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ANALYSIS OF THE EFFICIENCY OF TRADITIONAL TECHNOLOGIES OF WATER PREPARATION OF THE KREMENCHUK RESERVOIR OF THE DNIPRO RIVER TO ENSURE DRINKING NEEDS

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Abstract. *An analysis of the efficiency of the surface water treatment systems of the Dnipro reservoirs when their quality is changed to ensure the normative indicators of the quality of drinking water were carried out. The study of the effectiveness of traditional water treatment technologies was carried out by analyzing the results of laboratory studies of source and drinking water at the Dnipro water treatment plant with water intake from the Kremenchuk Reservoir (data from the Svitlovodsk Water and Sewage Services (SWS) of the Regional Municipal Production Enterprise (RMPE) of the Dnipro-Kirovograd), establishing correlations of quality indicators and assessing the state of water resources by the requirements of water legislation. The treatment plants of the Dnipro water supply station are not designed to treat water with a high content of biogenic substances during active phytoplankton vegetation, and under such conditions, increased doses of preliminary chlorination are used. As a result, water is polluted with residual chlorine and organochlorine. An increase in the dose of aluminum-containing coagulants in the corresponding period leads to an increase in the aluminum content in drinking water to the limit of the normative value (0,5 mg/dm^3). According to the results of research in drinking water, turbidity was found to be 1,4 higher and permanganate oxidizability 1,3 higher than the standard content; excesses of color, iron, and residual chlorine content were found only sporadically and were on average within the upper limits of normative values. Correlation analysis (Pearson and Spearman correlations methods) of the influence of temperature on the following hydrometric, chemical, and physical factors was carried out: changes in turbidity, color, and changes in the concentration of total iron and ammonia. The analysis confirmed the visual connection of oxygen with temperature and water level and the influence of factors on oxygen concentration. The practical aspects of phytoplankton extraction during water intake from Dnipro reservoirs and water treatment at stations have gained further scientific justification.*

Key words: *water resources, drinking water, purification technology, phytoplankton, water quality*

Relevance of research. The surface waters of the Dnipro reservoirs are characterized by long-term and seasonal fluctuations in the concentrations of the components of the chemical composition, indicators of physical properties, etc., which occur under the influence of climatic changes, economic activity, and the conditions of military operations on the territory of Ukraine. According to the results of monitoring studies, it was determined that more than 38 % of water samples from Dnipro reservoirs taken at centralized water supply facilities do not meet regulatory requirements. The tendency to deterioration of the ecological condition of surface waters in terms of sanitary-chemical and sanitary-microbiological indicators necessitates the search for ways to improve the efficiency of their preparation for use in drinking water supply systems. [1].

Hardness, alkalinity, and total mineralization have low concentrations, their values are far from the maximum permissible values, which are standardized in DSTU 4808:2007 [2]. The main problem of the Dnipro reservoirs is the "blooming" of water in the summer. In this regard, based on the results of laboratory tests of the source water parameters, the specialists of the treatment plants constantly adjust the optimal technological modes of water treatment to ensure the proper quality of drinking water. This adjustment is carried out within the framework of existing technologies and the constructions of treatment plants, but their emergency state is not able to meet the requirements for the quality of drinking water according to certain normative safety indicators [1].

Analysis of recent research and publications. The analysis of the efficiency of surface water treatment systems in the Dnipro reservoirs with changes in their quality has made it possible to establish that the main technological methods of existing water treatment technologies are coagulation, sedimentation, and filtration. This technology is designed for source water of the 1st and 2nd quality categories [2]. Over the past decades, significant climatic changes have occurred, and the temperature, water, and hydrological regimes of the Dnipro River have changed accordingly. The water quality characteristics began to correspond to 3 and in some cases 4 quality categories [2–4]. The vast majority of water treatment plants have completed their design service life. Today, the technologies installed during the construction of treatment plants cannot effectively clean the water of the Dnipro River.

The processes of natural water purification and the issue of resource conservation in the water supply industry are studied by foreign and domestic scientists [5–8]. The study of modern effective methods of water preparation is disclosed in publications [9–14]. The attention to the analysis of the characteristics of surface water contaminants and their removal during water treatment and intensification of water purification processes from dissolved organic substances is paid in recent publications of experts [14–23]. In particular, the complex relationship between changes in temperature, dissolved oxygen, hydrological regime, and chemical composition, which together form the qualitative composition of water in surface sources of drinking water supply, has been scientifically confirmed. The lack of a clear direct thermal stratification causes a change in the species and number of phytoplankton to vertical levels and water areas. The season and rhythm of nature cause the cyclical development of the hydroclimate, the formation of different intensities of biological processes, and the development of biomass in reservoirs. As a result, the available estimates of the effectiveness of combating phytoplankton directly at treatment plants are relative and can only be considered as examples in specific cases [24, 25].

At the same time, it remains an important task not only to increase the efficiency of water purification to the standard indicators but also to reduce the load on the water purification station due to the retention of a significant part of the pollutants directly in the water source, which is implemented by modernizing intake and treatment plants.

The purpose of the research is to analyze the effectiveness of the traditional technology of cleaning the surface waters of the Dnipro reservoirs (in the example of the Kremenchuk reservoir) to ensure the normative indicators of drinking water quality.

Research materials and methods. Research methods: empirical – when determining the specifics of the purification technology and water quality research; mathematical modeling using the regression analysis method – for the study of quality indicators of water resources and substantiation of the reliability of obtained results. The study of the effectiveness of traditional water purification technologies at water supply stations will be carried out by analyzing the results of laboratory studies of source and drinking water from a clear water reservoir (CWR) at the Dnipro water treatment plant with water intake from the Kremenchuk reservoir (data from the Svitlovodsk Water and Sewage Services of the Regional Municipal Production Enterprise of the Dnipro-Kirovograd, further – SWSS of the RMPE of the Dnipro-Kirovograd), the establishing correlations of water quality indicators and assessing the state of water resources by the requirements of water legislation.

To study water quality indicators, the data of the systematic production control of water safety and quality of the water supply laboratory of the SWSS of the RMPE of the Dnipro-Kirovograd were analyzed in the water intake and before entering the water supply network (from CWR). Per the procedure for monitoring water quality indicators, we analyzed the average monthly data of full chemical analysis of the quality of surface water for 2018–2023, daily (9:00 and 21:00) indicators of surface water quality for the summer months of 2018–2023, average daily (9:00) indicators of the content of hydro organics in the surface water of the reservoir for 2019–2023, average monthly indicators of full analysis (including 13 characteristic physicochemical indicators) of drinking water quality from CWR for 2018–2023.

Research results and their discussion. In recent years, the operation of water intake facilities, as well as the operation of water treatment plants with water intake from the Dnipro reservoirs, has been significantly complicated by peak, in fact, catastrophic outbreaks of phytoplankton reproduction (Table 1, Fig. 1), mainly cyanobacteria, which are associated with climate change – global warming, which leads to a decrease in the amount of oxygen in water [1]. The phytoplankton content varies by more than 150 times within a month (for example, in January 2019 from 245 cells/dm^3 to 201000 cells/dm^3, and in July 2023 from 40,000 cells/dm^3 to 368,000 cells/dm^3).

Existing treatment facilities are not designed to treat water with a high content of nutrients, and in such conditions, treatment plant specialists use increased doses of pre-chlorination. As a result, water is contaminated with residual chlorine and organochlorine. It has been established that the degradation of extracellular microcystin by chlorine depends on pH, chlorine exposure, and the presence of cyanobacterial cells [1, 26].

Indicators of the efficiency of surface water treatment systems of the Dnipro reservoirs to provide the population with drinking water. The water treatment process at the SWSS of the RMPE of the Dnipro-Kirovograd water supply station with water intake from the Kremenchuk reservoir consists of the following stages: oxidation with liquid chlorine (primary chlorination), coagulation before mixers, clarification in horizontal settling tanks, filtration with rapid filters and disinfection with liquid chlorine (secondary chlorination) before CWR (Table 2).

The drinking water purification technology at the researched units of the water treatment station of the SWSS of the RMPE of the Dnipro-Kirovograd, which uses the water of the Dnipro River as the source, includes the following water facilities: mixers, reaction chambers, horizontal settling tanks, fast filters with quartz sand filling, tanks of clean water.

1. The content of phytoplankton in the water of the Kremenchuk Reservoir in 2019–2023

The date	**Phytoplankton content, cells/dm^3**		
	maximum	**minimum**	**average monthly**
January 2019	201 000	1 270	54 472
July 2019	14 862 000	190 050	4 713 828
January 2020	1 714 000	4 070	129 022
July 2020	358 500	1 230	38 553
January 2021	2 605	365	835
July 2021	3 104 000	245	292 722
January 2022	1 220	230	648
July 2022	218 000	900	43 643
January 2023	8 150	290	2 112
July 2023	368 000	40 000	127 786

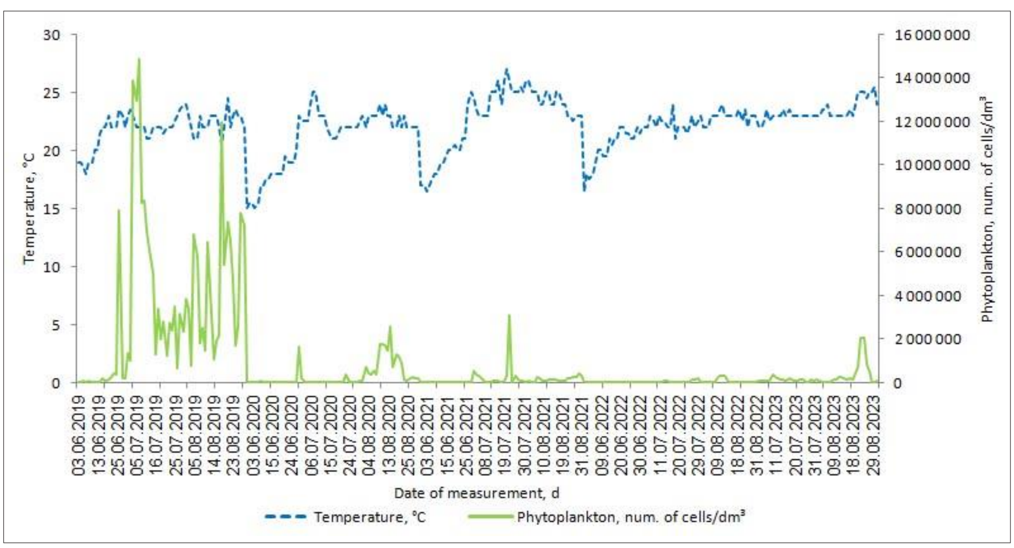

Fig. 1. Phytoplankton content in the water of the Kremenchuk Reservoir in the summer period of 2019–2023

The evaluation of the efficiency and adequacy of the water purification technology is carried out based on the results of summarizing the average monthly data of laboratory studies of the full chemical analysis of the quality of the surface and drinking water of CWR into the average annual content for the years 2018–2023 (Tables 3, 4).

Based on the analysis of the quantitative characteristics of some of the most priority indicators of water quality, which demonstrate the state of the sources of drinking water supply, the average and worst values of the group water quality indices characterizing the surface water at the water intake point of the Kremenchuk

2. Reagents used at the water supply station at the SWSS of the RMPE of the Dnipro-Kirovograd

Reagent	**Purpose**	**The SWSS of the RMPE of the Dnipro-Kirovograd**
Sodium hypochlorite	primary chlorination	+
Hydroxychloride of aluminum	coagulation	+
Flocculant Extraflock N 160, or equivalent	flocculation	–
Sodium hypochlorite	secondary chlorination	–
Liquid chlorine		+

3. Sanitary and chemical parameters of the surface water of the Kremenchuk Reservoir

Parameter	**Measure**	**Average annual content in the surface water**						**The class of water quality according to DSTU4808:2007** [2]
		2018	**2019**	**2020**	**2021**	**2022**	**2023**	
Turbidity	NTU	4.59	3.65	3.44	3.72	2.98	3.71	1
Color	degr.	44.46	32.13	29.17	38.83	45.5	66.92	2
Hydrogen indicator	units of pH	8.18	8.23	8.43	7.65	7.77	7.79	2–3
Ammonium ions	mg/dm^3	0.244	0.21	0.182	0.354	0.217	0.312	2–3
Nitrate ions	mg/dm^3	1.973	0.287	0.288	0.313	0.269	0.533	2–4
Nitrite ions	mg/dm^3	0.029	0.01	0.007	0.008	0.015	0.012	2–3
Total iron	mg/dm^3	0.347	0.295	0.29	0.339	0.38	0.505	3
Manganese	mg/dm^3	0.022	0.01	0.01	0.05	0.05	0.05	2
Aluminum	mg/dm^3	0.02	0.02	–	–	–	–	1
Permanganate oxidizability	mg/dm^3	8.99	8.47	7.78	8.6	8.84	9.64	2
Petroleum products	mg/dm^3	0.3	0.3	0.3	0.3	0.3	0.3	4
Chloride ions	mg/dm^3	18.16	23.39	24.28	21.13	18.94	17.49	1
Dissolved oxygen	mgO_2/dm^3	10.56	9.7	10.01	10.65	9.71	9.36	1

4. Sanitary and chemical parameters of the drinking water quality produced by the SWSS of the RMPE of the Dnipro-Kirovograd from the water of the Kremenchuk Reservoir

Parameter	**Measure**	**Average annual content in drinking water from the CWR**						**Normative content by DSanPiN 2.2.4-171-10** [27]
		2018	**2019**	**2020**	**2021**	**2022**	**2023**	
Turbidity	NTU	1.7	**1.3**	**1.33**	**1.1**	**1.1**	**1.09**	≤ 1.0
Color	degr.	19.25	12.2	11.88	14.13	17.33	18.04	≤ 20
Hydrogen indicator	units of pH	7.53	7.5	7.73	6.8	7.09	6.83	6.5–8.5
Ammonium ions	mg/dm^3	0.12	0.068	0.078	0.138	0.138	0.139	≤ 0.50
Nitrate ions	mg/dm^3	1.331	0.809	1.083	1.15	0.884	1.206	≤ 50
Nitrite ions	mg/dm^3	0.003	0.004	0.003	0.004	0.003	0.005	≤ 0.1
Total iron	mg/dm^3	0.176	0.12	0.108	0.123	0.14	0.174	≤ 0.20
Manganese	mg/dm^3	0.009	0.01	0.01	0.01	0.01	0.01	≤ 0.05
Aluminum	mg/dm^3	0.12	0.085	0.099	0.097	0.113	0.159	≤ 0.5
Permanganate oxidizability	mg/dm^3	–	**6.4**	**5.6**	**6.04**	**7.0**	**7.31**	≤ 5.0
Free chlorine residual	mg/dm^3	0.44	0.52	0.482	0.487	0.48	0.491	≤ 0.5
Chloride ions	mg/dm^3	25.4	32.05	34.0	32.33	30.03	31.94	≤ 250

Reservoir of the SWSS of the RMPE of the Dnipro-Kirovograd as “good” were determined, clean water of acceptable quality (Table 3) [2].

Among the indicated indicators, turbidity and permanganate oxidizability in the drinking water of the SWSS of the RMPE of the Dnipro-Kirovograd were found in concentrations that exceeded the normative values according to DSanPiN 2.2.4-171-10 [27]; excesses of color, total iron, chlorine residual content were found only sporadically and on average were in the upper limits of the normative values (in individual samples and in different years) (Table 4). This may be due to the difference in the composition of organic substances in the source water during the year.

A significant role in the constant seasonal deterioration of water quality and overspending of washing water and reagents is played by seasonal peaks of overloading of treatment facilities with phytoplankton, for which they are unsuitable for retention (Fig. 1). Accordingly, the picture of the use of reagents has changed in comparison with the technological map that was laid down during the design of typical treatment facilities. Aluminum-containing coagulants to purify water from pollutants that are in a colloidal state and are used on the SWSS of the RMPE of the Dnipro-Kirovograd with surface water intake from the Kremenchuk Reservoir. Working coagulant doses in the autumn-winter period, when water color is 30 degr., turbidity up to 3 mg/dm^3, are 10–30 mg/dm^3. Doses of a coagulant during the flood period and the “blooming” period of the Kremenchuk Reservoir reach 100–150 mg/dm^3 with the color of the source water 70–90 degr., turbidity 8–9 mg/dm^3. An increase in the dose of aluminum-containing coagulants during the specified period leads to a rise in the aluminum content in drinking water to the limit of the normative value (0,5 mg/dm^3).

Based on the observation data for the summer period of 2018–2023, an analysis of the influence of temperature on the following hydrometric, chemical, and physical factors was carried out at the water intake from the Kremenchuk Reservoir: changes in turbidity, color, and concentration of total iron and ammonium ions (Fig. 2–5).

To clarify the visually obtained connections of the analyzed factors (Fig. 2–5), the nature of their mutual influence, a correlation analysis of archival data of observations on the water intake of the Kremenchuk city for the period from May 30, 2014, to April 6, 2016, was carried out, regarding the impact on the concentration of dissolved oxygen of the following hydrometric, chemical, and physical factors: changes in the water level; changes in water influx and discharge; changes in Mn^{2+} and NH_4 concentration; temperature t (°C). Given that the data distribution does not correspond to normal law, both the parametric Pearson method and the non-parametric Spearman method were used to determine correlations. The results of statistical data processing are presented in the form of correlation tables (Tables 4, 5) [1].

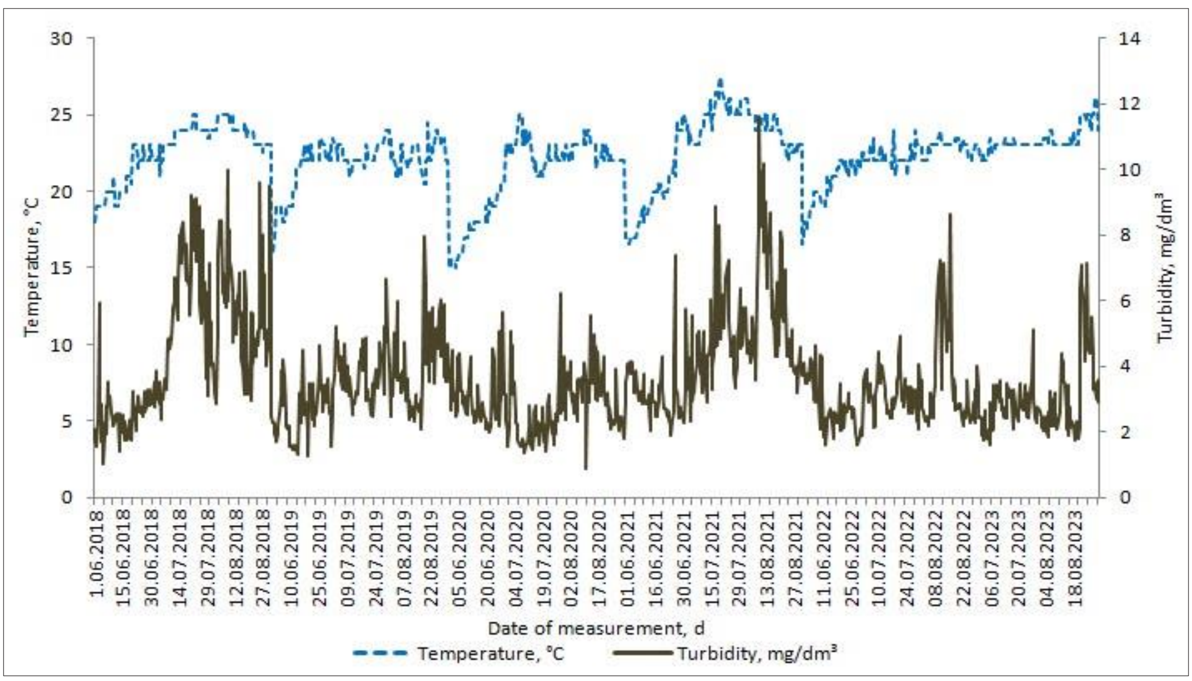

Fig. 2. Changes in the temperature and turbidity of surface waters at the water intake from the Kremenchuk Reservoir in the summer period of 2018–2023

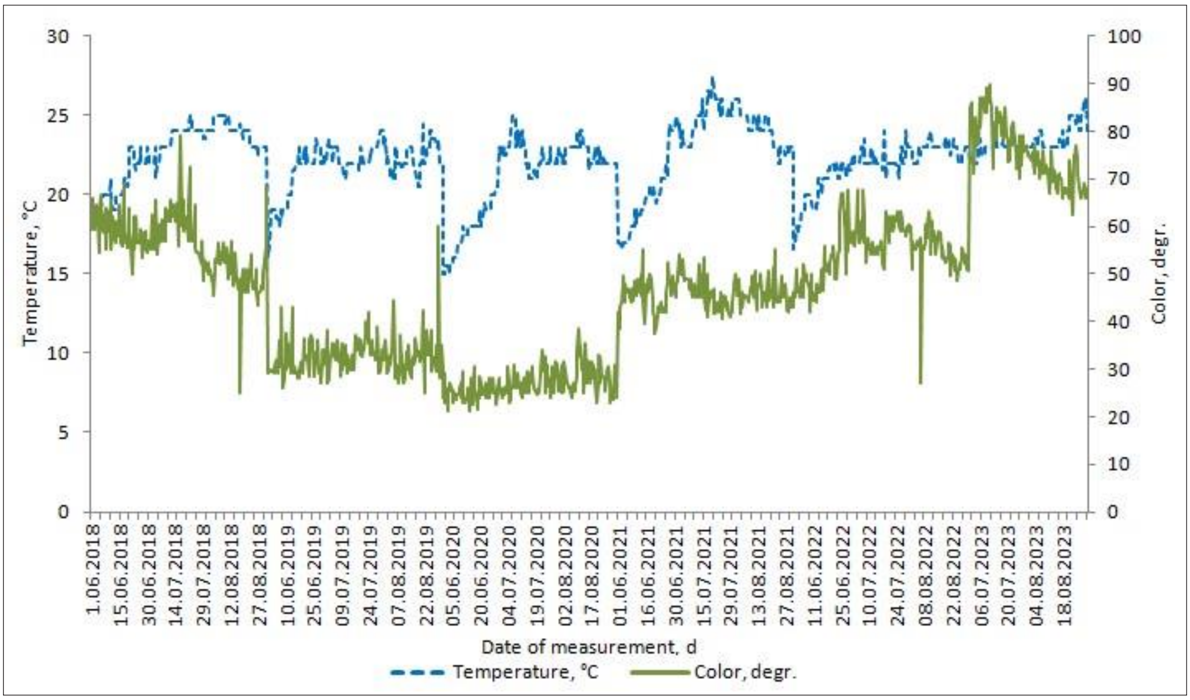

Fig. 3. Changes in the temperature and color of surface water at the water intake from the Kremenchuk Reservoir in the summer period of 2018–2023

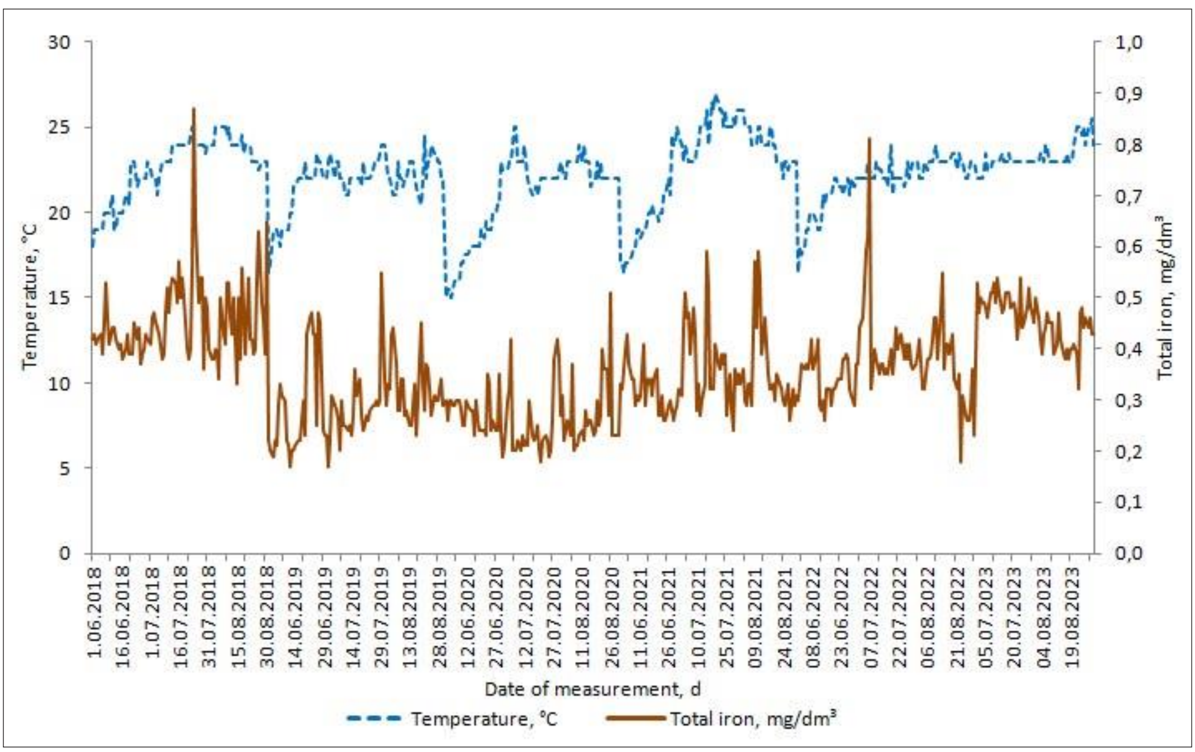

Fig. 4. Changes in the temperature and total iron concentration of surface water at the intake from the Kremenchuk Reservoir in the summer period of 2018–2023

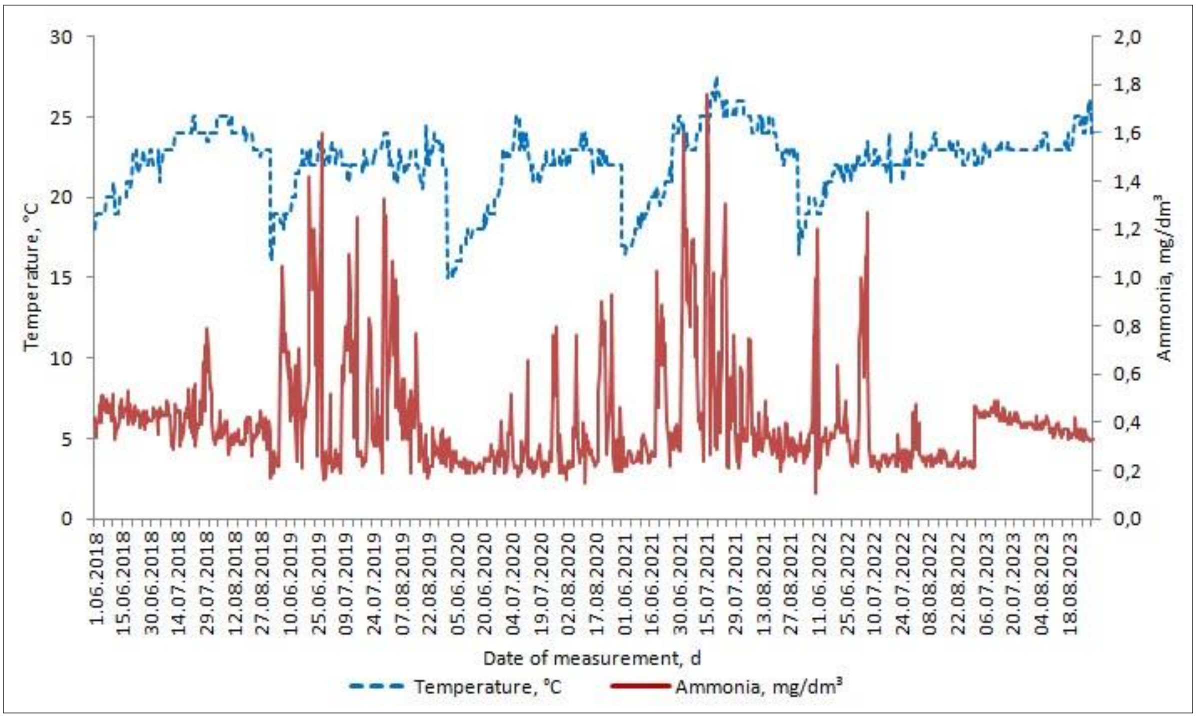

Fig. 5. Changes in the temperature and ammonia concentration of surface water at the water intake from the Kremenchuk Reservoir in the summer period of 2018–2023

4. Correlation of changes in water indicators at the Kremenchuk city water intake according to Pearson

	O_2	Mn	NH_4	t, °C	Level	Influx	Discharge
O_2	1.000	–0.329	–0.420	–0.743	–0.660	0.152	–0.011
Mn	–0.329	1.000	0.524	0.275	–0.042	–0.146	0.106
NH_4	–0.420	0.524	1.000	0.069	0.219	0.271	0.248
t, °C	–0.743	0.275	0.069	1.000	0.593	–0.303	0.015
Level	–0.660	–0.042	0.219	0.593	1.000	0.303	0.165
Influx	0.152	–0.146	0.271	–0.303	0.303	1.000	0.499
Discharge	–0.011	0.106	0.248	0.015	0.165	0.499	1.000

5. Correlation of changes in water indicators at the Kremenchuk city water intake according to Spearman

	O_2	Mn	NH_4	t, °C	Level	Influx	Discharge
O_2	1.000	–0.363	–0.440	–0.691	–0.644	0.256	–0.168
Mn	–0.363	1.000	0.466	0.564	0.150	–0.150	0.227
NH_4	–0.440	0.466	1.000	0.158	0.199	0.206	0.244
t, °C	–0.691	0.564	0.158	1.000	0.803	–0.336	–0.019
Level	–0.644	0.150	0.199	0.803	1.000	0.062	0.050
Influx	0.256	–0.150	0.206	–0.336	0.062	1.000	0.275
Discharge	–0.168	0.227	0.244	–0.019	0.050	0.275	1.000

The determining method of correlation analysis is the non-parametric method of Spearman, the additional one is the parametric method of Pearson. A comparison of the coefficients obtained by the two methods confirms their non-contradiction.

Correlation analysis confirms the visual connection of oxygen with temperature and water level (Tables 4, 5). This is evidenced by the correlation coefficients: −0,691 and −0,644, respectively, this is a pronounced influence of these factors on the oxygen concentration. That is, there is a significant negative relationship between temperature and the level of oxygen content in water. The higher the temperature and level, the lower the oxygen concentration. The effect of the correlation coefficient of ammonium nitrogen is also quite significant: -0,44, although it is not a vivid illustration of the inverse dependence (Table 5).

Regression analysis is used to determine the contribution of individual independent variables and the forecast of values.

The dependent variable – is oxygen concentration, independent variables: are temperature, soluble manganese, ammonium nitrogen, water level, influx, and discharge.

By constructing a multiple linear regression equation, we determine the contributions of individual independent variables. Using the method of least squares, the equation is obtained:

$$O_2M1 = 165{,}660995 - 0{,}203042912 \times Mn - 4.67263708 \times NH4 - 0{,}189655268 \times t - 1{,}96944342 \times Level + 0{,}16194699 \times Influx + 0.0234157502 \times Discharge$$

where: O_2M1 – concentration of soluble O_2, mg/dm^3; *Mn* – concentration of Mn^{2+}, mg/dm^3; *NH4* – concentration of NH_4, mg/dm^3; *t* – temperature, °C; *Level* – water level, m; *Influx* – water influx, hundreds of m^3/s; *Discharge* – water discharge, hundreds of m^3/s.

The model is characterized using the coefficient of multiple correlation, coefficient (index) of multiple determination, and adjusted coefficient of determination.

The coefficient (index) of multiple correlation R is used to assess the closeness of the joint influence of factors on the dependent variable. To assess the adequacy of the regression model, the coefficient of determination R^2 serves as a measure of the quality of the regression equation. The resulting model has the following characteristics: multiple correlation coefficients $R = 0{,}875$; coefficient of determination $R^2 = 0{,}766$; adjusted coefficient of determination $R^2_{adjusted} = 0{,}755$.

In Fig. 6 shows the real values of the oxygen concentration in the water of the Kremenchuk Reservoir and the resulting model.

Fig. 6. demonstrates the high correlation between the results of experimental studies and the obtained O_2M1 model, which confirms its adequacy.

The contribution of individual independent variables to the variation of the dependent variable is obtained from the equation and visualized on the Pareto chart (Fig. 7).

The way to improve the ecological condition of the Dnipro and its reservoirs is not to draw down them in stages, the ecological and economic effect of which is negligible compared to the projected total damage that may be caused to the nature and economy of Ukraine, but in

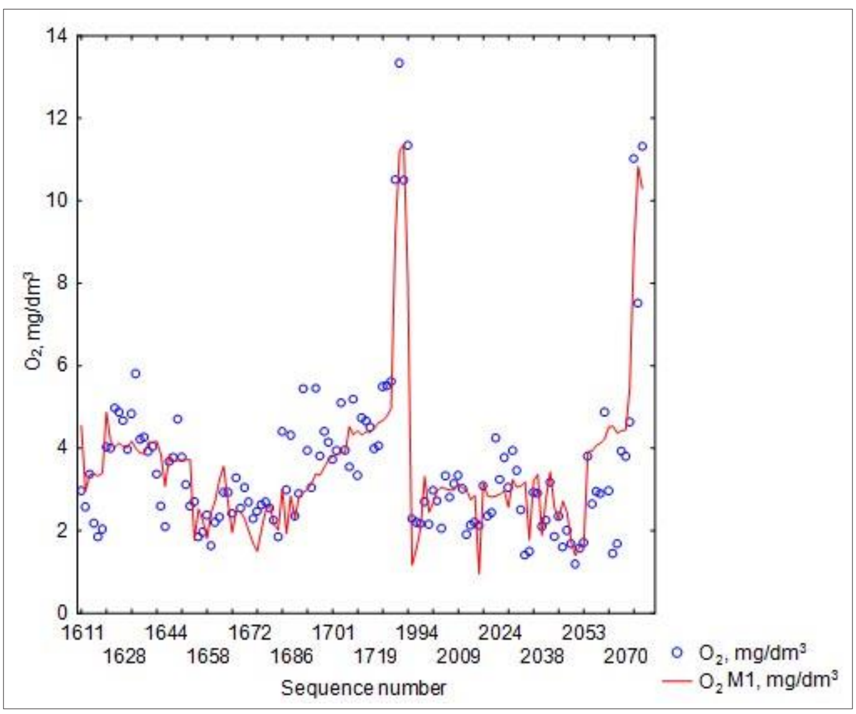

Fig. 6. Comparison of real values of oxygen concentration in the surface waters of the Kremenchuk Reservoir and the obtained O_2M1 model

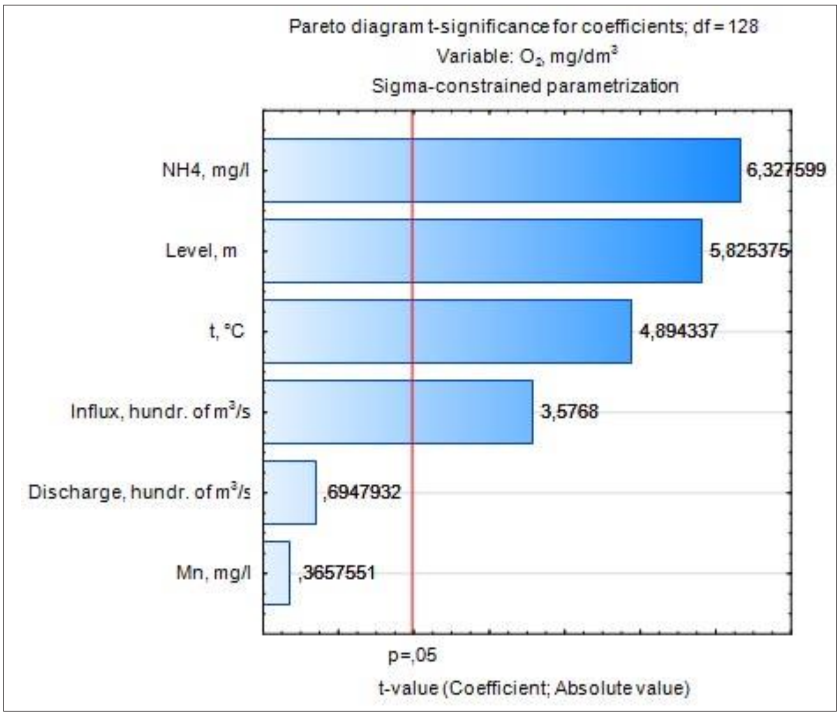

Fig. 7. The contribution of individual independent variables to the variation of the dependent variable according to the O_2M1 model for the surface waters of the Kremenchuk Reservoir

the implement environmentally and resource-saving technologies (innovations), scientifically based reconstruction and optimization of water using of the Dnipro reservoirs. The development of optimization of water supply and sewerage systems for cities whose water supply is provided by the Dnipro River should be consistent with river basin management plans and the post-war reconstruction of Ukraine [28–30].

Conclusions. An analysis of the effectiveness of traditional water treatment technologies at the Dnipro water treatment station with water intake from the Kremenchuk Reservoir showed that these treatment facilities are not designed to treat water with a high content of biogenic substances during the period of active phytoplankton vegetation (summer period of elevated temperatures) and under such conditions, used increased doses of the previous chlorination. As a result, water is polluted with residual chlorine and organochlorine, and the aluminum content in drinking water rises to the limit of the regulatory value (0,5 mg/dm^3). Turbidity 1.4 times higher and permanganate oxidizability 1,3 times higher than the standard content were found in the drinking water of the CWR. Correlation analysis of the effect of temperature on changes in turbidity, color, and changes in the concentration of total iron and ammonia confirmed the visual connection of oxygen with temperature and water level: the higher the temperature and level, the lower the oxygen concentration.

The practical aspects of phytoplankton extraction during intake of surface water from Dnipro reservoirs and water treatment at water treatment stations with the development of recommendations for the operation of water intake facilities have gained further scientific justification. Areas of work should include several normative-legal, engineering-technical, material-energy, economic, and other measures to improve the quality of drinking water; increasing the reliability of the water supply system; increasing the efficiency of the use of material and energy resources of the water supply system; scientific, technical and design support for the implementation of measures.

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АНАЛІЗ ЕФЕКТИВНОСТІ ТРАДИЦІЙНИХ ТЕХНОЛОГІЙ ПІДГОТОВКИ ВОДИ КРЕМЕНЧУЦЬКОГО ВОДОСХОВИЩА РІЧКИ ДНІПРО ДЛЯ ЗАБЕЗПЕЧЕННЯ ПИТНИХ ПОТРЕБ

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Анотація. *Проведено аналіз ефективності роботи систем очистки поверхневих вод дніпровських водосховищ при зміні їх якості для забезпечення нормативних показників якості питної води. Дослідження ефективності традиційних технологій водопідготовки здійснювали шляхом аналізу результатів лабораторних досліджень вихідної та питної води на Дніпровській водоочисній станції із забором води Кременчуцького водосховища (дані СВКГ ОКВП «Дніпро-Кіровоград»), встановлення кореляційних зв'язків якісних показників та оцінки стану водних ресурсів відповідно до вимог водного законодавства. Очисні споруди Дніпровської водоочисної станції не розраховані на очищення води з великим вмістом біогенних речовин у період активної вегетації фітопланктону і за таких умов застосовують підвищені дози попереднього хлорування. Як наслідок, відбувається забруднення води залишковим хлором і хлорорганікою. Зростання дози внесення алюмовмісних коагулянтів у відповідний період призводить до зростання вмісту алюмінію у питній воді до межі нормативного значення (0,5 мг/дм³). За результатами досліджень в питній воді виявлені перевищення каламутності в 1,4 та перманганатної окиснюваності в 1,3 раза від нормативного вмісту; перевищення забарвленості, заліза, вмісту залишкового хлору виявлялися лише епізодично та в середньому знаходилися у верхніх межах нормативних значень. Проведено кореляційний аналіз (методами Спірмана та Пірсона) впливу температури на наступні гідрометричні, хімічні та фізичні чинники: зміни каламутності, забарвленості, зміни концентрації заліза загального та аміаку. Аналіз підтвердив візуальний зв'язок кисню з температурою і рівнем води та вплив факторів на концентрацію кисню. Набули подальшого наукового обґрунтування практичні аспекти вилучення фітопланктону при заборі поверхневої води дніпровських водосховищ і обробці води на станціях водопідготовки.*

Ключові слова: *водні ресурси, питна вода, технологія очистки, фітопланктон, якість води*