www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2024, 74(2), pp. 147–164

Original scientific paper

UDC: 911.2:556[544.02](282.247.41)
https://doi.org/10.2298/IJGI240312009M

Received: March 12, 2024
Reviewed: April 5, 2024
Accepted: June 5, 2024

THE CURRENT CHEMICAL COMPOSITION OF INLAND WATER BODIES OF THE VOLGA-AKHTUBA FLOODPLAIN (RUSSIA)

Alina Mezhevova[1], *Yuliya Berestneva*[1*], *Alexander Belyaev*[1]

[1]Federal Scientific Centre of Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences, Volgograd, Russia; e-mails: mezhevova@vfanc.ru; berestneva-yv@vfanc.ru; info@vfanc.ru

Abstract: The problem of clean water is one of the most important environmental problems in the world. It is impossible to prevent the occurrence of adverse environmental situations without careful monitoring of the aquatic ecosystems state. The assessment of the current chemical composition of the Volga-Akhtuba floodplain shallow channels (Peschanyj, Dudak, and Dudachenok) in the water-bottom sediments system was carried out. Studied shallow channels dried out during the summer-autumn low-water period for the last few decades. Studies were carried out after the clearance and ecological rehabilitation of the shallow channels. It was found that almost all the studied indicators in water samples correspond to the established quality standards. There is uneven distribution of heavy metals in the studied shallow channels. It can be caused by the influence of hydrodynamic conditions, changes in water and sediment flow, as well as local factors, including the catchment heterogeneous geology. The analysis of the metals content in bottom sediments with permissible ones made it possible to detect excess for Hg (0.18–0.75 mg/kg), Cd (1–2.12 mg/kg), Mn (370.8–493.3 mg/kg), Ni (2.6–67.9 mg/kg), Pb (14.3–22 mg/kg), Zn (75.2–147 mg/kg). The content of As (1–1.4 mg/kg) and Cu (8.54–28.7 mg/kg) in bottom sediments does not exceed the permissible concentrations. The obtained results will form the basis for a general comprehensive assessment of the clearance and ecological rehabilitation of the Volga-Akhtuba floodplain watercourses. It is necessary to continue monitoring the watercourses state and strengthen efforts to preserve the resilient ecosystem of the Volga-Akhtuba floodplain.

Keywords: chemical composition; shallow channels; bottom sediments; Volga-Akhtuba floodplain; biosphere reserve

1. Introduction

The world faces a lot of environmental problems every day. The climate is changing, global warming is becoming more intense. As a result, freshwater is depleted, deforestation, air and water pollution are increasing very quickly (Advanced ESCC 2024, n.d.). Global freshwater demand predicted to exceed supply by 40% by 2030 according to the report of Mazzucato et al. (2023). Clean water is a valuable resource and a key element for a healthy environment and

*Corresponding author, e-mail: berestneva-yv@vfanc.ru

life on the planet as a whole (Li et al., 2022). It contains various chemical elements and substances that determine its quality and suitability for use by humans or animals. The chemical composition of water bodies can be changed by both natural processes (such as the plant and mineral cycle) and anthropogenic factors (manufacturing, agriculture, and industry). Environmental pollution, including water pollution, by chemicals is a serious problem that can lead to loss of biodiversity, destruction of ecosystems, and disease in humans (Balla et al., 2022). Water bodies pollution with heavy metals and pesticides is considered the most dangerous and complex problem (Li et al., 2022; Maaroof et al., 2023). Pb, Hg, and Cd are the most toxic metals in the aquatic environment (Ghafarifarsani et al., 2024). Organochlorine pesticides such as DDT, DDE, DDD, HCH are known for their resistance to biodegradation and harmful impacts on aquatic ecosystems (Riaz et al., 2021). In this regard, assessment of aquatic ecosystems chemical composition and their constant monitoring is a relevant and very important task.

Water quality is closely related to bottom sediments. They accumulate various substances, including various ecotoxicants with concentrations surpassing those found in the water (Zakrutkin et al., 2020). The accumulation of ecotoxicants is caused by both anthropogenic and natural factors. Natural factors associated with aquatic ecosystems pollution are caused by the processes of weathering, leaching of rocks and soils, pollutants transfer from the atmosphere, and death of plants and living organisms. Industry, economic, and agricultural activities, and insufficient environmental control are the main anthropogenic causes of aquatic ecosystems pollution. A shift in the sorption equilibrium leads to the reverse process—desorption—which will lead to an increase in the content of the corresponding ions in water. Bottom sediments can cause secondary pollution of water bodies (Zakrutkin et al., 2020) if the concentration of pollutants exceeds the maximum permissible concentrations (MPCs). Since the redistribution of chemical elements in the water-bottom sediments system can occur in both directions, it can be assumed that water is repeatedly polluted during the transition of chemical elements from the solid to the liquid phase (Romanova & Bolshanik, 2022). In addition, bottom sediments can serve as a nutrition source for some organisms. Therefore, their state also matters for the biodiversity of the aquatic ecosystem. Unlike water, which acts as a dynamic system, bottom sediments are a more informative environment for characterizing the level of ecosystems pollution, because they store pollutants, including heavy metals, for a longer period of time (Dauvalter, 2012). The data on the chemical composition of bottom sediments are also necessary for modeling the processes of pollutants transport in aquatic ecosystems and the environment as a whole, for assessing geochemical cycles, and establishing the availability of various elements in the ecological system (Dauvalter, 2012). The chemical composition of bottom sediments provides information about both the natural and anthropogenic components (Nitskaya & Antonenko, 2023) and it is an important indicator of the environment state (Romanova & Bolshanik, 2022). Study of bottom sediments will allow a more accurate assessment of water resources state.

It should be noted that the water content and ecological state of large water bodies (in this particular case, the Volga River) directly depend on the water content and state of small rivers, various watercourses, including shallow channels, that form the drainage basin. There are numerous small watercourses in the Volga-Akhtuba floodplain (Ovchinnikov et al., 2020). This floodplain is one of the unique places on earth (Belyaev et al., 2022) and its northern part is included in UNESCO Volga-Akhtuba Floodplain Biosphere Reserve. The ecosystem of the Volga-Akhtuba floodplain is facing significant disruptions. Inland water bodies of the

Volga-Akhtuba floodplain are continuously modified due to changes in the hydrological regime, processes of channel erosion, as well as massive developments. In addition, changes in the hydrological regime increase the likelihood of the pollution of water bodies due to ecotoxicants accumulated in bottom sediments. Many watercourses dry out or significantly reduce water levels in the summer. Shallow channels are in a deplorable condition (overgrown banks, silted bottom) and dry out by autumn in many areas of the Volga-Akhtuba floodplain. Measures for the ecological restoration of the Volga-Akhtuba floodplain began in 2014. The Volga-Akhtuba floodplain attracts the attention of many scientists. However, previous studies devoted to assessing the shallow channels state and other small watercourses after their rehabilitation have not been carried out, and there is also no comprehensive assessment of the effectiveness of the measures taken to restore water bodies and improve the overall environmental situation in the Volga-Akhtuba floodplain.

Despite the level of knowledge, monitoring of aquatic ecosystems chemical composition should be carried out regularly to identify long-term trends and possible changes, since the chemical composition can change under the influence of environmental factors such as climatic conditions, biological activity, and anthropogenic activities. This paper presents the results on the assessment of the current chemical composition of the Volga-Akhtuba floodplain shallow channels in the water-bottom sediments system after their clearance and ecological rehabilitation. Research was aimed at preserving and restoring small rivers and inland water bodies, protecting and preserving the environment, and preventing water pollution.

2. Study area

The Volga-Akhtuba floodplain stands as a truly unique natural wonder situated in the southern regions of Russia (Volgograd region, Astrakhan region, Republic of Kalmykia) between the Volga and Akhtuba rivers (Belyaev et al., 2022). The floodplain is a section of the Volga valley that has preserved its natural structure. The Volga valley consists of a delta and floodplain. The Volga delta with a terrestrial surface of 23,000 km^2 (Leummens, 2018) is one of the largest river deltas in the world. The floodplain extends for 450 km from Volgograd to Astrakhan (Kablov et al., 2015). There are many wetlands in the Volga-Akhtuba floodplain and they represent the unique value of the floodplain. This is due to the rich biodiversity, i.e., presence of various species of birds, plants, animals, and important habitats of aquatic life, as well as migratory birds (Belyaev et al., 2022; Kablov et al., 2015).

The Volga-Akhtuba floodplain is characterized by numerous unique water bodies that form a complex hydrographic network, the density of which is 0.8 km per 1 km^2 of area. Most of the floodplain lies within the Volgograd region. There are 91 watercourses, including: six channels, five distributary channels (Volozhka), eight backwaters, 72 shallow channels (erik) in the Volgograd part of the Volga-Akhtuba floodplain (Ovchinnikov et al., 2020). The Volga-Akhtuba Natural Park (Natural Park) was formed in the northern part of the floodplain within the Volgograd region (Figure 1). The Volga-Akhtuba floodplain ecosystems are classified as the first category of international significance (Belyaev et al., 2021) and included in UNESCO Volga-Akhtuba Floodplain Biosphere Reserve. The territory of the Natural Park has environmental, recreational, environmental-educational, and historical-cultural significance.

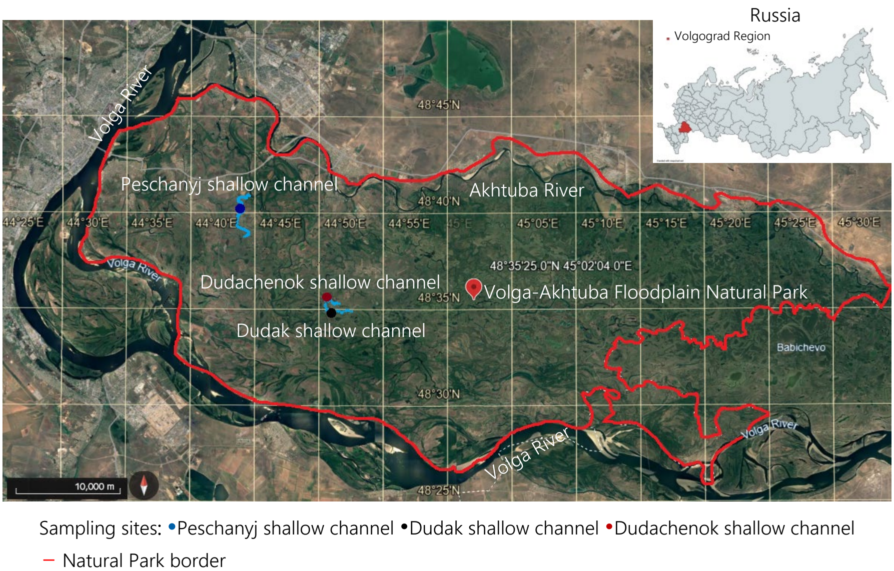

Figure 1. The location of Dudak, Dudachenok, and Peschanyj shallow channels at the Volga-Akhtuba Natural Park.
Note. Volga-Akhtuba Natural Park map. Adapted from "Google Earth (Version 10.52.0.0)," by Google, Google Maxar Technologies Airbus, 2024 (https://www.google.com/earth/about/versions/#earth-for-web). Copyrighted by Google. Russia map. Created with MapChart, 2024 (https://www.mapchart.net/russia.html). CC BY-SA 4.0.

The floodplain faces various threats from human activities such as pollution, deforestation, unstable hydrological regime, and overdevelopment (Kablov et al., 2015). These factors can disrupt the delicate balance of the ecosystem and pose risks to the environment. Most of the Volgograd region's enterprises discharge polluted water into watercourses due to outdated treatment facilities. There are enterprises that produce petroleum products, polymer materials, plant protection products, industrial and household chemicals, feed additives, shipbuilding and ship repair plants, metallurgical and engineering plants, agricultural enterprises, and agro-economic zones on the territory of the Volgograd region. People also live and engage in economic activities on the territory of the Natural Park (about 44,000 people). The ecological state of the Volga-Akhtuba floodplain is also determined by the removal of substances and pollutants from the territories located upstream of the Volga River. It can be assumed that the greatest contribution to the pollution of water bodies of the Volga-Akhtuba floodplain is made by the transit intake of heavy metals, which increases during the flood period. Climate change also poses a significant threat, as rising temperatures and unpredictable weather patterns can lead to additional strain on the floodplain. A critical ecological situation has been observed in the Volga-Akhtuba floodplain over the past decades. The greatest threats to most water bodies are critically low water levels, as well as siltation and waterlogging (Golub et al., 2020). The water volume of large lakes has decreased by 30–50% since 2014 in the Natural Park. The main reason for this state of the floodplain is the change in the natural flood regime in the

Lower Volga due to the construction of the Volga hydroelectric power station and reservoirs on the Volga River (Kablov et al., 2015). The hydrological regime of watercourses of the Volga-Akhtuba floodplain is currently almost completely dependent on releases from upstream reservoirs (Vasilchenko, 2022). Artificial regulation of floods (reduction in volume and duration, shift in time) has led to the transformation of agricultural landscapes, deterioration of the ecological state of water bodies, and a reduction in the reproduction of floodplain ecosystem resources (Belyaev et al., 2022).

There are watercourses that were subject to intense anthropogenic load and are not capable of self-regeneration on the territory of the Natural Park. Such water bodies include Dudak shallow channel (length: 2.8 km, width: 10–143 m, depth: up to 4 m), Dudachenok shallow channel (length: 1.5 km, width: 8–30 m, depth: up to 3 m), and Peschanyj shallow channel (length: 2 km, width: 11–56 m, depth: up to 3 m; Figure 1). These shallow channels became objects of study. Dudak shallow channel (sampling coordinates: 48°35′16′′N, 44°50′31′′E) and Dudachenok shallow channel (sampling coordinates: 48°35′29′′N, 44°50′50.6′′E) are located in the Sredneakhtubinsky district of the Volgograd region of Russia, Chapaevets village. Peschanyj shallow channel (sampling coordinates: 48°40′45′′N, 44°43′47′′E) is located in the Sredneakhtubinsky district of the Volgograd region of Russia, Velikiy Oktyabr village. These shallow channels were covered with soil, garbage, overgrown with plants, and dried out for over several decades. Their clearing and rehabilitation began in 2019. The shallow channels began to fill with water again in 2023. Samples of water and bottom sediments from the shallow channels were taken during the spring flood because it is one of the leading factors that determine the functioning of the entire natural system of the Volga-Akhtuba floodplain and there are very low water levels in the studied shallow channels in other periods. Photographs of the sampling sites for water and bottom sediments are presented in Figure 2. Ecological rehabilitation of shallow channels and other watercourses will help neutralize the negative consequences of the regulating of the Volga River water flow (Vasilchenko, 2022). Currently there are actively implemented measures for the rehabilitation and restoration of water bodies within the framework of the national project "Ecology", the federal project "Rehabilitation of the Volga" on the territory of the Volga-Akhtuba floodplain (Belyaev et al., 2021).

Figure 2. Photographs of the research objects.
Note. Panel A: Dudak shallow channel. Panel B: Dudachenok shallow channel. Panel C: Peschanyj shallow channel.

3. Data and methodology

All the studies were carried out in the Soil analysis laboratory of the Federal Scientific Centre of Agroecology Russian Academy of Sciences. Sampling was carried out once a month from March to June 2023. The water samples were collected from 10 sites (two from each site) of the corresponding shallow channel each time. Water was collected by discrete liquid sampler from the surface layer. In addition, five samples of bottom sediments in different sites (two from each site) of each shallow channel were collect for determinations of its chemical composition. Samples were taken by stainless steel bottom grab (van Veen grab). Since the depth of the water body was less than 10 m, the frequency of the sampling grid was 100 m.

Bottom sediment samples were dried to an air-dry state at room temperature. Totally dissolved solids of water samples were measured using a HANNA DIST-2 HI 98302 TDS Tester. The total hardness of water (Prirodoohrannyj normativnyj dokument federal'nyj, 2016) and hydrocarbonates (HCO_3^-; Prirodoohrannyj normativnyj dokument federal'nyj, 2017) in water were determined by titrimetric method. The total hardness of water measurement method is based on titrating a water sample with a solution of ethylenediaminetetraacetic acid disodium salt (0.01 mol/dm^3) in the presence of the indicator eriochrome black T until the color changes from cherry red to blue. The measurement method of the HCO_3^- concentration is based on the interaction of HCO_3^- ions with a strong acid to form weak carbonic acid, which decomposes in solution into H_2O and free CO_2. The sample of water is titrated with a solution of hydrochloric acid (0.02–0.05 mol/dm^3) to pH = 4.5 with indication of the equivalence point by pH meter. The pH of water samples was measured by pH meter "Expert-001".

Quantitative chemical analysis (determination of the mass fraction of water-soluble forms of ions) of water (Cl^-, F^-, SO_4^{2-}, PO_4^{3-}, NO_2^-, NO_3^-, NH_4^+, Mg^{2+}, Ca^{2+}, Na^+, K^+, Li^+, Ba^{2+}, Sr^{2+}; Prirodoohrannyj normativnyj dokument federal'nyj, 2018; Prirodoohrannyj normativnyj dokument federal'nyj, 2000) and bottom sediment samples (NH_4^+, K^+, Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, F^-, PO_4^{3-}, NO_3^-, $(COO)_2^{2-}$; Prirodoohrannyj normativnyj dokument federal'nyj, 2012; Prirodoohrannyj normativnyj dokument federal'nyj, 2010) was carried out by capillary electrophoresis using Kapel-105M. Ions possess different electrophoretic mobility. The capillary electrophoresis method is based on migration and separation of ions under the influence of an electric field. Identification and quantification of the analyzed ions is carried out indirectly by recording ultraviolet absorption at 267 nm. Water samples are analyzed after filtration through a "blue tape" filter, discarding the first 5 cm^3 of filtrate. Aqueous extracts of bottom sediments are prepared to determine the content of water-soluble cations and anions in them. Bottom sediment samples are mixed with water and shaken for 30 minutes. The resulting aqueous extract is centrifuged (5,000 rpm) for five minutes. Then the aqueous extract is filtered, discarding the first 5 cm^3 of the filtrate.

The concentration of heavy metals in bottom sediments was determined by MGA-1000 atomic absorption spectrometer with electrothermal atomization in a graphite furnace. The measurement method is based on the elements extraction from a sample and the resonant absorption of radiation from the source by free atoms of the elements being determined. Bottom sediment samples are pre-treated to destroy organic matter (calcination at a temperature of 450 °C), and then digested with concentrated hydrofluoric and nitric acids (Prirodoohrannyj normativnyj dokument federal'nyj, 2014). Pesticides content in bottom sediments was determined by Kristalluks-4000M gas chromatograph. The measurement method is based on the pesticides extraction from the bottom sediments, their identification, and determination of their mass fraction in the sample by gas chromatograph method. Pesticides are extracted with acetone or a mixture of acetone and n-hexane. The resulting extract is concentrated and purified with concentrated sulfuric acid (Rukovodyashchij document, 2011).

The classification of Alekin (1953) was used to classify water in the studied shallow channels. This classification combines the division principle according to the predominant ions with division by ratio between them. There are three classes (hydrocarbonate (carbonate), sulfate, and chloride) and three groups (calcium, magnesium, and sodium) into which natural waters are divided by predominant anion and cation respectively. The ratio between ions (in mg-eq/dm^3) makes it possible to determine the type of water. The obtained data in ionic form (mg/dm^3) were converted into equivalent form (mg-eq/dm^3) using conversion factors (Alekin, 1953). The relative content of the main ions (expressed as a percentage of equivalents of the total sum of ions in the test water) was used to determine the ratio between ions (Equation 1):

$$\%eq = \frac{a}{\sum_c + \sum_a} 100 \tag{1}$$

where a is content of each ion, mg-eq/dm^3, $\sum_a$ is sum of anions, mg-eq/dm^3, and $\sum_c$ is sum of cations, mg-eq/dm^3.

4. Results and discussion

4.1. The chemical composition of water from Peschanyj, Dudak, and Dudachenok shallow channels

Chemical analysis of water samples was carried out according to 18 parameters. Average data are presented in Table 1. The obtained values of the studied parameters of water chemical composition were compared with the MPCs for water bodies of fishery importance (Prikaz Ministerstva sel'skogo hozyajstva Rossijskoj Federacii ot 13.12.2016, 2016), as well as with the values approved in hygienic standards and safety requirements, and (or) harmlessness of environmental factors to humans (Postanovlenie No. 2 Glavnogo Gosudarstvennogo Sanitarnogo Vracha RF, 2021).

The studied parameters of water from Volga-Akhtuba floodplain shallow channels did not exceed the corresponding MPCs (Postanovlenie No. 2 Glavnogo Gosudarstvennogo Sanitarnogo Vracha RF, 2021; Prikaz Ministerstva sel'skogo hozyajstva Rossijskoj Federacii ot 13.12.2016, 2016), with the exception of Sr (Table 1). It was previously established and summarized in Brekhovskikh et al. (2017) that Sr content in the Volga waters exceeds the average value for global continental runoff of 0.06 mg/dm^3 (Gordeev, 2012). Sr concentration for the Volga River Delta varies from 0.41 to 0.53 mg/dm^3 (Moiseenko et al., 2005); for its sea edge it is 0.25–0.70 mg/dm^3 (Savenko et al., 2016). Sr content at the sea boundary of the mixing zone is 8.2–12.1 mg/dm^3 (Brekhovskikh et al., 2017). This is slightly higher than in the World Ocean, where it is 7.9 mg/dm^3 (Gordeev, 2012). Brekhovskikh et al. (2017) explain this by changes in river flow volumes, heterogeneous transformation of water in the delta area, different geological composition of the catchment, the intensity of evaporation and water exchange, and low involvement in chemical and biological intra-reservoir processes.

Table 1. The chemical properties of water from Peschanyj, Dudak, and Dudachenok shallow channels, average values

Parameters	Shallow channel			MPC*	MPC**
	Peschanyj	Dudak	Dudachenok		
pH	8.5	7.9	7.8	***	6.0–9.0
Total hardness, mg/dm^3	200.2	200.2	200.2	-	350.35
Total dissolved solids, mg/dm^3	260	270	250	-	1,500
NH_4^+, mg/dm^3	<0.5	<0.5	<0.5	0.5	1.5
K^+, mg/dm^3	2.7	2.7	4.6	50	-
Na^+, mg/dm^3	17	17	19	120	200
Mg^{2+}, mg/dm^3	12	11	11.6	40	50
Ca^{2+}, mg/dm^3	55	49	52	180	-
Li^+, mg/dm^3	<0.015	<0.015	<0.015	0.08	0.03
Ba^{2+}, mg/dm^3	<0.1	0.59	0.58	0.74	0.7
Sr^{2+}, mg/dm^3	0.6	0.89	0.97	0.4	7
Cl^-, mg/dm^3	26	31	32	300	350
SO_4^{2-}, mg/dm^3	72	70	68	100	500
NO_2^-, mg/dm^3	<0.2	<0.2	<0.2	0.08	3
NO_3^-, mg/dm^3	<0.2	1.61	1.83	40	45
F^-, mg/dm^3	0.2	0.14	0.14	0.75	1.5
PO_4^{3-}, mg/dm^3	<0.25	<0.25	<0.25	0.15	3.5
HCO_3^-, mg/dm^3	144	181	173	-	1,000

Note. *From "Prikaz Ministerstva sel'skogo hozyajstva Rossijskoj Federacii ot 13.12.2016 "Ob utverzhdenii normativov kachestva vody vodnyh ob"ektov rybohozyajstvennogo znacheniya, v tom chisle normativov predel'no dopustimyh koncentracij vrednyh veshchestv v vodah vodnyh ob"ektov rybohozyajstvennogo znacheniya" [Order of the Ministry of Agriculture of the Russian Federation dated December 13, 2016 "On approval of water quality standards for fishery water bodies, including standards for maximum permissible concentrations of harmful substances in the waters of fishery water bodies"]," by Ministry of Agriculture of the Russian Federation, 2016 (http://publication.pravo.gov.ru/Document/View/0001201701160006?index=1). In the public domain. **From "Postanovlenie No. 2 Glavnogo Gosudarstvennogo Sanitarnogo Vracha RF "Ob utverzhdenii sanitarnyh pravil i norm "Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya" [Decree No. 2 of the Chief State Sanitary Doctor of the Russian Federation "On approval of sanitary rules and norms "Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans"]," by the Chief State Sanitary Doctor of the Russian Federation, 2021 (https://faolex.fao.org/docs/pdf/rus215586.pdf). In the public domain. ***Must correspond to the background value of the parameter for water of fishery importance water body.

The main sources of Sr pollution are chemical fertilizers, industrial waste, wastewater, and rocks. Sr is not one of the priority elements in the study of the water bodies' ecological state and remains one of the least studied chemical elements. It has been proven that Sr is an antagonist of P, I, and Ca in living organisms due to its physicochemical similarity with Ca and Ba (Medvedev & Derevyagin, 2017). Sr easily penetrates into the bone tissue of vertebrates, where it accumulates. Increased Sr content in organism causes rickets and other diseases, and can exhibit a general toxic effect (Peng et al., 2021). In the future, regularly monitoring of the Sr content in studied shallow channels is necessary.

The results also showed that the water in all the studied shallow channels belong to the category of freshwater according to the generally accepted classification of natural waters (based on total dissolved solids data). The classification of Alekin (1953) was used to classify water in the studied shallow channels according to their chemical composition. Based on this classification, natural waters are divided into three classes according to the predominant anion. Each class is divided into three groups according to the predominant cation. Several types are distinguished in groups based on the ratio between ions. The relationship between ions and their relative content from the total sum of ions in the water samples was calculated according to Equation 1 and graphically presented in Figure 3.

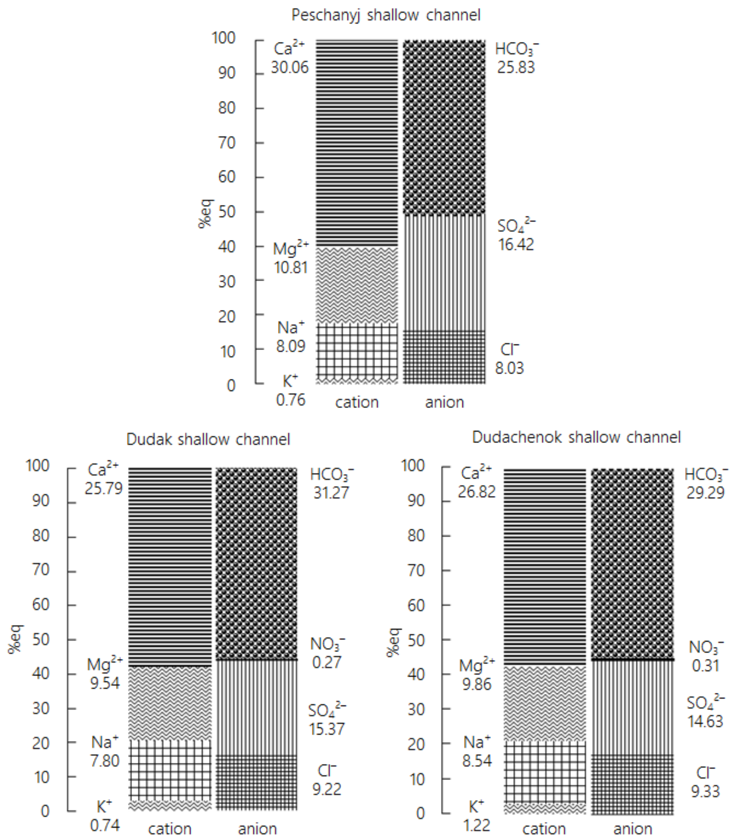

Figure 3. Diagrams of the chemical composition of water from the studied shallow channels.

The results (Figure 3) indicate that the water in Peschanyj, Dudak, and Dudachenok shallow channels belong to the hydrocarbonate class (the predominant anion) and to the calcium group (the predominant cation). The type of studied natural waters was also determined according to the classification of Alekin (1953) based on the relationship between cations and anions (Figure 3). For all objects of study, the relation $HCO_3^- < Ca^{2+} + Mg^{2+} < HCO_3^- + SO_4^{2-}$ is true. Therefore, the water in the studied objects belongs to the second type.

4.2. The chemical composition of bottom sediments from Peschanyj, Dudak, and Dudachenok shallow channels

4.2.1. Content of water-soluble cations and anions in bottom sediments

Bottom sediment samples were analyzed by capillary electrophoresis to determine the content of water-soluble forms of cations and anions (Table 2). The level of water-soluble cations and anions in bottom sediments must be monitored to assess the ecological state of aquatic ecosystems. Such forms of elements are able to activate from the solid state and migrate to the aquatic environment, where they become biologically available. The results of the study showed that bottom sediment samples had distinct chemical composition (Table 2), while all the studied shallow channels share close surface water chemistry (Table 1). This is mainly due to the catchment geology (Nomosatryo et al., 2021).

Table 2. The chemical properties of bottom sediments from Peschanyj, Dudak, and Dudachenok shallow channels, average values

Parameters	Shallow channel		
	Peschanyj	Dudak	Dudachenok
NH_4^+, mg/kg	2.77	19.6	9.7
K^+, mg/kg	13.8	53.4	9
Na^+, mg/kg	34.4	71	27
Mg^{2+}, mg/kg	20.5	118	17
Ca^{2+}, mg/kg	85	458	72
Cl^-, mg/kg	32.7	98	36
SO_4^{2-}, mg/kg	398	1,360	128
NO_3^-, mg/kg	<3	183	<3
F^-, mg/kg	<1	1.46	<1
PO_4^{3-}, mg/kg	<3	<3	<3
$(COO)_2^{2-}$, mg/kg	<3	4.53	<3

Figure 4 shows a comparative study of the chemical composition of water and bottom sediments from the corresponding shallow channels. Analysis of the obtained data showed that the content of the corresponding ions in bottom sediments is higher than in water. This indicates the possibility of cations and anions migration into the water column with an increase in the concentration of the corresponding ions. Therefore, regular monitoring of the chemical composition of both water and bottom sediments is necessary for reliable results on the distribution, geochemical migration, biologically availability of elements, and substances of aquatic ecosystems, as well as for the timely detection of pollution and ensuring the safety of water resources.

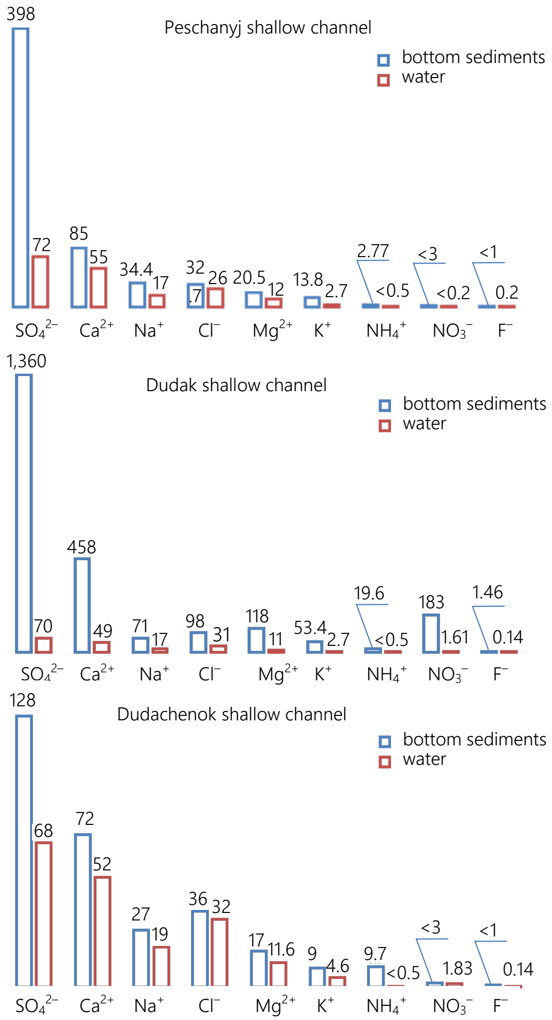

Figure 4. Content of cations and anions in bottom sediments (mg/kg) and water (mg/dm^3) from Peschanyj, Dudak, and Dudachenok shallow channels.

4.2.2. Content of heavy metals and pesticides in bottom sediments

Heavy metals and pesticides are the most common and dangerous pollutants in water bodies. Heavy metals are sometimes good indicators of environmental pollution (Briffa et al., 2020). Metals contained in bottom sediments are capable of being "fixed" in stable fractions. However, changes in pH lead to their washing out and absorption by the flora and fauna of water bodies. There are the following metals Cu, Zn, Cd, Pb, Ni, Hg, Mn, and As in bottom sediments samples. Pesticides (α-HCH, γ-HCH, P,P'-DDE, P,P'-DDT) were not detected. The corresponding data are presented in Table 3.

Table 3. Content of heavy metals and pesticides in bottom sediments

Parameters	Shallow channel		
	Peschanyj	Dudak	Dudachenok
As, mg/kg	1.1	1	1.4
Hg, mg/kg	0.75	0.2	0.18
Cd, mg/kg	2.12	1	1.5
Mn, mg/kg	370.8	493.3	460
Cu, mg/kg	8.54	28.7	17.1
Ni, mg/kg	2.6	65	67.9
Pb, mg/kg	18.5	22	14.3
Zn, mg/kg	75.2	145	147
α-HCH, mg/kg	<0.01	<0.01	<0.01
γ-HCH, mg/kg	<0.01	<0.01	<0.01
P,P'-DDE, mg/kg	<0.005	<0.005	<0.005
P,P'-DDT, mg/kg	<0.01	<0.01	<0.01

MPCs of heavy metals in bottom sediments in Russia have not yet been established. Therefore, to compare the established concentrations of metals in the bottom sediments with the permissible ones (Table 4) the authors used background concentrations (Tikhomirov & Markov, 2009), standards adopted in some Dutch-Russian projects (Golinskaya, 2009; Normativy i kriterii ocenki zagryazneniya donnyh otlozhenij v vodnyh ob'ektah Sankt-Peterburga, 1996), which are based on the standards and criteria proposed by the Dutch Environmental Protection Agency, as well as MPCs established by Dauvalter (2012) for freshwater bottom sediments of the European North, and maximum permissible levels (MPLs) of metal content developed by Anokhina (2004).

The content of As and Cu in bottom sediments of all the studied shallow channels does not exceed the permissible concentrations, which are given in Table 4. A comparison of the established concentrations of heavy metals with background concentrations revealed:

- an excess of Cd and Zn content for all objects of study;
- an excess of Ni content in bottom sediments from Dudak and Dudachenok shallow channels; and
- an excess of Pb content in bottom sediments from Peschanyj and Dudak shallow channels.

A comparison of the established concentrations of heavy metals with MPC revealed:

- an excess of Cd content in bottom sediments from Peschanyj shallow channel, and
- an excess of Mn content in bottom sediments from Dudak and Dudachenok shallow channels.

A comparison of the established concentrations of heavy metals with MPL (Table 4) revealed:

- an excess of Hg content for all objects of study;
- an excess of Pb content in bottom sediments from Peschanyj and Dudak shallow channels; and
- an excess of Ni and Zn content in bottom sediments from Dudak and Dudachenok shallow channels.

A comparison of the established concentrations of heavy metals with permissible concentrations specified in the Dutch-Russian projects revealed:

- an excess of Cd content for all the objects of study;
- an excess of Hg content in bottom sediments from Peschanyj shallow channel; and
- an excess of Ni and Zn content in bottom sediments from Dudak and Dudachenok shallow channels.

Table 4. Permissible concentrations of heavy metals in bottom sediments

Standards	As, mg/kg	Hg, mg/kg	Cd, mg/kg	Mn, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg
Background concentrations*	-	-	0.11	520	33	27.9	16.0	44
MPC**	-	-	1.5	400	30	200	500	200
MPL***	18.33	0.04	2.2	-	32	53	18	105
Standards adopted in Dutch-Russian projects****	29	0.3	0.8	-	35	35	85	140

Note. *Background concentrations of heavy metals in bottom sediments. From "Nakoplenie tyazhelyh metallov v donnyh otlozheniyah akval'nyh kompleksov vodohranilishcha sezonnogo regulirovaniya stoka [Heavy metals accumulation in bottom deposits of aquatic complexes in a reservoir of seasonally controlled outflow]," by O. A. Tikhomirov and M. V. Markov, 2009, *Uchenye Zapiski Kazanskogo Universiteta. Seriya. Estestvennye Nauki*, *151*(3), 143–152 (https://kpfu.ru/portal/docs/F_1107635653/151_3_est_14.pdf). In the public domain.

**MPC of heavy metals in bottom sediments. From *Geoekologiya donnyh otlozhenij ozer* [Geoecology of Lake Bottom Sediments], by V. A. Dauvalter, 2012, MSTU Publishing House. In the public domain.

***MPL of heavy metals in bottom sediments. From *Ekologicheskoe normirovanie soderzhaniya zagryaznyayushchih veshchestv v donnyh otlozheniyah Kujbyshevskogo vodohranilishcha* [Environmental regulation of the pollutants content in bottom sediments of the Kuibyshev reservoir; Dissertation Abstract], by O. K. Anokhina, 2004, Kazan Federal University (https://dspace.kpfu.ru/xmlui/handle/net/31762?show=full&locale-attribute=en). In the public domain.

****Standards adopted in Dutch-Russian projects. From "Normativy i kriterii ocenki zagryazneniya donnyh otlozhenij v vodnyh ob'ektah Sankt-Peterburga. Regional'nyj normativ [Standards and criteria for the evaluation of pollution of bottom sediments in water bodies of St. Petersburg. Regional standard]," by Open Joint Stock Company "Lenmorniiproekt", 1996 (https://docs.cntd.ru/document/352042722). In the public domain. From "Ocenka soderzhaniya ryada metallov v donnyh otlozheniyah vodoemov vostochnogo Orenburzh'ya [Assessment of the content of a number of metals in bottom sediments of reservoirs in the eastern Orenburg region]," by L. V. Golinskaya, 2009, *Vestnik of the Orenburg State University*, *6*(100), 558–559 (http://vestnik.osu.ru/doc/1226/article/4637/lang/0). In the public domain.

The obtained results indicate potentially critical elements (Hg, Cd, Mn, Ni, Pb, Zn), which require regular monitoring. There is uneven distribution of heavy metals in the studied shallow channels (Table 3), which is consistent with literature data for the Lower Volga (Maslov et al., 2021; Tomilina et al., 2018). Literature data analysis also shows that heavy metals content in bottom sediments of the Lower Volga varies among different authors (Brekhovskikh et al., 2017; Lychagin et al., 2015). It can be assumed that this is due to the influence of hydrodynamic conditions, changes in water and sediment flow, as well as local factors of aquatic ecosystems, including due to the catchment heterogeneous geology. Also, the difference between the obtained and the literature data may be due to the fact that the studied shallow channels have dried out during the summer-autumn low-water period for the last few decades.

5. Conclusion

Studies of the chemical composition of water and bottom sediments from the Peschanyj, Dudak, and Dudachenok shallow channels after their clearance and ecological rehabilitation were carried out. Such studies were carried out for the first time after the clearance and ecological rehabilitation of the Volga-Akhtuba floodplain shallow channels. The obtained data showed that almost all the studied parameters in water samples correspond to the established quality standards. However, Sr values (0.6–0.97 mg/dm^3) were higher than the MPCs for water bodies of fishery importance (0.4 mg/dm^3) in all the water samples.

However, such Sr content was noted by a number of authors and is typical for the Volga waters. The water in all the study objects is fresh and corresponds to the hydrocarbonate class, calcium group, and second type. There are levels of the corresponding ions in bottom sediments that exceed those in the water. The research results showed that heavy metals in bottom sediments of the studied shallow channels were unevenly distributed: Cu (8.54–28.7 mg/kg), Zn (75.2–147 mg/kg), Cd (1–2.12 mg/kg), Pb (14.3–22 mg/kg), Ni (2.6–67.9 mg/kg), Hg (0.18–0.75 mg/kg), Mn (370.8–493.3 mg/kg), and As (1–1.4 mg/kg). It can be caused by the influence of hydrodynamic conditions, changes in water and sediment flow, as well as local factors, including the catchment heterogeneous geology. A comparative analysis of the metal content in the studied bottom sediments with the corresponding values of the published standards for bottom sediments of freshwater systems makes it possible to determine potentially critical elements (Hg, Cd, Mn, Ni, Pb, and Zn), which require regular monitoring. The content of As and Cu in bottom sediments of all the studied shallow channels does not exceed the permissible concentrations.

The obtained results can subsequently be used to develop and improve a regional system for assessing water quality, a comprehensive assessment of clearance and ecological rehabilitation of the Volga-Akhtuba floodplain watercourses, as well as to assess the environmental risk for the population that actively uses inland water bodies as a drinking-water source and for technical purposes.

Acknowledgments

This study was carried out as the part of the State Assignment No FNFE-2022-0011 "Development of a new methodology for the optimal bioresources management in the agrolandscapes of the arid zone of the Russian Federation using system-dynamic modeling of soil-hydrological processes, a complex assessment of the impact of climate changes and anthropogenic pressures on agrobiological potential and forest growing conditions". Part of results were presented at an international conference "XI International Scientific and Practical Conference Innovative Technologies in Environmental Science and Education", Divnomorskoe village, Russia, September 4–10, 2023.

References

Advanced ESCC 2024. (n.d.). *Third Global Summit on Advances in Earth Science and Climate Change*. Advanced ESCC 2024. Retrieved January 23, 2024 from https://advanced-earth-climate-change.peersalleyconferences.com/

Alekin, O. A. (1953). *Osnovy gidrohimii. Uchebnoe posobie dlya vuzov* [Fundamentals of hydrochemistry. Textbook for universities]. Gidrometeoizdat.

Anokhina, O. K. (2004). *Ekologicheskoe normirovanie soderzhaniya zagryaznyayushchih veshchestv v donnyh otlozheniyah Kujbyshevskogo vodohranilishcha* [Environmental regulation of the pollutants content in bottom sediments of the Kuibyshev reservoir; Dissertation Abstract, Kazan Federal University]. Kazan Federal University Digital Repository. https://dspace.kpfu.ru/xmlui/handle/net/31762?show=full&locale-attribute=en

Balla, D., Zichar, M., Kiss, E., Szabó, G., & Mester, T. (2022). Possibilities for Assessment and Geovisualization of Spatial and Temporal Water Quality Data Using a WebGIS Application. *ISPRS International Journal of Geo-Information*, *11*(2), Article 108. https://doi.org/10.3390/ijgi11020108

Belyaev, A. I., Istomin, A. P., Pugacheva, A. M., Zhikharev, A. G., Sukhov, A. A., & Arkov, D. P. (2021, September 20–25). *Kompleks mer, napravlennyh na sohranenie unikal'noj ekosistemy Volgo-Ahtubinskoj pojmy na territorii Volgogradskoj oblasti* [Complex measures aimed at the preservation of the unique ecosystem of the Volgo-Akhtub floodplain on the territory of the Volgograd region]. The All-Russian theoretical and practical conference with international participation "Trans boundary water bodies: use, management, conservation", Sochi, Russia. https://rwec.ru/docs/events/conf2021/sbornik-2021.pdf

Belyaev, A. I., Pugacheva, A. M., & Korneeva, E. A. (2022). Assessment of Ecosystem Services of Wetlands of the Volga–Akhtuba Floodplain. *Sustainability*, *14*(18), Article 11240. https://doi.org/10.3390/su141811240

Brekhovskikh, V. F., Ostrovskaya, E. V., Volkova, Z. V., Monakhov, S. K., Perekalsky, V. M., Abramov, N. N., Nemirovskaya, I. A., Savenko, A. V., Pokrovsky, O. S., Agatova, A. I., Lapina, N. M., Torgunova, N. I., Brezgunov, V. S., Petrova, N. V., Kurdina, L. V., Kurapov, A. A., Zubanov, S. A., & Nepomenko, L. F. (2017). *Zagryaznyayushchie veshchestva v vodakh Volzhsko-Kaspiiskogo basseina* [Pollutants in Water of the Volga–Caspian Basin]. Sorokin Roman Vasil'evich.

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, *6*(9), Article e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

Dauvalter, V. A. (2012). *Geoekologiya donnyh otlozhenij ozer* [Geoecology of lake bottom sediments]. MSTU Publishing House.

Ghafarifarsani, H., Rohani, M. F., Raeeszadeh, M., Ahani, S., Yousefi, M., Talebi, M., & Hossain, M. S. (2024). Pesticides and heavy metal toxicity in fish and possible remediation – a review. *Annals of Animal Science*. Ahead of print. https://doi.org/10.2478/aoas-2024-0012

Golinskaya, L. V. (2009). Ocenka soderzhaniya ryada metallov v donnyh otlozheniyah vodoemov vostochnogo Orenburzh'ya [Assessment of the content of a number of metals in bottom sediments of reservoirs in the eastern Orenburg region]. *Vestnik of the Orenburg State University*, *6*(100), 558–559. http://vestnik.osu.ru/doc/1226/article/4637/lang/0

Golub, V. B., Chuvashov, A. V., Bondareva, V. V., Gerasimova, K. A., & Nikolaichuk, L. F. (2020). Changes in the Flora Composition of the Volga–Akhtuba Floodplain after Regulation of the Flow of Volga River. *Arid Ecosystems*, *10*, 44–51. https://doi.org/10.1134/S2079096120010047

Google Earth (Version 10.52.0.0), Google Maxar Technologies Airbus. (2024). Retrieved May 4, 2024 from https://www.google.com/earth/about/versions/#earth-for-web

Gordeev, V. V. (2012). *Geoximiya sistemy` reka-more* [Geochemistry of the river-sea system]. IP Matushkina I.I.

Kablov, V. F., Kostin, V. E., & Sokolova, N. A. (2015). *Volgo-Ahtubinskaya pojma. Ekologicheskaya situaciya: problemy i resheniya po ee uluchsheniy* [Volga-Akhtuba floodplain. Ecological situation: problems and solutions for its improvement]. VSTU. https://volpi.ru/files/department/ekos/ecos_activity/monograph.pdf

Leummens, H. J. L. (2018). Volga River Delta (Russia). In C. M. Finlayson, G. R. Milton, R. C. Prentice, & N. C. Davidson (Eds.), *The Wetland Book* (pp. 945–958). Springer. https://doi.org/10.1007/978-94-007-4001-3_29

Li, Y., Li, Q., Jiao, S., Liu, C., Yang, L., Huang, G., Zhou, S., Han, M., & Brancelj, A. (2022). Water Quality Characteristics and Source Analysis of Pollutants in the Maotiao River Basin (SW China). *Water*, *14*(3), Article 301. https://doi.org/10.3390/w14030301

Lychagin, M. Yu., Tkachenko, A. N., Kasimov, N. S., & Kroonenberg, S. B. (2015). Heavy Metals in the Water, Plants, and Bottom Sediments of the Volga River Mouth Area. *Journal of Coastal Research*, *31*(4), 859–868. https://doi.org/10.2112/JCOASTRES-D-12-00194.1

Maaroof, B. F., Omran, M. H., Al-Qaim, F. F., Salman, J. M., Hussain, B. N., Abdellatif, M., Carnacina, I., Al-Hasani, B., Jawad, M. R., & Hussein, W. A. (2023). Environmental assessment of Al-Hillah River pollution at Babil Governorate (Iraq). *Journal of the Geographical Institute "Jovan Cvijić" SASA*, *73*(1), 1–16. https://doi.org/10.2298/IJGI2301001M

MapChart. (2024). *Russia map*. MapChart. Retrieved May 4, 2024 from https://www.mapchart.net/russia.html

Maslov, A. V., Nemirovskaya, I. A., & Shevchenko, V. P. (2021). Distribution of Heavy Metals in Gray Silts in the Volga Cascade of Reservoirs. *Water Resources*, *48*, 977–990. https://doi.org/10.1134/S0097807821060117

Mazzucato, M., Okonjo-Iweala, N., Rockström, J., & Shanmugaratnam, T. (2023). *Turning the Tide: A Call to Collective Action*. Global Commission on the Economics of Water. https://watercommission.org/

publication/turning-the-tide-a-call-to-collective-action/

Medvedev, I. F., & Derevyagin, S. S. (2017). *Tyazhelye metally v ekosistemah* [Heavy metals in ecosystems]. Rakurs. https://www.arisersar.ru/Litera/107.12.17.pdf

Moiseenko, T. I., Gashkina, N. A., Sharova, Y. N., & Pokoeva, A. G. (2005). Ecotoxicological Assessment of After-Effects of the Volga River Water Contamination. *Water Resources*, *32*(4), 369–383. https://doi.org/10.1007/s11268-005-0048-6

Nitskaya, S. G., & Antonenko, I. V. (2023). Mikroelementnyj sostav donnyh otlozhenij vodnyh ob"ektov v usloviyah gorodskoj zastrojki [Microelement composition of bottom sediments of water bodies in urban conditions]. *Bulletin of the South Ural State University. Chemistry series*, *15*(1), 149–158. https://cyberleninka.ru/article/n/mikroelementnyy-sostav-donnyh-otlozheniy-vodnyh-obektov-v-usloviyah-gorodskoy-zastroyki

Nomosatryo, S., Tjallingii, R., Schleicher, A. M., Boli, P., Henny, C., Wagner, D., & Kallmeyer J. (2021). Geochemical Characteristics of Sediment in Tropical Lake Sentani, Indonesia, Are Influenced by Spatial Differences in Catchment Geology and Water Column Stratification. *Frontiers in Earth Science*, *9*, Article 671642. https://doi.org/10.3389/feart.2021.671642

Normativy i kriterii ocenki zagryazneniya donnyh otlozhenij v vodnyh ob'ektah Sankt-Peterburga. Regional'nyj normativ [Standards and criteria for the evaluation of pollution of bottom sediments in water bodies of St. Petersburg. Regional standard], Open Joint Stock Company "Lenmorniiproekt" (1996). https://docs.cntd.ru/document/352042722

Ovchinnikov, A. S., Loboiko, V. F., Yakovlev, S. V., Ovcharova, A. Yu., Ivantsova, E. A., & Solovyova, I. A. (2020). *Vodohranilishcha, prudy i ozyora Volgogradskoj oblasti* [Reservoirs, ponds and lakes of the Volgograd region]. Volgograd State Agrarian University. https://elibrary.ru/item.asp?id=46597838

Peng, H., Yao, F., Xiong, S., Wu, Z., Niu, G., & Lu, T. (2021). Strontium in public drinking water and associated public health risks in Chinese cities. *Environmental Science and Pollution Research*, *28*, 23048–23059. https://doi.org/10.1007/s11356-021-12378-y

Postanovlenie No. 2 Glavnogo Gosudarstvennogo Sanitarnogo Vracha RF "Ob utverzhdenii sanitarnyh pravil i norm "Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya" [Decree No. 2 of the Chief State Sanitary Doctor of the Russian Federation "On approval of sanitary rules and norms "Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans"], SanPiN 1.2.3685-21 (2021). https://faolex.fao.org/docs/pdf/rus215586.pdf

Prikaz Ministerstva sel'skogo hozyajstva Rossijskoj Federacii ot 13.12.2016 "Ob utverzhdenii normativov kachestva vody vodnyh ob"ektov rybohozyajstvennogo znacheniya, v tom chisle normativov predel'no dopustimyh koncentracij vrednyh veshchestv v vodah vodnyh ob"ektov rybohozyajstvennogo znacheniya" [Order of the Ministry of Agriculture of the Russian Federation dated December 13, 2016 "On approval of water quality standards for fishery water bodies, including standards for maximum permissible concentrations of harmful substances in the waters of fishery water bodies"], No. 552 (2016). http://publication.pravo.gov.ru/Document/View/0001201701160006?index=1

Prirodoohrannyj normativnyj dokument federal'nyj. Kolichestvennyj himicheskij analiz pochv. Metodika izmerenij massovoj doli vodorastvorimyh form kationov ammoniya, kaliya, natriya, magniya, kal'ciya v pochvah, gruntah, gline, torfe, osadkah stochnyh vod, donnyh otlozheniyah metodom kapillyarnogo elektroforeza s ispol'zovaniem sistemy kapillyarnogo elektroforeza "Kapel'" [Natural-normative document federal. Quantitative chemical analysis of soils. A method for mass fraction measuring of water-soluble forms of ammonium, potassium, sodium, magnesium, calcium cations in soils, soils, clay, peat, sewage sludge, bottom sediments using the capillary electrophoresis method by "Kapel" capillary electrophoresis system], The Federal Supervisory Natural Resources Management Service of the Russian Federation, 16.1:2:2.2:2.3.74-2012 (2012).

Prirodoohrannyj normativnyj dokument federal'nyj. Kolichestvennyj himicheskij analiz vod. Metodika i izmerenij massovoj koncentracii gidrokarbonatov v probah prirodnyh i stochnyh vod titrimetricheskim metodom [Natural-normative document federal. Quantitative chemical analysis of water. Methodology for hydrocarbonates mass concentration measuring in samples of natural and waste waters using the titrimetric method], The Federal Supervisory Natural Resources Management

Service of the Russian Federation, 14.1:2:3.99-97 (2017).

Prirodoohrannyj normativnyj dokument federal'nyj. Kolichestvennyj himicheskij analiz vod. Metodika izmerenij obshchej zhestkosti v probah prirodnyh i stochnyh vod titrimetricheskim metodom. [Natural-normative document federal. Quantitative chemical analysis of water. Methodology for total hardness measuring in samples of natural and waste waters using the titrimetric method], The Federal Supervisory Natural Resources Management Service of the Russian Federation, 14.1:2:3.98-97 (2016).

Prirodoohrannyj normativnyj dokument federal'nyj. Kolichestvennyj himicheskij analiz vod. Metodika vypolneniya izmerenij massovyh koncentracij hlorid-ionov, nitrit-ionov, sul'fat-ionov, nitrat-ionov, ftorid-ionov i fosfat-ionov v probah prirodnyh, pit'evyh i ochishchennyh stochnyh vod s primeneniem sistemy kapillyarnogo elektroforeza "Kapel'" [Natural-normative document federal. Quantitative chemical analysis of water. Methodology for mass concentrations measuring of chloride ions, nitrite ions, sulfate ions, nitrate ions, fluoride ions and phosphate ions in samples of natural, drinking and treated wastewater using "Kapel" capillary electrophoresis system], The Federal Supervisory Natural Resources Management Service of the Russian Federation, 14.1:2:3:4.282-18 (2018).

Prirodoohrannyj normativnyj dokument federal'nyj. Kolichestvennyj himicheskij analiz vod. Metodika vypolneniya izmerenij massovyh koncentracij kationov kaliya, natriya, litiya, magniya, kal'ciya, ammoniya, stronciya, bariya v probah pit'evyh, prirodnyh, stochnyh vod metodom kapillyarnogo elektroforeza s ispol'zovaniem sistemy kapillyarnogo elektroforeza "Kapel'" [Natural-normative document federal. Quantitative chemical analysis of water. Methodology for mass concentrations measuring of potassium, sodium, lithium, magnesium, calcium, ammonium, strontium, barium cations in samples of drinking, natural, and waste waters using capillary electrophoresis by "Kapel" capillary electrophoresis system], The Federal Supervisory Natural Resources Management Service of the Russian Federation, 14.1:2:4.167-2000 (2000).

Prirodoohrannyj normativnyj dokument federal'nyj. Metodika izmerenij massovoj doli vanadiya, kadmiya, kobal'ta, marganca, medi, mysh'yaka, nikelya, rtuti, svinca, hroma i cinka v probah pochv, gruntov, donnyh otlozhenij, osadkov stochnyh vod atomno-absorbcionnym metodom s elektrotermicheskoj atomizaciej s ispol'zovaniem atomno-absorbcionnyh spektrometrov serii "MGA" [Natural-normative document federal. Methodology for mass fraction measuring of vanadium, cadmium, cobalt, manganese, copper, arsenic, nickel, mercury, lead, chromium and zinc in samples of soils, bottom sediments, sewage sludge by the atomic absorption method with electrothermal atomization using atomic absorption spectrometers series "MGA"], The Federal Supervisory Natural Resources Management Service of the Russian Federation, 16.1:2:2.2:2.3.63-09 (2014).

Prirodoohrannyj normativnyj dokument federal'nyj. Metodika izmerenij massovoj doli vodoractvorimyh form hlorid-, sul'fat-, oksalat-, nitrat-, ftorid-, formiat-, fosfat-, acetat- ionov v pochvah, gruntah teplichnyh, glinah, torfe, osadkah stochnyh vod, aktivnom ile, donnyh otlozheniyah metodom kapillyarnogo elektroforeza s ispol'zovaniem sistemy kapillyarnogo elektroforeza "Kapel'" [Natural-normative document federal. Methodology for mass fraction measuring of water-soluble forms of chloride, sulfate, oxalate, nitrate, fluoride, formate, phosphate, acetate ions in soils, greenhouse soils, clays, peat, sewage sludge, activated sludge, bottom sediments using the capillary electrophoresis method by the "Kapel" capillary electrophoresis system], The Federal Supervisory Natural Resources Management Service of the Russian Federation, 16.1:2:2.3:2.2.69-10 (2010).

Riaz, U., Rafi, F., Naveed, M., Mehdi, S. M., Murtaza, G., Niazi, A. G., & Mehmood, H. (2021). Pesticide Pollution in an Aquatic Environment. In G. H. Dar, K. R. Hakeem, M. A. Mehmood, & H. Qadri (Eds.), *Freshwater Pollution and Aquatic Ecosystems. Environmental Impact and Sustainable Management* (pp. 131–163). Apple Academic Press.

Romanova, T. I., & Bolshanik, P. V. (2022). Characteristics of the chemical composition of bottom sediments from springs in Khanty-Mansiysk. *International Research Journal*, *10*(124). https://doi.org/10.23670/IRJ.2022.124.33

Rukovodyashchij document. Massovaya dolya galoidorganicheskih pesticidov P,P'-DDT, P,P'-DDE, α-GHCG, γ-GHCG, trifluralina v probah pochvy. Metodika izmerenij metodom gazozhidkostnoj hromatografii [Guideline document. Mass fraction of organohalogen pesticides P,P'-DDT, P,P'-DDE, α-HCH, γ-HCH, trifluralin in soil samples. Method of measurements using gas chromatography], All-Russia Research

Institute of Hydrometeorological Information, World Data Centre, 52.18.180-2011 (2011).

Savenko, A. V., Brekhovskikh, V. F., & Pokrovsky, O. S. (2016). Macro- and Microelement Water Composition of the Volga River Delta and Its Interannual Variability. *Arid Ecosystems*, *6*(1), 8–17. https://doi.org/10.1134/S2079096116010042

Tikhomirov, O. A., & Markov, M. V. (2009). Nakoplenie tyazhelyh metallov v donnyh otlozheniyah akval'nyh kompleksov vodohranilishcha sezonnogo regulirovaniya stoka [Heavy metals accumulation in bottom deposits of aquatic complexes in a reservoir of seasonally controlled outflow]. *Uchenye Zapiski Kazanskogo Universiteta. Seriya. Estestvennye Nauki*, *151*(3), 143–152. https://kpfu.ru/portal/docs/F_1107635653/151_3_est_14.pdf

Tomilina, I. I., Gapeeva, M. V., & Lozhkina, R. A. (2018). Ocenka kachestva vody i donnyh otlozhenij kaskada vodohranilishch reki Volga po pokazatelyam toksichnosti i himicheskogo sostava [Assessing the quality of water and bottom sediments in Volga cascade of reservoirs by characteristics of toxicity and water chemistry]. *Transactions of IBIW RAS*, *81*(84), 107–131. https://cyberleninka.ru/article/n/otsenka-kachestva-vody-i-donnyh-otlozheniy-kaskada-vodohranilisch-reki-volga-po-pokazatelyam-toksichnosti-i-himicheskogo-sostava

Vasilchenko, A. A. (2022). Spatial Analysis of the Volga-Akhtuba Floodplain Irrigated Fields Infrastructure in the Volgograd Region. *Scientific Agronomy Journal*, *4*(119), 12–18. https://doi.org/10.34736/FNC.2022.119.4.002.12-18

Zakrutkin, V. E., Gibkov, E. V., Reshetnyak, O. S., & Reshetnyak, V. N. (2020). Donnye otlozheniya kak indikator pervichnogo i istochnik vtorichnogo zagryazneniya rechnyh vod uglepromyshlennyh territorij Vostochnogo Donbassa [River sediments as river waters' primary pollution indicator and secondary pollution source in East Donbass coal-mining areas]. *Izvestiya RAN. Seriya Geograficheskaya*, *84*(2), 259–271. https://doi.org/10.31857/S2587556620020168