oil and gas regions, and fibers. These findings highlight the risk of ecotoxicity, accumulation of heavy metals, pollution, and subsequent changes. in the microflora.

Another study by Zhang et al. (2022) showed the correlation between rapid urbanization and the presence of organic pollutants in bottom sediments. The authors noted that there was a strong correlation between the studied sediment parameters, such as heavy metals, and urbanization. Factors such as industry runoffs and domestic wastewater were major sources of contamination, while other non-point sources like solid waste and natural sources still showed signs of contamination (Kibria et al., 2021) showed the influence of climatic change on pollutant mobilization, ecotoxicity, and bioaccumulation. In their study, they showed that an increase in temperature and extreme events may enhance the release, degradation, transportation, and mobilization of both hydrophobic and hydrophilic pollutants in the estuarine and marine environments. Nawrot et al. (2021) and Vermeiren et al. (2021) showed the relationship between grain size in sediments and bioaccumulation (Nawrot et al., 2021) showed that potentially toxic elements such as metalloids and non-metals entering the aquatic ecosystem were associated with fine- grained fractions of suspended solids and sediments due to their large surface areas and high sorption capacities.

In Kazakhstan, preliminary studies have been carried out to shed some light on the unique characteristics of bottom sediments. Mameshova & Asanov, (2023) conducted a study on clay sediments in the southern region, taking into consideration its volume, optical density, and filtration process. The differences in the sediments were attributed to their chemical compositions and particle sizes. Nokhrin et al. (2024) conducted a study on the bottom sediments of the Shershnevskoye reservoir in the city of Chelyabinsk. From their study, they discovered that all the tested bottom sediment samples displayed chronic toxicity, and two samples displayed acute toxicity due to the release of toxic products from the mineralization of organic matter. These findings align with global trends, reinforcing the critical role of bottom sediments as indicators of ecological health and repositories of environmental contaminants. As reservoirs of both toxic and beneficial substances, sediments serve as valuable archives for understanding historical and ongoing processes within aquatic ecosystems.

We set the tasks of searching for connections and correlations between the chemical and granulometric composition and the organic matter content in bottom sediments. The study and analysis of all control parameters allow for finding correlations between indicators and deepening the understanding of these processes (Mamikhin et al., 2023; Paramonova et al., 2023; Bugubaeva et al., 2024; Chashkov et al., 2024). Looking ahead, interdisciplinary approaches that integrate sedimentology, chemistry, and environmental science will be essential for advancing our understanding of sediment processes and by leveraging cutting-edge technologies and fostering international collaboration, researchers can develop more effective strategies for sediment management and pollution mitigation. Thus, the goal of the study is to analyze the chemical and granulometric composition of bottom sediments in the Verkhnetobolskoe and Karatomarskoe reservoirs in North Kazakhstan. This study presents a novel approach to winter sampling and comprehensive analysis of bottom sediments in reservoirs under ice-covered conditions in North Kazakhstan. It highlights the strong correlations between granulometric fractions, organic matter content, and chemical composition, offering new insights into the environmental and agricultural implications of sediment composition in temperate freshwater systems. The findings provide valuable reference data and methodological advancements for sediment monitoring in similar climatic regions

MATERIALS & METHODS

Two water bodies of the Kostanay region in the North region of Kazakhstan were selected as an object of comprehensive monitoring of sediment indicators (Fig. 1): the Verkhnetobolskoye (52°30'40"N 62°15'00" E) and Karatomarskoye reservoirs (52°53'40"N 63°01'45" E). The study was conducted in February and March of 2024.

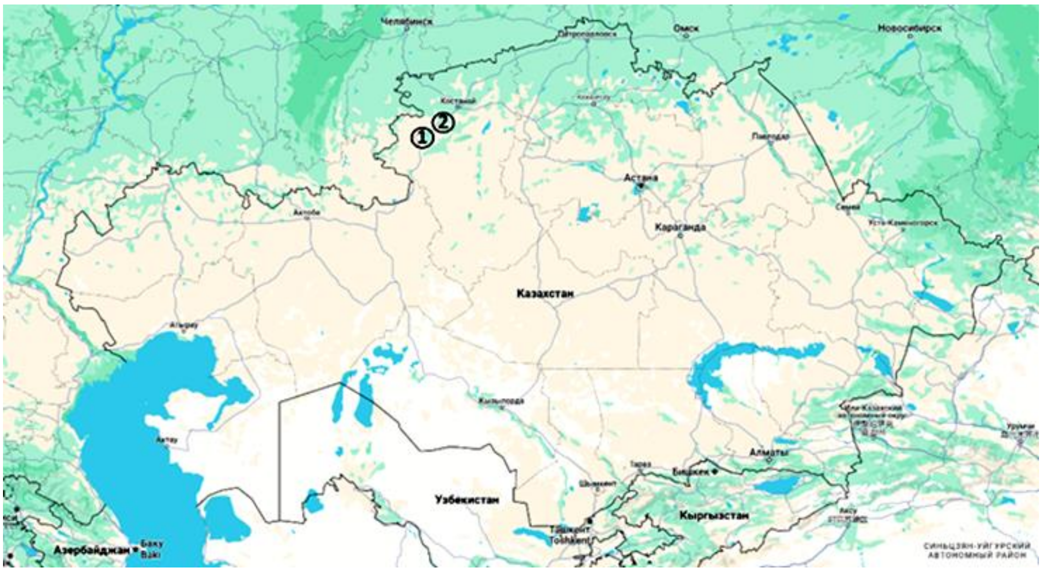


Fig. 1: The Verkhnetobolskoye reservoir is marked on the map of Kazakhstan with a black circle with the number 1. The Karatomarskoe reservoir is marked on the map of Kazakhstan with a black circle with the number 2

The February/March season in this region is characterized by high and stable snow cover. The average air temperature during sampling ranged from -3 to -10°C. The weather was clear and sunny. The average thickness of the reservoir ice at the sampling sites was approximately 1 m. When organizing sampling, sites in the coastal part of reservoirs were selected considering the distribution of bottom sediments and their movement patterns. The most important informative areas concerning physicochemical parameters are those where there is no flushing of the bottom sediments.

The selection was guided by the requirements for the point type of samples and periodic sampling to assess the quality of samples against the standards for the content of indicators in water. Using a composite sample makes the differences between individual samples unclear. The sediment and water sampling points at reservoir sites are indicated in Fig. 2 and 3. Sediment and water sampling were conducted from the same points. The distances between the sampling points averaged between 1 and 6km.

The following sediment control indicators were selected during a comprehensive assessment of the reservoirs:

1) the metal and toxic compound content;
2) the organic matter content;
3) grain sizes and granulometric composition of bottom sediments;
4) total phosphorus.

To drill ice and prepare holes for sediment sampling, a special drill with a gasoline engine of the required power was used. The drill was 0.2m in diameter and 1 m long. When sampling sediments in the coastal zone at a depth of up to 1.5m, special tubular sediment grabs on a rod were used. The sediment grabs are made of stainless steel and equipped with special blades. This allows the selection of solid bottom sediments. The selected samples were stored in containers that did not affect the primary physicochemical properties of the samples and ensured compliance with the determined indicators. Regulatory recommendations included methods of sample preservation depending on the indicator. To store the deposition material, we used 3L plastic containers for food products. Sampling equipment included drills for preparing holes in the ice, sediment grab samplers made of stainless steel and equipped with special blades, ladles, a meter rod, and plastic containers for storing food products with sealed lids. All samples were sent to the laboratory for storage and subsequent studies. When measuring the values of the indicators, high-class analytical equipment was used, including the ContrAA 800g atomic absorption spectroanalyzer (Germany), the SF-56 UV spectrophotometer (Russia), the UV-1900i Shimadzu two-beam spectrophotometer (Japan), and ATX224R Shimadzu laboratory analytical scales (Japan), etc. All measuring instruments and analytical equipment were calibrated using standard samples of the properties and composition of materials with a known content of chemical components, including standard samples with a given concentration of elements and intended for spectral analysis methods in aqueous solutions. This ensured the accuracy of measurements following regulatory documents. When assessing compliance with maximum permissible concentration (MPC), it is preferable to focus on the shapes of elements in a bound state, the so-called total forms. When evaluating the content of elements, it is convenient to use the concept of Clarke. The Clarke or the Clarke number expresses the average content of chemical elements in the Earth's crust, water bodies, and soils in urban areas compared to the total mass of this system. However, different researchers give different Clarke values for content objects.

When assessing the content of organic matter, plant residues are removed from sediment samples. The analyzed soil samples in an air-dry state are placed in pre-weighted porcelain crucibles so that the sample occupies no more than 2/3 of the crucible volume. They are weighed with an error of no more than 0.001g, placed in a cold drying cabinet, and heated to 105°C. The samples are dried to a constant mass. The weight of the air-dry soil sample should be at least 50g. Next, the samples are annealed in a muffle furnace at (525±25)°C, cooled in a calcium chloride desiccator, and weighed with an error of no more than 0.001g. The samples are annealed again and

Fig. 2: Sampling points at the Verkhnetobolskoe reservoir sites.

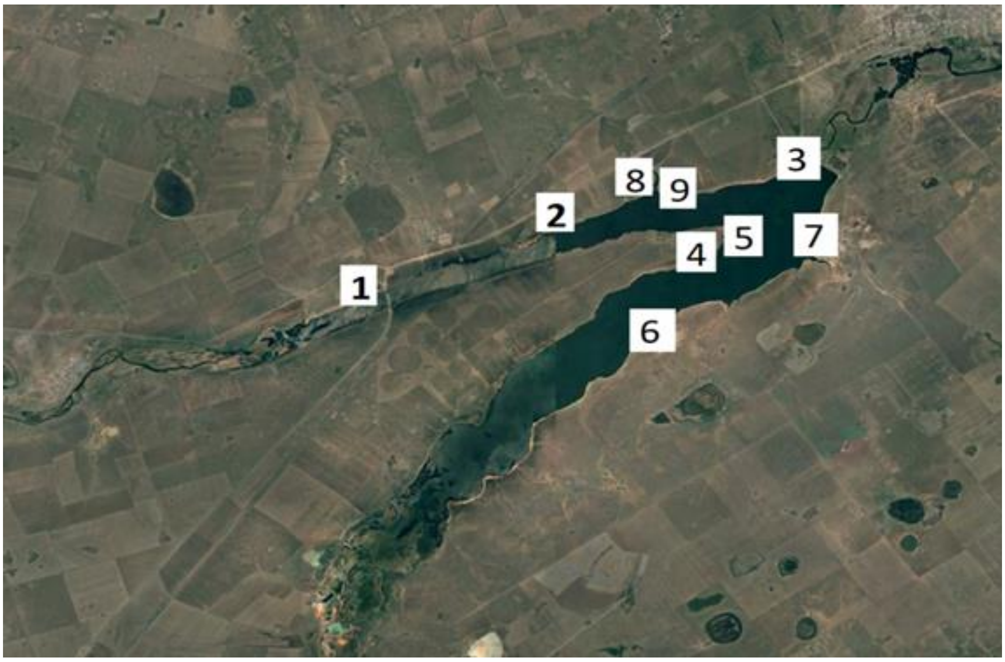


Fig. 3: Sampling points at the Karatomarskoe reservoir sites.

weighed until a constant weight is established. After cooling and weighing, the change in the weight of the ash residue is estimated. If the weight change is less than 0.005g, then the analysis is completed, and the lowest weight value is taken. When the weight changes by 0.005g or more, crucibles with ash residue are annealed additionally. Annealing is completed if the difference in weight during two consecutive weighings is less than 0.005g. The relative organic matter (humus) content in soil (W), as a percentage, is calculated using the formula:

$$W = (m-m1)x100/m \quad (1)$$

where W is the relative organic matter content, %;
m is the weight of dry soil, g;
m1 is the weight of the soil after annealing, g.
We used laboratory heating equipment, including an electric furnace SNOL 8.2/1100, a drying cabinet SNOL 67/350, etc.

Random changes were evaluated using the law of normal distribution or logarithmic normal distribution. Measurement results were statistically processed using the standard Excel package with the 2024 Analysis extension version.

RESULTS & DISCUSSION

Assessment of the Granulometric Composition of Bottom Sediments

Based on our studies of the granulometric composition of bottom sediments of the coastal zones in the Verkhnetobolskoe and Karatomarskoe reservoirs, we obtained data on the mass percentage composition of fractions with sizes of grains (granules) of bottom sediments (Table 1 and 2). Table 1 and 2 also show the average values of the fraction sizes and the standard deviation of the results. Fig. 4 and 5 reflect the percentage mass distributions of grain particles by size in sediment samples. The resulting fractional composition of the bottom sediments can be classified by particle size. The names of the fractions are conditional and linked to the grain sizes of the fractions obtained during the sieve analysis, considering the available sieves (Table 3). The granulometric composition of bottom sediments in reservoirs provides a lot of information and helps in determining sediment transport dynamics, nutrient cycling, sedimentation, and contaminant retention in aquatic ecosystems (Abuzahrah et al., 2023). From our results, we notice that medium fraction of particle size 0.1 - 1,0 dominate the bottom sediments of

Table 1: Granulometric composition of the bottom sediment samples from the Verkhnetobolskoe reservoir

Particle grain sizes,mm	Sample numbers and sampling points								Average value, %	SD
	1	2	3	4	5	6	7	8		
	Mass content values of fractions of sediment particles with grain sizes, %									
>2.50	10.33	9.48	11.50	8.65	3.85	20.19	11.68	3.98	10.0	5.1
1.60-2.50	6.17	6.61	4.81	5.32	5.22	6.38	7.51	4.06	5.8	1.1
1.00-1.60	9.42	9.89	7.92	8.17	11.92	6.98	10.27	7.73	9.0	1.6
0.63-1.00	10.62	12.80	17.18	14.77	24.08	5.24	12.39	8.13	13.2	5.8
0.40-0.63	11.49	13.98	26.37	25.50	26.09	6.21	14.90	12.39	17.1	7.8
0.315-0.40	5.09	5.13	7.65	6.71	6.58	2.75	5.90	4.92	5.6	1.5
0.20-0.315	16.32	11.75	12.65	16.38	12.04	21.76	13.41	31.85	17.0	6.8
0.16-0.20	2.88	2.18	1.94	2.06	1.75	10.48	2.26	2.35	3.2	2.9
0.10-0.16	17.85	10.51	4.80	7.58	4.37	17.10	13.23	17.92	11.7	5.7
0.063-0.10	3.68	5.90	1.68	2.23	1.29	1.18	4.08	2.21	2.8	1.6
0.050-0.063	2.72	1.52	0.61	0.72	0.49	0.33	1.49	1.25	1.1	0.8
<0.050	3.25	10.00	2.88	1.90	2.18	1.28	2.72	3.06	3.4	2.7

Table 2: Granulometric composition of the bottom sediment samples from the Karatomarskoe reservoir

Particle grain sizes,mm	Sample numbers and sampling points									Average value, %	SD
	1	2	3	4	5	6	7	8	9		
	Mass content values of fractions of sediment particles with grain sizes, %										
>2.50	1.77	0.56	4.04	0.09	0.24	71.41	16.43	5.02	7.11	11.85	22.92
1.60-2.50	2.66	0.45	2.48	0.44	0.40	5.91	7.19	10.98	1.90	3.60	3.67
1.00-1.60	5.58	1.60	8.07	2.77	2.45	6.01	9.77	19.50	2.67	6.49	5.62
0.63-1.00	9.27	6.12	17.28	10.71	10.71	4.21	7.67	20.75	5.73	10.27	5.50
0.40-0.63	12.52	18.01	26.45	25.86	23.47	4.87	10.47	25.26	10.61	17.50	8.12
0.315-0.40	7.37	9.44	7.39	7.89	9.88	1.61	3.83	3.88	7.00	6.48	2.78
0.20-0.315	25.41	41.30	23.36	31.31	33.28	2.11	21.53	8.34	29.60	24.03	12.26
0.16-0.20	4.66	4.95	3.09	4.25	3.70	0.65	5.20	1.84	5.81	3.80	1.68
0.10-0.16	17.79	13.79	6.43	10.40	10.20	2.44	14.72	4.00	21.21	11.22	6.28
0.063-0.10	5.19	1.95	0.69	1.90	1.82	0.45	1.73	0.17	4.51	2.05	1.73
0.050-0.063	1.65	0.39	0.16	0.71	0.62	0.07	0.35	0.02	1.23	0.58	0.55
<0.050	6.02	1.27	0.38	3.48	3.06	0.15	1.07	0.04	2.48	2.00	1.97

Table 3: Mass content of fractions with grain size in the reservoir bottom sediments

Name	grain sizes,mm	Sample numbers and sampling points								Average value, %	SD	Coefficient of variation (Cv), %
		1	2	3	4	5	6	7	8			
		Mass content of fractions, in %										
Verkhnetobolskoye reservoir												
Coarse fraction	>1	25.92	25.99	24.23	22.14	21	33.55	29.46	15.77	24.76	5.4	24.63
Medium fraction	0.10 – 1.00	64.25	56.35	70.60	73	74.91	63.54	62.09	77.56	67.79	7.32	22.80
Small fraction	<0.10	9.64	17.42	5.17	4.85	3.97	2.79	8.30	6.51	7.33	4.65	3.85
Karatomarskoe reservoir												
Coarse fraction	>1.00	10.01	2.61	14.58	3.30	3.08	83.33	33.38	35.50	11.67	21.94	24.63
Medium fraction	0.10 – 1.00	77.01	93.61	84.01	90.43	91.24	15.88	63.43	64.07	79.96	73.29	22.80
Small fraction	<0.10	12.86	3.60	1.24	6.09	5.50	0.67	3.14	0.24	8.22	4.62	3.85

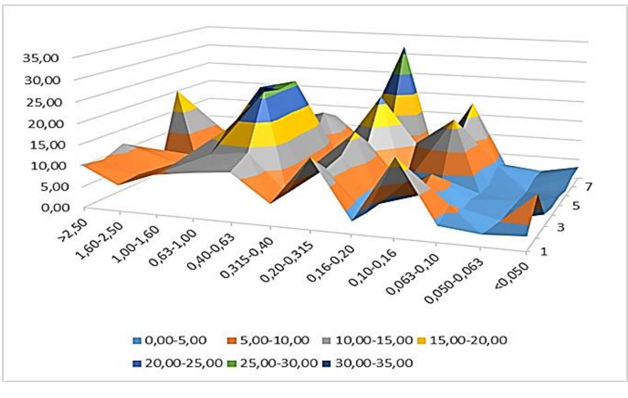


Fig. 4: Percentage mass distribution of fractions with grain size in bottom sediment samples from the Verkhnetobolskoe reservoir.

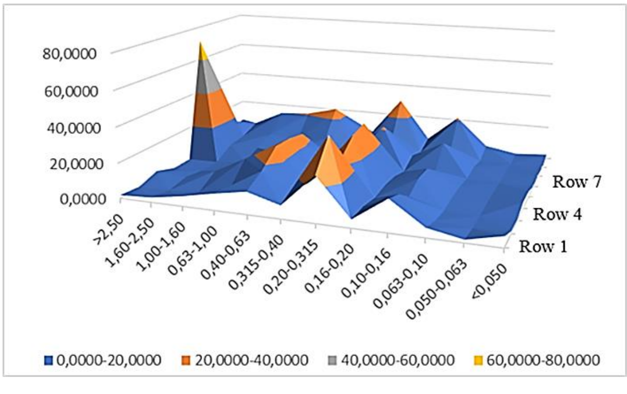


Fig. 5: Percentage mass distribution of fractions with particle grain size in the bottom sediment samples from the Karatomarskoe reservoir.

both reservoirs. This particle size corresponds to sand which has a grain size of about 0.05-2mm (Kazberuk et al., 2021). The predominance of these particles suggests that there could be a moderate retention of heavy metals in the bottom sediments due to its surface area. From a soil management perspective, there is little reports in scientific literature about the possibility of agricultural use of sandy bottom sediment as they hold the least organic matter. (Kazberuk et al., 2021) suggest that they can be treated with fertilizers in order to make to increase their productivity.

Assessment of the Chemical Composition of Bottom Sediments

We studied the chemical composition of sediment samples from the reservoirs (Table 4 and 5). Based on our laboratory studies, indicators of the total forms of the

Table 4: The main chemical components content in the sediment samples from the Verkhnetobolskoe reservoir

Indicator	Sample number and sampling point								Average value	SD	Cv, %
	1	2	3	4	5	6	7	8			
SiO2	651.99	596.30	744.35	801.27	896.36	921.99	548.45	824.95	748.21	128.99	17.2
Al2O3	114.90	145.65	114.44	85.52	59.91	34.57	107.32	74.96	92.16	33.17	36.0
Fe2O3	96.68	55.75	43.09	30.38	20.51	25.42	38.29	28.65	42.35	23.03	54.4
K2O	16.32	19.87	14.61	12.07	8.67	10.29	13.53	10.01	13.17	3.48	26.4
MgO	15.65	21.89	27.22	0.00	14.59	15.14	28.65	7.20	16.29	9.06	55.6
CaO	5.23	15.11	6.80	18.51	7.57	3.38	84.03	6.51	18.39	25.28	137.4
TiO2	8.39	8.34	4.87	4.43	2.27	2.44	6.43	5.14	5.29	2.19	41.5
P2O5	3.45	2.82	1.41	0.57	0.75	0.94	1.02	1.17	1.52	0.98	64.4
MnO	1.26	1.07	0.58	0.51	0.39	0.27	0.77	0.49	0.67	0.32	48.2
S	0.67	0.61	0.23	0.32	0.30	0.52		0.48	0.39	0.21	53.0
Sr	0.16	0.18	0.12	0.13	0.09	0.06	0.23	0.08	0.13	0.05	41.1
Zr	0.20	0.21	0.11	0.17	0.07	0.15	0.18	0.23	0.17	0.05	29.9
Cr	0.04	0.10	0.11		0.04	0.08	0.12	0.08	0.085	0.02	33
Co	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	37.3
Ni	0.05	0.05	0.04	0.03	0.03	0.02	0.04	0.03	0.04	0.01	30.8
Cu	0.05	0.03	0.02	0.01	0.01		0.02		0.03	0.02	58.0
Zn	0.11	0.08	0.04	0.02	0.02		0.04		0.07	0.03	43.9
As	0.03	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01	69.7
Rb	0.03	0.07	0.04	0.03	0.02	0.03	0.04	0.03	0.04	0.01	37.2
Y	0.02	0.03	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.01	34.2
Nb	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.002	29.9
Pb	0.02	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	53.0

Table 5: The main chemical components content in the sediment samples from the Karatomarskoe reservoir

Indicator	Sample number and sampling point									Average value	SD	Cv, %
	1	2	3	4	5	6	7	8	9			
SiO2	740.4	805.7	984.7	906.6	884.1	836.5	814.0	1.009.5	754.7	859.6	94.63	11.00
Al2O3	94.93	77.4	34.6	51.5	58.1	49.2	57.2	15.3	66.4	56.11	23.10	41.18
Fe2O3	36.32	32.8	13.28	18.69	23.06	37.11	26.50	10.63	33.32	25.75	9.94	38.59
K2O	17.18	18.57	9.14	12.21	13.25	15.20	14.25	8.84	12.37	13.45	3.28	24.41
MgO				16.38		13.36	19.06			16.26	2.85	17.54
CaO	12.36	17.53	4.94	6.08	7.10	3.94	14.63	1.32	27.24	10.57	8.21	77.62
TiO2	5.68	6.08	3.04	3.11	4.06	2.63	3.44		3.77	3.98	1.26	31.65
P2O5	1.62	0.97	0.76	0.83	0.95	1.44	1.12	0.74	1.61	1.11	0.35	31.69
MnO	0.73	0.66	0.20	0.45	0.44	0.23	0.20	0.08	0.78	0.42	0.26	61.79
S	0.38	0.76	0.26	0.62	0.76	2.84	1.61	0.32	3.77	1.26	1.24	98.94
Sr	0.14	0.16	0.07	0.09	0.1	0.23	0.11	0.02	0.11	0.11	0.06	50.91
Zr	0.14	0.14	0.15	0.12	0.13	0.09	0.17	0.03	0.15	0.12	0.04	34.23
Cr	0.06	0.12	0.07	0.07	0.08	0.06	0.12		0.07	0.08	0.03	30.92
Co	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.003	30.77
Ni	0.03	0.03	0.03	0.02		0.02	0.02	0.02	0.02	0.02	0.01	25.86
Cu	0.02	0.02	0.02		0.01				0.02	0.02	0.004	22.68
Zn	0.04	0.02			0.02	0.02	0.03		0.03	0.03	0.01	37.21
As	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.001	28.05
Rb	0.04	0.04	0.02	0.03	0.03	0.04	0.04	0.02	0.03	0.03	0.01	28.54
Y	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.01	0.00	38.74
Nb	0.01	0.01	0.00	0.00	0.01	0.00	0.00		0.00	0.01	0.00	14.99
Pb	0.02	0.02		0.01	0.01		0.01	0.00	0.02	0.01	0.01	55.77

chemical element content were obtained. The concentrations of the components shown in Tables 6 and 7 are expressed in g/kg. Empty cells in the tables mean that the concentration of the component was analytically small, or no indicator was determined in this sample. The basis of the chemical composition of bottom sediment samples from the reservoirs is oxides of silicon, aluminum, iron, magnesium, calcium, titanium, phosphorus, and manganese. Heavy and rare metals and elements, such as strontium, zirconium, chromium, nickel, cobalt, copper, zinc, rubidium, yttrium, niobium, lead, and arsenic, were detected in analytically significant concentrations. Tables 4 and 5 reflect the main chemical component content in the sediment samples taken from sections of reservoirs. The average values for the reservoir and the SD from the mean values are also given. For most samples, the SD of the value did not exceed 50% of the average value. This indicates a stable composition of bottom sediments at all reservoir sampling points. The data correlate well with scientific descriptions of such objects. Tables 4 and 5 show the SD and Cv.

We obtained the following results when assessing the concentrations of potentially toxic elements in the bottom sediments (Table 6). The copper, lead, manganese, nickel, and zinc content (in average values) in total forms did not exceed the MPC standards. Cobalt, arsenic, and chromium content exceeded the MPC standards. The MPC for strontium was not established.

The chemical composition of the bottom sediments revealed a stable presence of oxides, heavy metals, and rare elements, with certain PTEs exceeding maximum permissible concentrations (MPC). This agrees with the work of (Sałata et al., 2023), who concluded in their research that the content of individual metals increases with the content of colloidal fractions in the sediment. This implies a decrease in metal content as grain size increases. The presence of cobalt, arsenic, and chromium in levels over the MPC standards calls for more research on these specific reservoirs and could be a result of anthropological effects.

Table 6: Concentrations of potentially toxic elements in the sediment samples from the Verkhnetobolskoe reservoir

Indicator	Sample number and sampling point									MPC,g/kg	
	1	2	3	4	5	6	7	8	9	Active form	Total content
					Verkhnetobolskoye reservoir						
Cu	0.05	0.03	0.02	0.01	0.01		0.02		-	0.00*	0.06***
Zn	0.11	0.08	0.04	0.02	0.02		0.04		-	0.02**	0.10***
Mn	1.26	1.07	0.58	0.51	0.39	0.27	0.77	0.49	-		1.50*
Ni	0.05	0.05	0.04	0.03	0.03	0.02	0.04	0.03	-	0.00*	0.08***
Co	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	-	0.00*	
As	0.03	0.01	0.01	0.01	0.01		0.01	0.01	-		0.00**
Pb	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	-	0.01*	0.03*
Cr (trivalent)	0.04	0.10	0.11		0.05	0.09	0.12	0.08	-	0.01*	
					Karatomarskoe reservoir						
Cu	0.02	0.01	0.02		0.01				0.02	0.0*	0.06***
Zn	0.04	0.02			0.02	0.02	0.03		0.03	0.02**	0.1***
Mn	0.51	0.46	0.14	0.31	0.30	0.16	0.14	0.06	0.55		1.5*
Ni	0.03	0.02	0.03	0.02		0.02	0.01	0.02	0.02	0.0*	0.08***
Co	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.0*	
As	0.01	0.01	0.01	0.00	0.01	0.01	0.00		0.01		0.00**
Pb	0.02	0.02		0.01	0.01		0.01	0.00	0.02	0.0*	0.03*
Cr (trivalent)	0.06	0.12	0.07	0.07	0.08	0.06	0.12		0.07	0.0*	

Notes: *General sanitary limited nuisance value; **Translocation limited nuisance value; ***According to the requirements of the Methodologicalguidelines for determining heavy metals in the soils of farmland and land for crop production

Table 7: The organic matter content in the samples from the Verkhnetobolskoe reservoir. The results of statistical processing of measurement results

Indicator	Sample numbers of sediment samples							
	1	2	3	4	5	6	7	8
Number of samples	9.00	6.00	6.00	5.00	5.00	6.00	6.00	6.00
Average value of the organic matter content in the sample, %	0.69	1.14	0.30	0.41	0.25	0.22	0.66	0.83
SD	0.05	0.09	0.09	0.12	0.07	0.02	0.06	0.15
Sample variance	0.003	0.08	0.01	0.01	0.005	0	0.004	0.02
Cv, %	7.90	8.32	29.01	29.79	29.48	9.18	8.96	18.48

Assessment of the Organic Matter Content in Bottom Sediments

Our results correlated well with general scientific data and emphasized the specifics of the bottom coastal sediments in the reservoirs. The average organic matter content in sediment samples is 0.05-1.14%. The organic matter content in sediment samples and the results of statistical processing of measurement results are shown in Table 7 and 8. During the assessment, sections of the coastal zone of the reservoirs were identified, in which bottom sediments were saturated with organic matter and had a pronounced sapropel structure. The organic matter content is consistent with the nature of the bottom sediment, sandy. This finding agrees with the work of (Kazberuk et al., 2021)**.** Although the sediment has low to medium organic matter content, it can still be utilized in agriculture after treating with fertilizers as suggested by (Kiani et al., 2020). However, the simultaneous presence of PTEs necessitates pre-treatment or selective extraction methods to mitigate risks of heavy metal transfer to soils and crops. Innovative approaches, such as phytoremediation or chemical stabilization, could be explored to address these challenges (Bhat et al., 2022). Based on the measurement results, the data spread is well approximated to the average value. The Cv or relative SD has low values on average and in most measurements does not exceed 30%. During the assessment, we identified samples of bottom silts with a pronounced sapropel structure saturated with organic matter.

Assessment of the Relationship between the Indicators of Organic Matter Content and the Size Fractions of the Granulometric Composition of Bottom Sediments

Assessing correlations between indicators is an important scientific tool for predicting the properties of materials and forecasting processes. Publications that provide a comprehensive assessment of the relationships between the indicators of bottom sediments emphasize the multifactorial influence on the dynamics of processes and the need to consider as many factors and parameters as possible (Nugmanov et al., 2022, 2023). We conducted a correlation analysis between the content of fractions with a grain size of sediment particles and the organic matter content in the reservoir sediment samples (Table 9 and 10). Based on the results of the correlation analysis between the mass content of sediment fractions with grain sizes and the content of organic matter, sufficiently high levels of dependence between fractions with grain sizes ranging from 0.16mm and below were established (Table 11). The largest values of the correlation coefficients between the content of fractions with particle grain size and the organic matter content concerned fractions with a particle grain size less than 0.1mm (Table 11). With an increase in grain size above 0.16mm, there was a sharp decrease in the dependence between the mass content of sediment fractions with grain size and the organic matter content (Fig. 6). Most organic substances are concentrated in the fractions of the bottom sediments in both reservoirs with a grain size of less than 0.16mm (fractions 9-12 in Table 11), including siltstone, clay, and sapropel fractions. Regarding fractions with a grain size above 0.16mm, the mass content of fractions either did not correlate with the content of organic matter or the correlation values were negative (Fig. 6). To make it easier to predict the correlation coefficients between the mass content of fractions with grain sizes and the organic matter content, the polynomial approximant equations of the second degree and the corresponding values of approximation reliability (R2) for the fractional range with a particle grain size of less than 0.16mm were

Table 8: The organic matter content in the samples from the Karatomarskoe reservoir. The results of statistical processing of measurement results

Indicator	Sample numbers of sediment samples								
	1	2	3	4	5	6	7	8	9
Number of samples	6	6	6	6	6	6	6	6	6
Average value of the organic matter content in the sample, %	0.61	0.10	0.05	0.24	0.31	0.37	0.15	0.19	0.29
SD	0.04	0.01	0.00	0.01	0.10	0.12	0.02	0.12	0.04
Sample variance	0.0017	0.0002	0.0000	0.0001	0.0106	0.0149	0.0003	0.0139	0.0013
Cv, %	6.66	12.40	9.64	3.93	33.55	33.06	11.21	63.40	13.84

Table 9: The organic matter content and mass content of fractions with particle grain size in the bottom sediment samples in the Verkhnetobolskoe reservoir

Sample numbers	1	2	3	4	5	6	7	8
Organic matter content, %	0.69	1.14	0.30	0.41	0.25	0.22	0.66	0.83
grain sizes of fractions,mm	Mass content of fractions with a certain particle grain size, %							
>2.50	10.33	9.48	11.50	8.65	3.85	20.19	11.68	3.98
1.60-2.50	6.17	6.61	4.81	5.32	5.22	6.38	7.51	4.06
1.00-1.60	9.42	9.89	7.92	8.17	11.92	6.98	10.27	7.73
0.63-1.00	10.62	12.80	17.18	14.77	24.08	5.24	12.39	8.13
0.40-0.63	11.49	13.98	26.37	25.50	26.09	6.21	14.90	12.39
0.315-0.40	5.09	5.13	7.65	6.71	6.58	2.75	5.90	4.92
0.20-0.315	16.32	11.75	12.65	16.38	12.04	21.76	13.41	31.85
0.16-0.20	2.88	2.18	1.94	2.06	1.75	10.48	2.26	2.35
0.10-0.16	17.85	10.51	4.80	7.58	4.37	17.10	13.23	17.92
0.063-0.10	3.68	5.90	1.68	2.23	1.29	1.18	4.08	2.21
0.050-0.063	2.72	1.52	0.61	0.72	0.49	0.33	1.49	1.25
<0.050	3.25	10.00	2.88	1.90	2.18	1.28	2.72	3.06

Table 10: The organic matter content and mass content of fractions with a particle grain size in the bottom sediment samples in the Karatomarskoe reservoir

Sample numbers	1	2	3	4	5	6	7	8	9
Organic matter content, %	0.61	0.10	0.05	0.24	0.31	0.37	0.15	0.19	0.29
grain sizes of fractions	Mass content of fractions with a certain particle grain size, %								
>2.50	1.77	0.56	4.04	0.09	0.24	71.41	16.43	5.02	7.11
1.60-2.50	2.66	0.45	2.48	0.44	0.40	5.91	7.19	10.98	1.90
1.00-1.60	5.58	1.60	8.07	2.77	2.45	6.01	9.77	19.50	2.67
0.63-1.00	9.27	6.12	17.28	10.71	10.71	4.21	7.67	20.75	5.73
0.40-0.63	12.52	18.01	26.45	25.86	23.47	4.87	10.47	25.26	10.61
0.315-0.40	7.37	9.44	7.39	7.89	9.88	1.61	3.83	3.88	7.00
0.20-0.315	25.41	41.30	23.36	31.31	33.28	2.11	21.53	8.34	29.60
0.16-0.20	4.66	4.95	3.09	4.25	3.70	0.65	5.20	1.84	5.81
0.10-0.16	17.79	13.79	6.43	10.40	10.20	2.44	14.72	4.00	21.21
0.063-0.10	5.19	1.95	0.69	1.90	1.82	0.45	1.73	0.17	4.51
0.050-0.063	1.65	0.39	0.16	0.71	0.62	0.07	0.35	0.02	1.23
<0.050	6.02	1.27	0.38	3.48	3.06	0.15	1.07	0.04	2.48

Table 11: Correlation coefficients between the organic matter content and particle sizes less than 0.16mm

Particle grain sizes,mm	0.16-0.1	0.1-0.063	0.063-0.05	0.05-0.0
	Verkhnetobolskoye reservoir			
Organic matter	0.37	0.88	0.65	0.82
	Karatomarskoe reservoir			
Organic matter	0.27	0.63	0.71	0.74

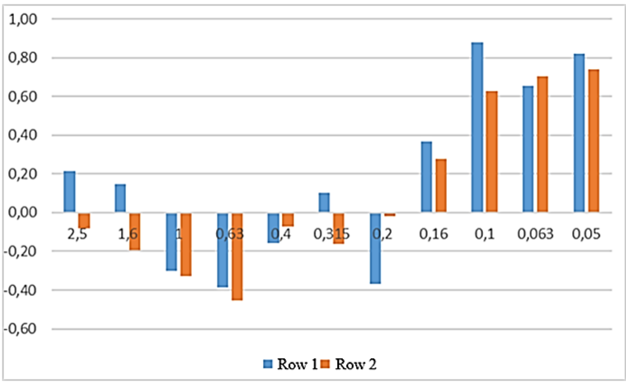


Fig. 6: Correlation coefficients between the mass content of fractions with grain sizes and the organic matter content in the sediment samples in the Verkhnetobolskoe (row 1) and Karatomarskoe reservoirs (row 2).

proposed and constructed (Table 12). The dependence graphs at the bottom horizontally reflect the values of particle sizes. The horizontal axis reflects the correlation coefficient value. Our findings correlate with the study of (Minyuk, 2022), who concluded that a decrease in fraction size is always followed by an enrichment in sediment nutrients; Al_2O_3, Fe_2O_3, K_2O, TiO_2, MnO, P_2O_5.

Assessment of Connections and Dependencies between Indicators of the Chemical Composition of Bottom Sediments and Grain Sizes of Sediment Fractions

Based on the results of the correlation analysis, we obtained sufficiently high values of correlation dependences between the concentrations of most chemical components and fractions of bottom sediments with a particle grain size of less than 0.1mm (Table 13). This indicates that fractions of bottom sediments with a grain size of less than 0.16mm absorb Al_2O_3, Fe_2O_3, K_2O, TiO_2, MnO, P_2O_5, Ni, Cu, Zn, Zr, As, Y, Rb, Pb, etc. We emphasize the high degree of adsorption of organic matter by fractions of bottom sediments with grain sizes less than 0.1mm. The results are consistent with the provisions of the guidelines for Monitoring and Assessment of Transboundary and International Lakes of the United Nations Economic Commission for Europe Working group. Coarse- grained sediment components are characterized by low levels of heavy metals and organic pollutants. This generally helps to reduce the concentration of pollutants in the total sample volume

Table 12: graphs and equations of dependencies between the organic matter content and the mass content of fractions with grain sizes of sediment particles

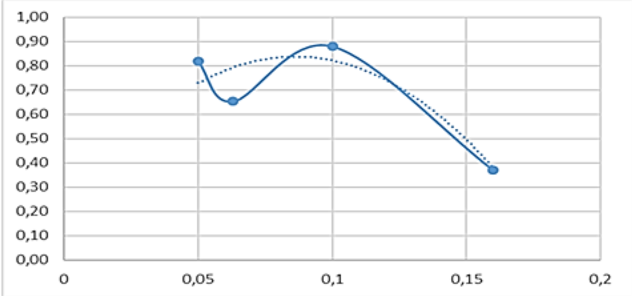
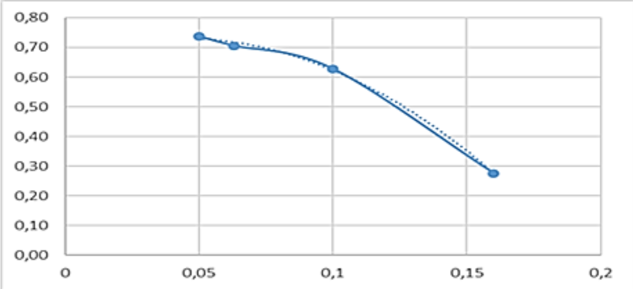
Water reservoir	Polynomial equation R2	Dependency graphs
Verkhnetobolskoye reservoir	y= -84x2+14x+0.22 R^2=0.79	
Karatomarskoe reservoir	y= -33x2+3x+0.67 R^2=0.99	

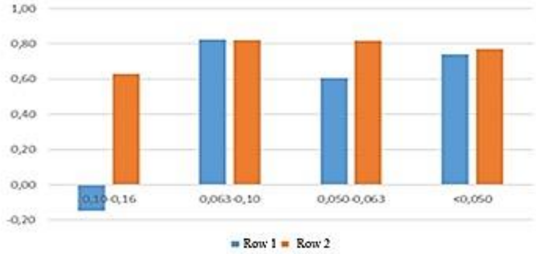
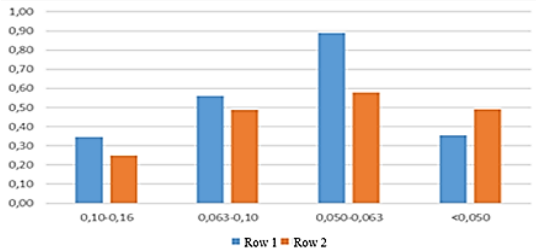
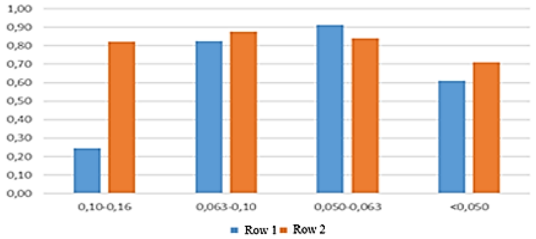
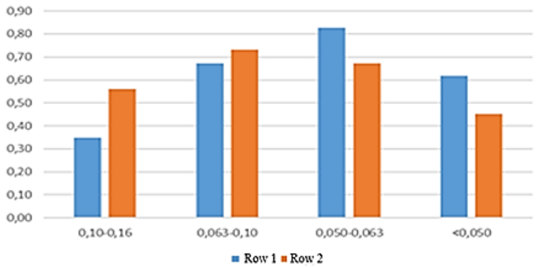
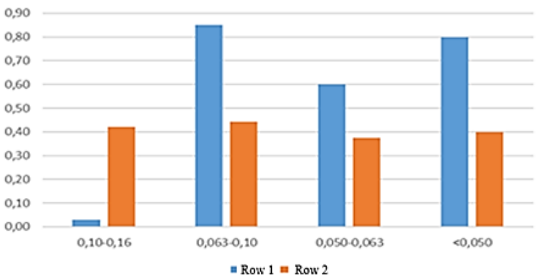
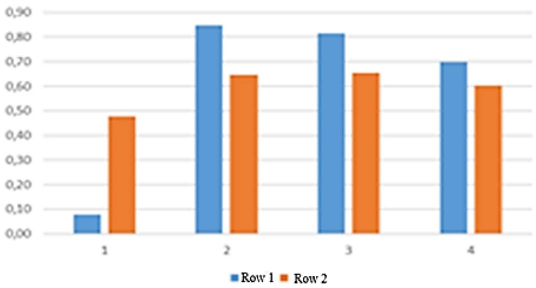
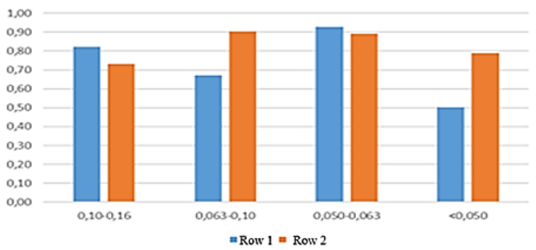
Table 13: Correlation coefficients between the mass content of fractions with grain sizes and the content of indicators of the chemical composition of bottom sediments

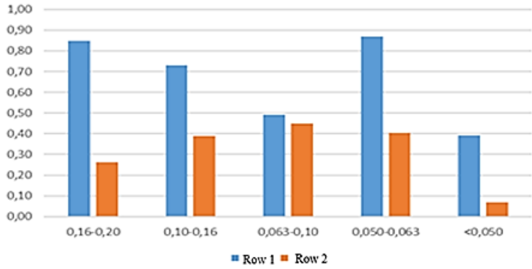
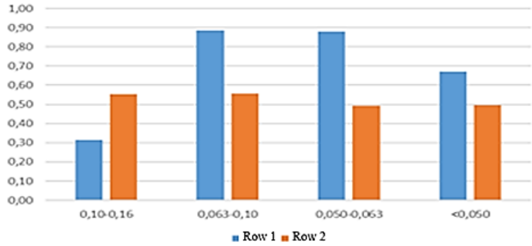
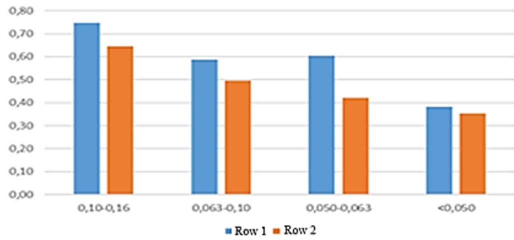
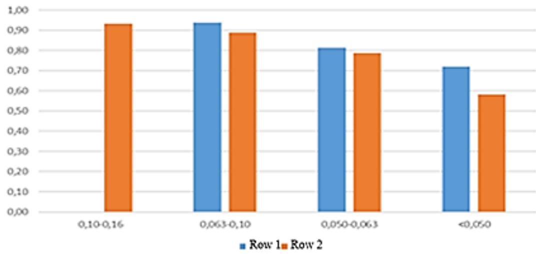
Indicator	VTR	KR	VTR	KR	VTR	KR	VTR	KR	VTR	KR	VTR	KR
	grain sizes of fractions in mm											
	0.20-0.315	0.20-0.315	0.16-0.20	0.16-0.20	0.10-0.16	0.10-0.16	0.063-0.10	0.063-0.10	0.050-0.063	0.050-0.063	<0.050	<0.050
Al2O3		0.56		0.63		0.63	0.83	0.82	0.61	0.82	0.74	0.77
Fe2O3					0.35		0.56	0.49	0.89	0.58	0.35	0.49
K2O							0.85	0.44	0.60	0.37	0.80	0.40
P2O5						0.56	0.67	0.73	0.83	0.67	0.62	0.45
MnO				0.69		0.82	0.83	0.88	0.91	0.84	0.61	0.71
TiO2				0.51		0.55	0.89	0.56	0.88	0.49	0.67	0.49
Zr					0.75	0.65	0.59	0.50	0.60	0.42	0.38	0.35
Ni		0.54		0.39	0.08	0.48	0.85	0.65	0.81	0.65	0.70	0.60
Cu			0.85	0.26	0.73	0.39	0.49	0.45	0.87	0.40	0.39	
Zn			0.87	0.52	0.82	0.73	0.67	0.90	0.93	0.89	0.50	0.79
As			0.80						0.89			
Rb			0.87		0.82	0.35	0.96	0.39	0.59	0.31	0.91	0.28
Sr							0.80		0.60	0.11	0.42	0.07
Y						0.93	0.9	0.89	0.81	0.79	0.72	0.58
Pb				0.64		0.77	0.54	0.64	0.89	0.46		

VTR is the Verkhnetobolskoe reservoir, KR is the Karatomarskoe reservoir, R is the correlation coefficient

volume (Tomilina et al., 2018b). The content of chromium, sulfur, cobalt, silicon, magnesium, and calcium oxides does not correlate with the mass content of alluvial and clay fractions and the organic matter content. Table 13 shows the values of the correlation coefficients between the mass content of fractions with grain sizes and the content of indicators of the main components of the chemical composition of bottom sediments. For the fractions of bottom sediments in both reservoirs with a grain size below 0.16mm, the connections with a high value of correlation coefficients were traced (Table 14). The results emphasize that similar dependencies with high correlation coefficients were observed between the mass content of fractions with grain sizes and the chemical composition of the main components of the bottom sediments in both reservoirs. This also indicates that the fractions of bottom sediments with a grain size of less than 0.16mm absorb Al2O3, Fe2O3, K2O, TiO2, MnO, P2O5, Ni, Cu, Zn, Zr, As, Y, Rb, Pb, etc. While our study provides valuable insights into the granulometric and chemical composition of bottom sediments, several gaps remain. The bioavailability and speciation of heavy metals in these sediments require further investigation to accurately assess ecological risks. Advanced analytical techniques, such as X-ray diffraction (XRD) or inductively coupled plasma mass spectrometry (ICP-MS), could provide more detailed insights into sediment mineralogy and trace element distribution (Ito et al., 2022). Furthermore, long-term monitoring studies are needed to capture temporal variations in sediment composition and pollutant dynamics under changing climatic and anthropogenic pressures. In conclusion, the granulometric and chemical characteristics of bottom sediments in North Kazakhstan's reservoirs provide critical insights into their ecological functions and management implications. Bottom sediments play a pivotal role in pollutant retention and nutrient cycling, but their potential to act as sources of contamination underscores the need for cautious management. Future research should focus on integrated approaches that combine sediment analysis with hydrological and ecological assessments to support sustainable water and soil resource management in the region.

Table 14: Correlations between the indicators of bottom sediments in the reservoirs

No.	Bottom sediment component	Fraction with grain size (mm)	R, correlation coefficient	Correlation coefficient ratio diagrams
1	Al2O3	< 0.16	0.95	
2	Fe2O3	< 0.16	0.72	
3	MnO	< 0.1	0.88	
4	P2O5	< 0.1	0.85	
5	K2O	< 0.1	0.89	
6	Ni	< 0.31	0.89	
7	Zn	< 0.31	0.67	

8	Cu	< 0.16	0.61	
9	TiO2	< 0.1	0.51	
10	Zr	< 0.16	0.91	
11	Y	< 0.1	0.96	

Conclusion

We determined the content of the main chemical component content, heavy metals and elements, and organic matter and the fractional granulometric composition of the sediment samples. We developed methods of sediment and water sampling in winter from under the ice cover of the reservoir. The main chemical components forming bottom sediments were the oxides of silicon, aluminum, iron, potassium, magnesium, calcium, and titanium. This confirms previous studies on bottom sediments of freshwater reservoirs. The copper, lead, manganese, nickel, and zinc content in total forms does not exceed the MPC standards. Cobalt, arsenic, and chromium content exceed the MPC standards. The average content of iron (considering the recalculation from the oxide form to the elemental form), manganese (considering the recalculation from the oxide form to the elemental form), chromium, and strontium did not exceed the average values in Clarkes of elements in the Earth's crust. The content of chromium, sulfur, cobalt, silicon, magnesium, and calcium oxides did not correlate with the mass content of sediment fractions with a grain size of less than 0.1mm and the content of organic matter. The relationships between the mass content of fractions with grain sizes, indicators of the chemical composition of the main components of bottom sediments, and the organic matter content in both reservoirs had similar dependencies with high values of correlation coefficients.

Acknowledgment: This study was conducted within the framework of a grant program targeted financing of research by scientists under the project for 2023-2025 on the topic with the individual registration number BR21881993 "Creation of a system for operational monitoring of water resources and environmental control of hydraulic engineering structures in North Kazakhstan" with the correspondent source of funding (Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan).

Author's Contribution: AY, VC and AN wrote the article. AY and AJ performed the data analysis. TP drafted the manuscript. DK designed the study. AN contributed to the interpretation of the results. VC worked out with technical details. AJ contributed to the design of the figures. TP, DK and AY collected all the data.

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