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Ecological condition of marine waters in the area of dredging operations of the kashagan field, Kazakhstan

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Abstract
To determine the hydrophysical and hydrochemical parameters of sea water and their changes during dredging works in the north-eastern part of the Caspian Sea along the Western Approach Route and near/inside block D, islands EPC-2, EPC-3, EPC-4 and island A of the Kashagan field.
Measurement of hydrophysical parameters: salinity, temperature, turbidity, dissolved oxygen concentration, electrical conductivity, pH of seawater was carried out using a portable multi-parameter analyser "Horiba-U53" directly in the water column. Water transparency was determined using a Secchi disc. The depth of the water layer was determined using a sounder. Hydrochemical investigations were carried out for seven parameters, with allcomponents sampled in the near-surface and benthic horizons. Water samples were taken using probes or bathometers: BM-48, GR-18 or their analogues.
Hydrochemical analyses of seawater samples for: biogens (NO_2, NO_3, NH_4, N_{total}, and P_{total}), synthetic surfactants, phenols, hydrocarbons including polyaromatic hydrocarbons (PAHS), heavy metals, chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5). These were carried out in laboratory conditions using analytical equipment according to scientifically accepted methods.
The data obtained as a result of the research allow us to draw the following conclusion: changes in the amount of suspended sediment in sea water lead to changes in physical and chemical properties of water (increase in turbidity, disturbance of sediment composition and properties), changes in biotopes, deterioration of oxygen regime, optical properties of water and temperature regime.

Key Words
Kashagan field, hydrophysical and hydrochemical parameters, seawater, dredging, Caspian Sea.

Экологическое состояние морских вод в районе дноуглубительных работ месторождения «Кашаган»

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Резюме
Целью работы является контроль за гидрофизическими и гидрохимическими параметрами морской воды, их изменением в ходе дноуглубительных работ в северо-восточной части Каспийского моря вдоль Западного подходного пути и вблизи/внутри блока D, островов EPC-2, EPC-3, EPC-4 и острова А месторождения «Кашаган».
Измерение гидрофизических параметров: соленость, температура, мутность, концентрация растворенного кислорода, электропроводность, pH морской воды выполнялась с помощью портативного многопараметрического анализатора типа «Horiba-U53» непосредственно в толще воды. Определение прозрачности воды проводилась с помощью диска Секки. Глубина водного слоя определялась с помощью лота. Гидрохимические исследования проводились по семи параметрам, при этом пробы по всем компонентам отбирались в приповерхностном и придонном горизонтах. Отбор проб воды производились с помощью зондов или батометров: БМ-48, ГР-18 или их аналогов.
Гидрохимические исследования проб морской воды на содержание: биогенов (NO_2, NO_3, NH_4, $N_{общ}$, и $P_{общ}$), синтетические поверхностно-активные вещества (СПАВ), фенолов, углеводородов включая полиароматические углеводороды (ПАУ), тяжелых металлов, химическое потребление кислорода (ХПК) и биохимическое потребление кислорода ($БПК_5$) проводились в лабораторных условиях на аналитическом оборудовании, согласно аккредитованных методов.
Данные, полученные в результате исследований, позволяют сделать следующий вывод: изменение количества взвеси в воде моря приводит к изменению физических и химических свойств воды (повышение мутности, нарушение состава и свойств осадков), изменению биотопов, ухудшению кислородного режима, оптических свойств воды, температурного режима.

Ключевые слова
Месторождение «Кашаган», гидрофизические и гидрохимические параметры, морская вода, дноуглубительные работы, Каспийское море.

INTRODUCTION

The Kashagan field, one of the largest and most complex offshore fields discovered to date, is a single hydrocarbon deposit with geological reserves estimated at 4.65 billion tonnes (36.6 billion barrels) and covers an area of approximately 75 km x 45 km. The field is located in the shelf zone of the north-eastern part of the Kazakhstan sector of the Caspian Sea, 75 kilometres south of the city of Atyrau. It is administratively part of the Atyrau region of the Republic of Kazakhstan.

In recent years, the average level of the Caspian Sea has been declining. Recent forecasts indicate that this trend is likely to continue [1–5]. The North Caspian Operating Company (NCOC) conducted dredging works within the framework of the project "Development of Kashagan field facilities. Marine Complex. Marine Shipping Canals (without estimate documentation)", State Expertise Opinion #15-0081/21 dated 26.03.2021 in order to ensure uninterrupted marine logistics operations and emergency evacuation. The total length of dredging works is 56 kilometres.

Dredging was carried out outside the Akzhaik State Reserve protected area, a water protection zone and restricted use zone to ensure normal fish spawning and rafting of juvenile fish from 1 April to 15 July, fishing areas, bird nesting and seal concentration areas (Article 269 of the Ecological Code) [6] (Fig. 1).

The purpose of this work is to determine the state of seawater of the CaspianSea during dredging operations.

The surveys were carried out concurrently with cutter suction dredging in the northern part of the Caspian Sea along the Western Approach Route and near/inside Block D, islands EPC-2, EPC-3, EPC-4 and Island A (Fig. 2).

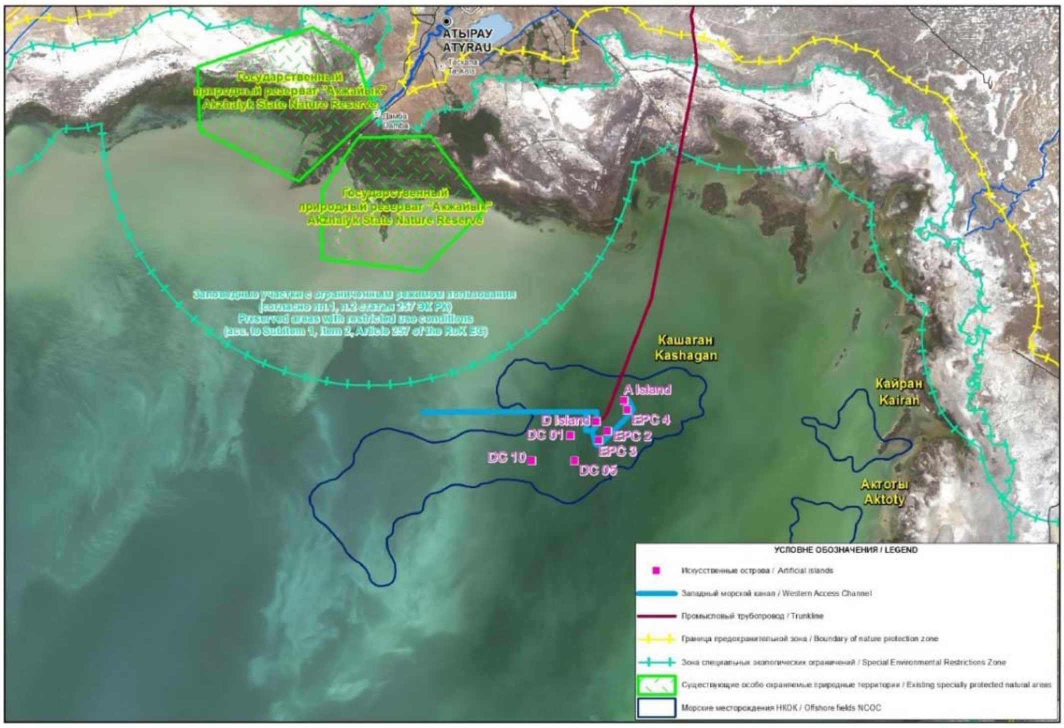

Figure 1. Dredging site

Рисунок 1. Участок проведения дноуглубительных работ

Figure 2. Map of canal and spoil heap locations

Рисунок 2. Ситуационная карта расположения каналов и отвалов

MATERIAL AND METHODS

Controlled parameters and frequency of observations during dredging arepresented in Table 1.

At the work sites, where the sea depths are more than 3 m, studies on hydrological, hydrophysical and hydrochemical indicators were carried out in the surface and bottom horizons. At depths of less than 3 m all studies were carried out at the 1st horizon (1/2 of the total depth).

Monitoring of seawater quality includes hydrophysical and hydrochemical types of observations and research.

Table 1. Parameters and frequency of seawater monitoring
Таблица 1. Контролируемые параметры и периодичность мониторинга морской воды

Monitoring stations Станции мониторинга	**Controlled parameters** Контролируемые параметры	**MAC (mg/dm)^3** ПДК (мг/дм)^3	**Measurement intervals** Интервалы измерения	**Method of analysis** Метод анализа
KCR-1-KCR-11 3 control stations KCR-1-KCR-11 3 контрольные станции	BOD_5 БПК$_5$	3.0	By stage По этапам	Electrometry Электрометрия
	nitrogen ammonium азот аммония	0.5		Spectrophotometry Спектрофотометрия
	nitrate nitrogen нитратный азот	40.0		Spectrophotometry Спектрофотометрия
	nitrate nitrogen нитритный азот	0.08		Spectrophotometry Спектрофотометрия
	nitrate nitrogen общий азот	-		Spectrophotometry Спектрофотометрия
	total phosphorus общий фосфор	-		Spectrophotometry Спектрофотометрия
	COD ХПК	0.05		Chromatography Хроматография
	PAHS ПАУ	-		Chromatography Хроматография
	synthetic surfactants (anionic surfactants) синтетические поверхностно-активные вещества (анионные поверхностно-активные вещества)	0.1		Spectrophotometry Спектрофотометрия
	Phenols фенолы	-		Spectrophotometry Спектрофотометрия
	heavy metals: тяжелые металлы:			Atomic emission spectrometry Атомно-эмиссионная спектрометрия
	Al	-		
	As	0.1		
	Ba	2.0		
	Cd	0.01		
	Cr	-		
	Cz	0.005		
	Fe	0.05		
	Hg	0.0001		
	Ni	0.01		
	Pb	0.01		
	V	0.001		
	Zn	0.05		

Measurements of hydrophysical parameters: salinity, temperature, turbidity, dissolved oxygen concentration, electrical conductivity, and pH of seawater were performed using a portable multi-parameter analyser of the "Horiba-U53" type (or an oceanic measuring device "Sea Guard RCM") directly in the water column. Water transparency was determined using a Secchi disc ⌀300 mm with a reference accuracy of 0.05 m. The depth of the water layer was determined using a sounder.

The zones of increased turbidity distribution form "plumes". The distribution of turbidity plumes was determined by the granulometric composition of the dredged bottom soil, dredging and disposal technology, hydrological andhydrodynamic conditions, etc.

Measurements were taken in the vicinity of four cutter suction dredgers and one mechanical dredger. In each case, 3 samples were taken at distances of approximately: 300, 500 (along the slurry pipeline) and 1000 (near the slurry discharge point) metres from the dredgers.

A platform with stationary automatic equipment "YSO EXO 2" and current profiler "ADTP Nortek" was installed at the conditional background station beyond the turbulence boundary from the main axis of the channel at a distance of more than 2 km.

Hydrochemical studies were carried out for seven parameters, with all components sampled in the near-surface and benthic horizons. In hydrochemical studies of seawater, sampling was carried out in accordance with the provisions of relevant standards [7–9]. Water samples were taken using probes or bathometers: BM-48, GR-18 or their analogues. Before each sampling instruments were completely cleaned. Further, depending on the type of analysis, the sample was spread in special containers made of borosilicate glass or PCV in necessary volume for analytical work. Further samples were filtered and preserved according to accepted methods. Storage and transport of samples were carried out in accordance with the provisions of the relevant standard [10].

Hydrochemical analyses of seawater samples for: biogens (NO_2, NO_3, NH_4, N_{total}, and P_{total}), synthetic surfactants, phenols, hydrocarbons including polyaromatic hydrocarbons (PAHs), heavy metals, COD and BOD_5 were carried out in laboratory conditions using analytical equipment according to scientifically accepted methods.

RESULTS AND DISCUSSION

The characteristics of the current state of physical and chemical parameters of seawater in the area of dredging of the Offshore Complex of the Kashagan field, has been determined based on the materials of reports conducted in the area of channels in the spring, summer and autumn periods 2021–2022 [11–12].

A schematic of the monitoring stations in the area is shown in Figure 3.

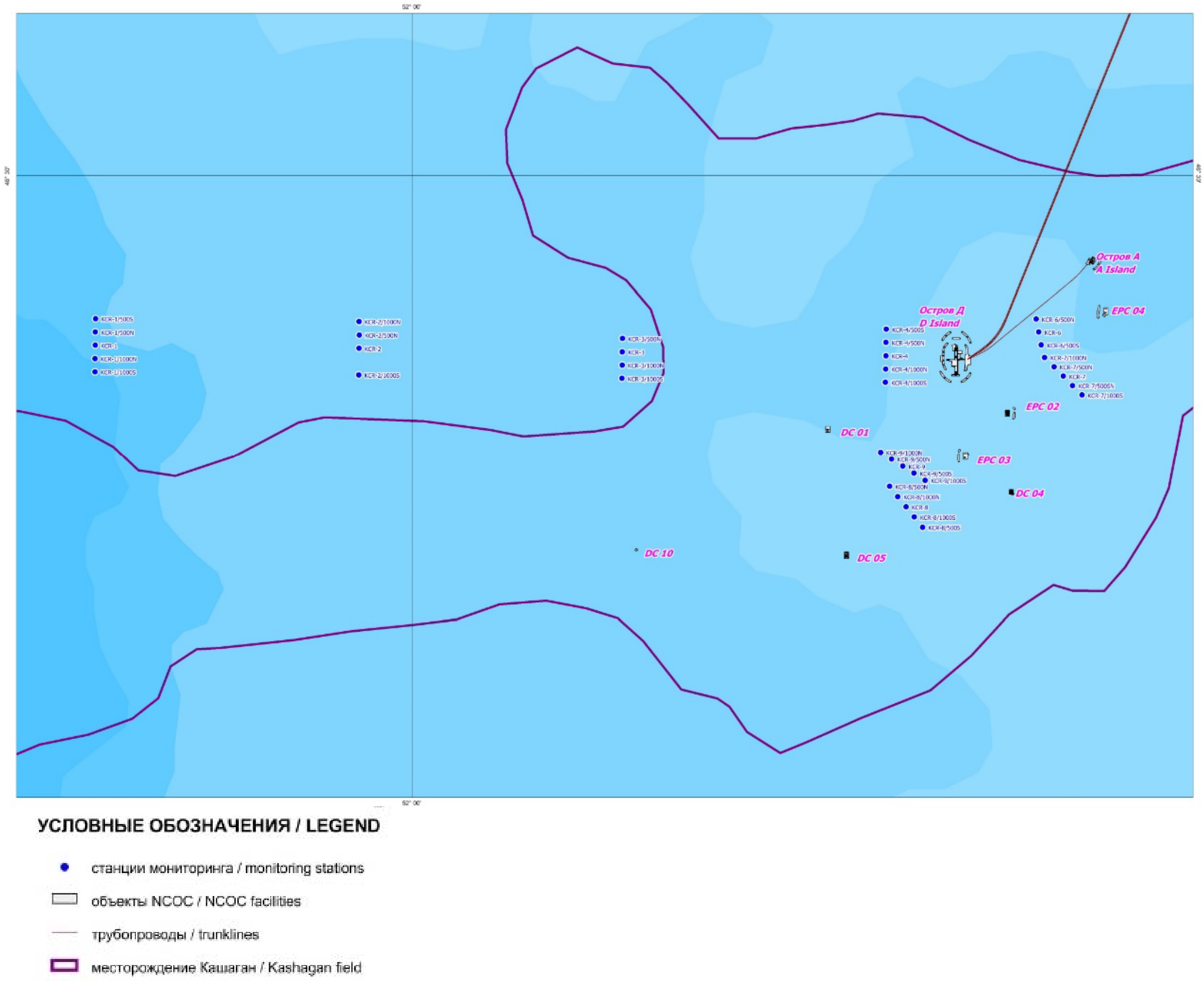

Figure 3. Impact monitoring stations in the West Canal area
Рисунок 3. Станции мониторинга воздействия в районе западного канала

In 2021–2022, the values of pH, salinity, turbidity, dissolved oxygen in water determined in situ in the study water area in the vicinity of the projected canal mainly reflected seasonal fluctuations in meteorological conditions and were at the level of multiyear averages.

Water temperatures in 2021 at the stations ranged from: 15.7°C–16.8 °C in spring, 22.3 °C–24.9 °C in summer, and 13.9°C–18.4 °C in autumn. In 2022, water temperatures ranged from: 6.5–11.6°C in spring, 24.9–28.2 °C in summer, and 17.5–21 °C in autumn.

pH values are mainly determined by the state of carbonate equilibrium throughout the North Caspian, and fluctuate in the alkaline range. In 2021, a minimum pH concentration of 7.20 was recorded in spring and a maximum of 9.89 in autumn. In 2022, pH values in the study area ranged from 8.11–8.63 in spring, 8.21–8.44 in summer and 8.04–8.18 in autumn.

Mean salinity values in 2021 ranged from 8.35 to 9.9 ‰ and in 2022 from 7.5 to 12.01 ‰.

Average dissolved oxygen values in 2021 decreased from spring to summer (from 12.73 mg/dm^3 to

7.06 g/dm^3) and increased to 9.2 g/dm^3 by autumn. In 2022, dissolved oxygen ranged from 9.03 to 11.73 g/dm^3, 6.5 to 7.43 g/dm^3 in spring and 7.44 to 9.91 g/dm^3 in autumn.

The formation of zones ("plumes") of increased turbidity causes a natural decrease in water clarity. Immediately in the area of dredging or disposal, transparency is minimal (may be less than 10 cm). The extent and duration of the decrease in transparency is highly dependent on the particle size distribution of the transported soils/sediments (inversely dependent on the coarseness of the predominant fractions). The effect is maximally pronounced and prolonged when fine (clayey) fractions predominate.

Turbidity values in 2021 ranged from: spring – 65 – 81 NTU; summer – 72 – 193 NTU; autumn – 33.3 – 293 NTU units. In 2022, turbidity values ranged from: spring – 43 – 323 NTU; summer – 2 –141 NTU; autumn – 13 – 67 NTU units. The maximum values can be attributed to the influence of storm waves.

Turbidity in the near-bottom water layer during dredging operations, as atthe background stations, was higher than in the surface layer. The turbidity valuefrom dredging consistently decreased from the dredger to the slurry discharge site which was favoured by the use of cooking pot technology during slurry discharge. According to the Information Bulletin on the state of the environment in the Republic of Kazakhstan (2021–2022), the water quality of the Northern Caspian Sea is not normalized (5th class according to the Unified System of Classification of Water Quality in Water Bodies) [13].

In 2021, the maximum BOD values$_5$ did not exceed 1.0 mgO_2/dm^3 insummer and 1.5 mgO_2/dm^3 in autumn. The average BOD in 2022 was 1.38 mgO_2/dm^3 in spring, while in summer and autumn were close at 0.88 mgO_2/dm^3 and 0.09 mgO_2/dm^3, respectively (Fig. 4).

COD content during this period varied from below detection limits (<10 mgO_2/dm^3) to 195 mgO_2/dm^3. In summer and autumn 2022 the mean COD contents were close at 0.88 mgO_2/dm^3 and 0.094 mgO_2/dm^3 respectively (Fig. 5).

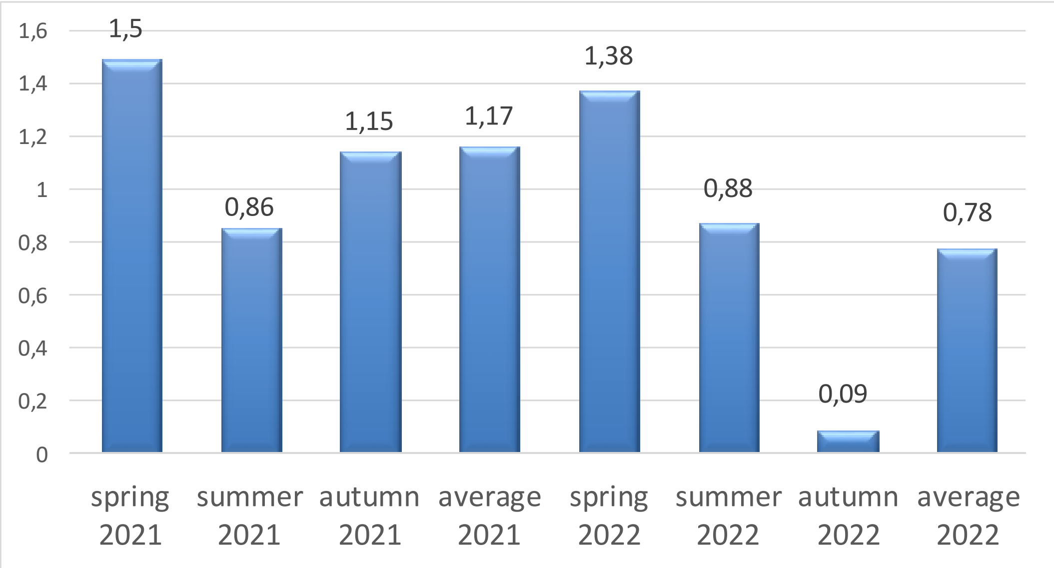

Figure 4. Average BOD_5 contents (mgO_2/dm^3) in water of the canal water area in 2021–2022
Рисунок 4. Средние содержания $БПК_5$ (мгO_2/дм^3) в воде акватории канала в 2021–2022 гг.

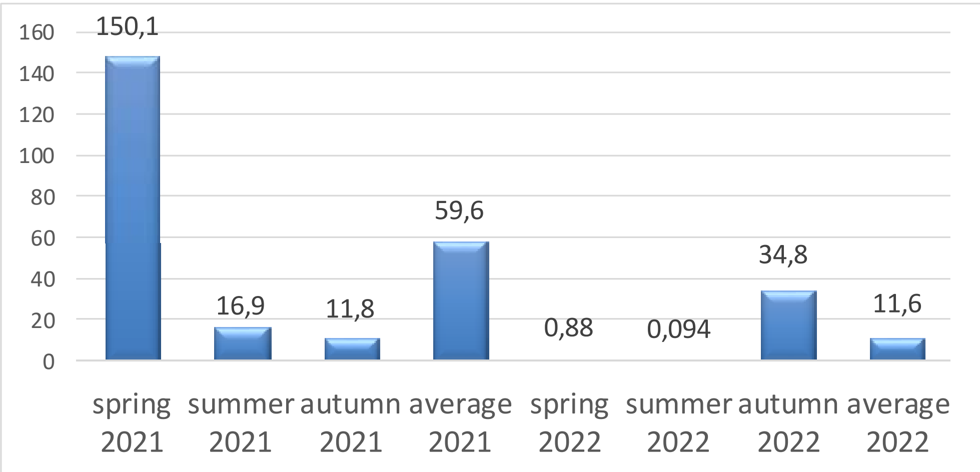

Figure 5. Average COD content (mgO_2/dm^3) in water of the canal water area in2021–2022.
Рисунок 5. Средние содержания ХПК (мгO_2/дм^3) в воде акватории канала в 2021–2022 гг.

During the spring, summer and autumn seasons of 2021–2022, concentrations of nitrogen group nutrients (ammonium nitrogen, nitrite nitrogen, nitrate nitrogen and total nitrogen) and phosphorus were universally below the detection limit of the analytical methods.

In 2021, hydrocarbon concentrations were everywhere below the detection limit of the analytical method (<0.02 mg/dm^3), except for a single case in autumn at station KCR-4/500S (0.10 mg/dm^3). In the spring and summer of 2022, hydrocarbon concentrations were mostly below the sensitivity threshold of the method of analysis. In autumn in 2022, hydrocarbon concentrations ranged from to 0.44 mg/dm^3, with an average of 0.229 mg/dm^3.

During all study periods 2021–2022, phenolic concentrations ranged from below the detection limits of the method of analysis (<0.005–<0.0005 mg/dm^3).

Synthetic surfactants concentrations in the study area from 2021–2022 ranged from "below detection limits" except in autumn 2022, when they ranged from 0.025 to 0.07 mg/dm^3, with an average of 0.048 mg/dm^3.

During the observation period (2021–2022) the contents of aluminium, arsenic, barium, cadmium, chromium, copper, iron, nickel, mercury, lead, vanadium and zinc were monitored in the sea water. The average concentrations of heavy metals detected in the study area for the specified period are given in Table 2.

Table 2. Mean, maximum and minimum values of heavy metal concentrations in seawater in the study area in 2021–2022
Таблица 2. Средние, максимальные и минимальные значения концентраций тяжелых металлов
в морской воде на исследованном участке в 2021–2022 гг.

Season Сезон	**Significance** Значение	**Metals (mg/dm^3) /** Металлы (мг/дм^3)											
		As	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Ni**	**Pb**	**V**	**Zn**	**Al**
Spring 2021 Весна 2021	Min. Мин.	-	-	-	-	0,0156	-	-	-	-	0,00137	-	-
	Max. Макс.	-	-	-	-	0,0147	-	-	-	-	0,00135	-	-
	Average Среднее	<0,0003	<0,007	<0,00003	<0,0003	0,0151	<0,020	<0,00003	<0,0003	<0,0003	0,00136	<0,003	<0,007
Summer 2021 Лето 2021	Min. Мин.	-	-	-	-	0,0136	-	-	-	-	0,00191	-	-
	Max. Макс.	-	-	-	-	0,0182	-	-	-	-	0,00259	-	-
	Average Среднее	<0,0003	<0,007	<0,00003	<0,0003	0,01484	<0,02	<0,00003	<0,0003	<0,0003	0,00224	<0,003	<0,007
Autumn 2021 Осень 2021	Min. Мин.	-	-	-	-	0,0178	-	-	-	-	0,00198	-	-
	Max. Макс.	-	-	-	-	0,0194	-	-	-	-	0,00247	-	-
	Average Среднее	<0,0003	<0,007	<0,00003	<0,0003	0,0185	<0,02	<0,00003	<0,0003	<0,0003	0,00225	<0,003	<0,007
Average 2021 Средняя 2021	Average Среднее	<0,0003	<0,007	<0,00003	<0,0003	0,0161	<0,02	<0,00003	<0,0003	<0,0003	0,00195	<0,003	<0,007
Spring 2022 Весна 2022	Min. Мин.	-	-	-	-	<0,0003	-	-	-	-		-	-
	Max. Макс.	-	-	-	-	0,012	-	-	-	-		-	-
	Average Среднее	<0,001	<0,02	<0,0001	<0,001	0,0076	<0,1	<0,0001	<0,001	<0,001	<0,001	<0,01	<0,02
Summer 2022 Лето 2022	Min. Мин.	-	-	-	-	0,0123	-	-	-	-		-	-
	Max. Макс.	-	-	-	-	0,0185	-	-	-	-		-	-
	Average Среднее	<0,001	<0,02	<0,0001	<0,001	0,0155	<0,100	<0,0001	<0,001	<0,001	<0,001	<0,01	<0,02
Autumn 2022 Осень 2022	Min. Мин.	-	-	-	-	-	-	-	-	-		-	-
	Max. Макс.	-	-	-	-	-	-	-	-	-		-	-
	Average Среднее	<0,005	<0,025	<0,0001	<0,005	<0,0005	<0,01	<0,00001	<0,005	<0,002	<0,001	<0,1	<0,02
Average 2022 Среднее 2022		<0,005	<0,025	<0,0001	<0,005	<0,0005	0,0077	<0,00001	<0,005	<0,002	<0,01	<0,1	<0,02

Over the study period, in all seasons, concentrations of aluminium, arsenic, barium, cadmium, chromium, iron, nickel, mercury, lead and zinc were below the detection limits of the analytical methods. Only copper was detected at significant concentrations in 2021 between 0.0149 mg/dm^3 and 0.0186 mg/dm^3, in the spring and summer of 2022 between 0.0109 and 0.0185 mg/dm^3. In autumn 2022, copper concentrations were below the detection limit of the method of analysis.

In general, the survey area is characterised by background copper pollution due to natural conditions.

The dynamics of copper (MAC 0.005 mg/dm^3) and vanadium (MAC 0.001 mg/dm^3) content for the mentioned period is shown in Figures 6, 7.

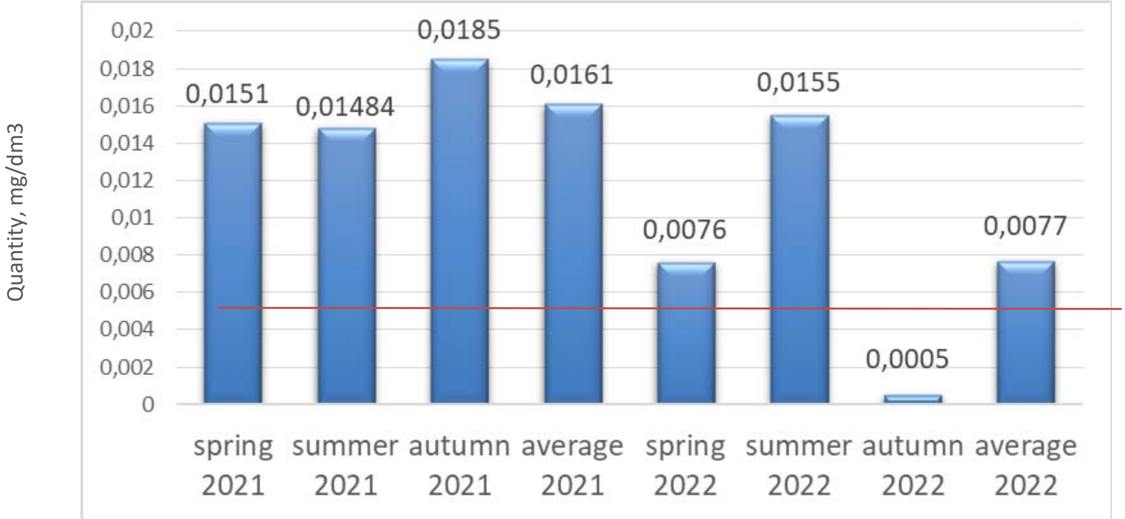

Figure 6. Average copper content in water of the canal water area in 2021–2022
Рисунок 6. Средние содержания меди в воде акватории канала в 2021–2022 гг.

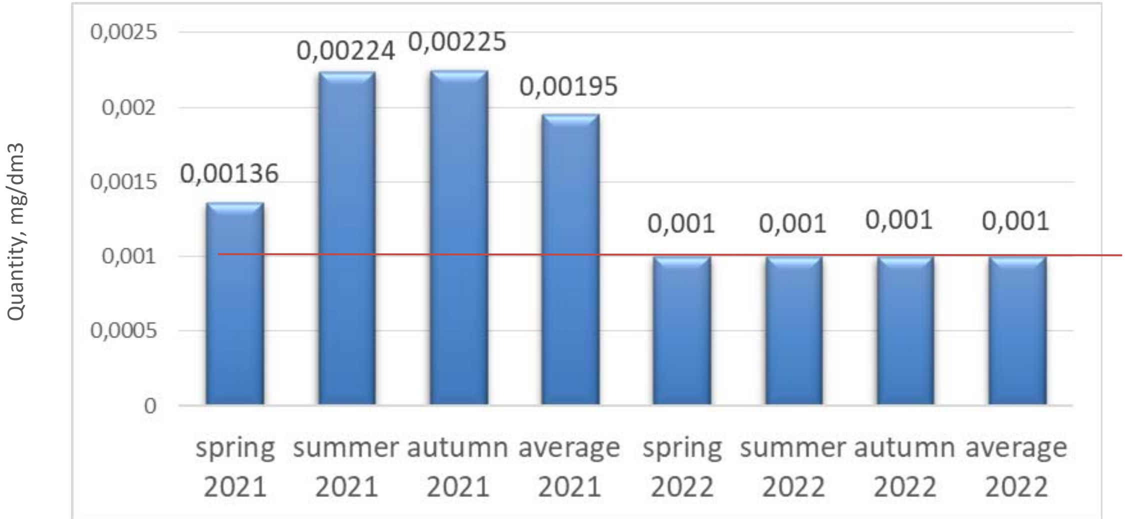

Figure 7. Average vanadium content in water of the canal water area in 2021–2022
Рисунок 7. Средние содержания ванадия в воде акватории канала в 2021–2022 гг.

CONCLUSION

Under natural conditions, it is in the coastal and shelf zone of the sea that the most intensive processes of sediment redistribution between the bottom and the water column occur. Changes in bottom relief during dredging and storage of bottom soil lead to more or less pronounced changes in the hydrodynamic regime, redistribution of currents, changes in water quality and chemical composition of the bottom biotope.

Changes in the amount of suspended sediment in sea water lead to changes in physical and chemical properties of water (increase in turbidity, disturbance of sediment composition and properties), changes in biotopes, sorption of organics, deterioration of oxygen regime, optical properties of water and temperature regime. These can cause reduction of photosynthesis intensity, damage to filtration organs, behavioural disorders, stresses, anoxia, death, deterioration of feeding conditions, deterioration of reproduction conditions, structural and functional rearrangements of populations and communities.

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