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ECOLOGICAL ASSESSMENT AND FORECASTING OF SURFACE WATER CONDITIONS IN THE DNIPRO RIVER IN ZAPORIZHZHIA

Purpose. To provide a comprehensive environmental assessment and forecast of the condition of surface waters of the Dnipro River within the Zaporizhzhia region, with a focus on the dynamics of key water quality indicators during the period 2013–2024. Special attention is given to anthropogenic factors, particularly the consequences of military actions and the destruction of the Kakhovka Hydroelectric Power Plant, which significantly altered the hydrological regime and impacted the ecological balance of the river.

Methods. Systems analysis, statistical data processing methods, distribution analysis, and regression modeling were employed to assess retrospective dynamics and predict future trends.

Results. Long-term monitoring data obtained from the Water Monitoring Laboratory of the Basin Water Resources Department of the Azov Sea Rivers were used. The primary focus was on evaluating six key water quality indicators: phosphates, ammonium, sulfate and chloride ions, biochemical oxygen demand over five days (BOD_5), and dissolved oxygen concentration, to assess the ecological state of the Dnipro River's surface waters in the Zaporizhzhia region, particularly in the drinking water intake area (DVS No. 1) in the upper reservoir of the Dnipro HPP. Phosphate and ammonium concentrations show periodic fluctuations driven by seasonal factors and fertilizer usage. Sulfate levels exhibit high variability of both natural and anthropogenic origin, while chloride concentrations remain relatively stable. Data on dissolved oxygen and BOD_5 indicate seasonal dynamics, which have been disrupted since 2023 due to the destruction of the Kakhovka Dam. The analysis confirmed the river's capacity for partial self-recovery, particularly under reduced anthropogenic pressure during wartime. Regression models were developed for predictive assessment of pollution levels and environmental risks.

Conclusions. The study identified key ecological problems in the Dnipro River, including organic and mineral pollution, disrupted hydrological regimes, and decreased oxygenation. The war-related destruction of hydrotechnical infrastructure exacerbated these issues. Despite this, the river demonstrated resilience through natural self-purification processes, especially as phosphate and ammonium loads declined. Restoration of ecological balance will require systemic monitoring, rehabilitation of water infrastructure, and regulation of pollutant sources. The developed models provide a basis for forecasting and managing surface water quality under both peacetime and post-war recovery scenarios.

KEY WORDS: *Dnipro River, war consequences, surface water, ecological monitoring, phosphate, ammonium, sulfate, chloride, dissolved oxygen, BOD$_5$, anthropogenic impact, forecasting*.

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Introduction

The issue of preserving water resources in river basins, particularly their rational utilization, is extremely relevant under current conditions. Since the beginning of the war, Ukraine's water resources have experienced additional anthropogenic impact, thus necessitating continuous monitoring of surface water conditions. Among the rivers affected by this additional impact is the Dnipro. Therefore, there is a need to conduct a comprehensive analysis of the ecological state of the Dnipro River basin to identify the most pressing problems requiring immediate solutions. As is known, the surface waters of the Dnipro River are of key importance for water supply in Ukraine. At the same time, the Dnipro's aquatic ecosystem is under constant anthropogenic pressure, causing gradual and persistent deterioration of its ecological state. To improve the quality of surface waters in the Dnipro basin, it is necessary to implement a reliable and effective model for forecasting the state of the ecosystem, including accounting for the impact of war.

Objects and Research Methods

To assess the impact of anthropogenic load, including war impact on the surface water conditions in the Dnipro River in Zaporizhzhia, a study was conducted on the water quality of the Dnipro River using data from the Water Monitoring Laboratory of the Basin Department for Water Resources of Azov Rivers. Comparative analysis was carried out for the monitoring station: Dnipro River, 328 km, Zaporizhzhia, upper tailrace of the Dnipro HPP, drinking water intake of Zaporizhzhia (DWS No. 1) (47°81'80" N, 35°10'00" E) during 2015-2024.

Results and Discussion

The ecological state of the Dnipro River has long attracted attention, as it is the country's main waterway, but remains under constant anthropogenic pressure [1-4]. Considering the changing situation, there is a need for continuous monitoring of its surface water quality in the context of main pollutants, which include phosphate and ammonium ions, sulfates and chlorides, and others, as well as assessing the ratio of BOD$_5$ to dissolved oxygen concentration.

Phosphates play a key role in the functioning of biota and hydroecosystems in general. Under optimal concentration conditions, they contribute to increased ecosystem productivity and influence the species composition of aquatic organisms. However, exceeding the maximum permissible limits of phosphates changes the trophic status of water bodies, stimulating the development of organisms that release harmful metabolites, negatively affecting other inhabitants of the water body and deteriorating water quality. Phosphate levels in aquatic environments vary seasonally, related both to their sources (weathering and dissolution of rocks, application of phosphorus fertilizers and detergents) and biological processes (life activities and death of organisms). The main sources of anthropogenic phosphate pollution are considered to be agricultural runoff, wastewater from treatment facilities, and industrial enterprises [5-7].

Ammonium ions are one form of nitrogen naturally present in the environment. They are primarily concentrated in the upper layers of the hydrosphere, where intensive decomposition of protein substances from aquatic organisms and accumulation of their metabolic products occur. In this context, ammonium acts as a natural element of the aquatic environment, involved in the nitrogen cycle in the biosphere. At the same time, its concentration must remain within permissible levels, as excessive content can cause serious ecological consequences. Specifically, elevated NH_4^+ levels in surface waters promote the development of eutrophication [4, 9], which harms biodiversity: this phenomenon stimulates excessive growth of certain algae species, which reduce dissolved oxygen content in the water. As a result, the water bodies' ability to self-purify is significantly impaired.

Sulfates are the most common anions present in aquatic ecosystems. The main factors for increasing their concentration in water bodies are the processes of organism death, oxidation of substances, and influx from groundwater [10, 11]. Sulfate ions (SO_4^{2-}) enter natural waters primarily through dissolution of sulfur-containing minerals such as gypsum, as well as through oxidation of sulfur and sulfides. Additionally, a significant portion consists of sulfur released during the decomposition of plant and animal remains, as well as from wastewater.

Chlorides enter surface waters from mineral fertilizers containing chlorine-containing potassium compounds, as well as from domestic and industrial effluents. Due to high solubility, chlorides are poorly adsorbed by suspended matter and are hardly assimilated by aquatic organisms. Their concentration plays an important role in forming non-carbonate water hardness. Chloride ion (Cl^-) also enters water bodies through dissolution of chlorine-containing minerals. An additional source is atmospheric transport from marine and oceanic areas to continental water bodies. The significant increase in chloride concentrations in recent years is associated with increased impact of industrial and municipal wastewater [11].

The biochemical oxygen demand (BOD) indicator shows how much oxygen is required for complete oxidation of organic substances in a water body. During the oxidation and decomposition of organic matter, BOD values decrease. Simultaneously with consumption, oxygen enters surface waters from the atmosphere and water saturation with dissolved oxygen occurs. This diffusion compensates for oxygen losses during decomposition of organic matter in water. This relationship is described by the well-known Streeter-Phelps model, which allows evaluation of the balance between oxygen consumption in water due to organic matter decomposition and its recovery through atmospheric diffusion. This, in turn, allows assessment of water quality and its capacity for natural self-purification [12, 13].

When monitoring surface waters, it is important not only to determine the content of substances in them, but also to compare the obtained data with maximum permissible concentrations, which are indicators of the safe level of harmful substances per unit volume or mass in the aquatic environment that has minimal impact on human health [14, 15].

The research object was the surface water condition of the Dnipro River within the monitoring station: Dnipro River, 328 km, Zaporizhzhia, upper tailrace of the Dnipro HPP, drinking water intake of Zaporizhzhia (DWS No. 1) (47°81'80" N, 35°10'00" E). The study covered the period 2013-2024 and was conducted for the following parameters: phosphate ions, ammonium ions, sulfate ions, chloride ions, BOD_5, and dissolved oxygen.

Figure 1 presents the results of analysis of phosphate and ammonium ion dynamics in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

Analysis of phosphate and ammonium ion dynamics in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024 revealed clear changes that are both seasonal and anthropogenically induced. During 2017-2020, indicators for both ions demonstrated relative stability with typical fluctuations caused by surface runoff from agricultural lands and domestic discharges.

Since 2021, there has been a trend toward decreased phosphate concentration, reaching a minimum in mid-2022. Simultaneously, in July 2022, an abnormally high spike in ammonium ion concentration was observed, exceeding 0.8

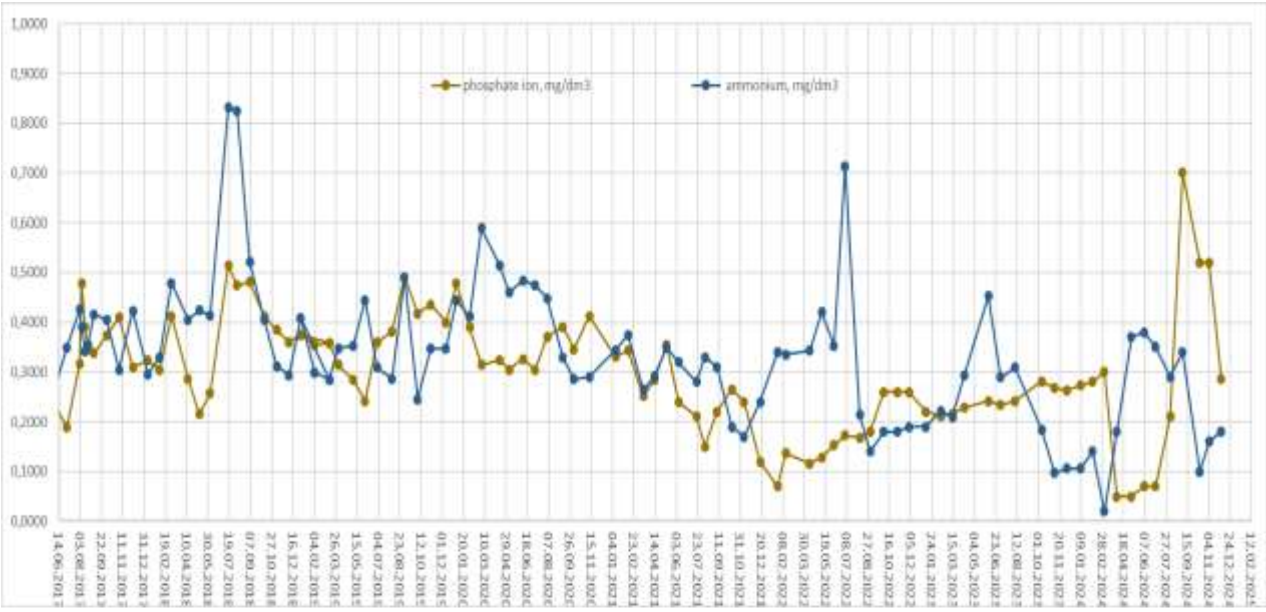

Fig. 1 – Dynamics of phosphate and ammonium ion content in Dnipro River surface waters in Zaporizhzhia during 2017-2024

mg/dm³. This may be a result of local discharges or increased mineralization of organic matter under conditions of reduced flow, high temperature, and dissolved oxygen deficit.

In 2023-2024, ammonium content gradually decreases, indicating activation of nitrification processes. In the presence of oxygen, ammonium is oxidized to nitrites (by bacteria of the genus Nitrosomonas) and further to nitrates (Nitrobacter), indicating improved water body aeration and stabilization of ecosystem processes. Phosphates during this period demonstrate gradual growth with individual sharp peaks (September-October 2024), likely related to mobilization of phosphates from bottom sediments under anaerobic conditions or through the influence of organic matter decomposition (SPAR).

Overall, a complex interaction of chemical and biogeochemical processes is observed - reduced anthropogenic load decreased phosphate and ammonium influx, while changes in hydrodynamics, particularly through HPP damage, affected flow, oxygen regime, and remobilization of compounds from bottom sediments.

Figure 2 presents the results of analysis of sulfate and chloride ion dynamics in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

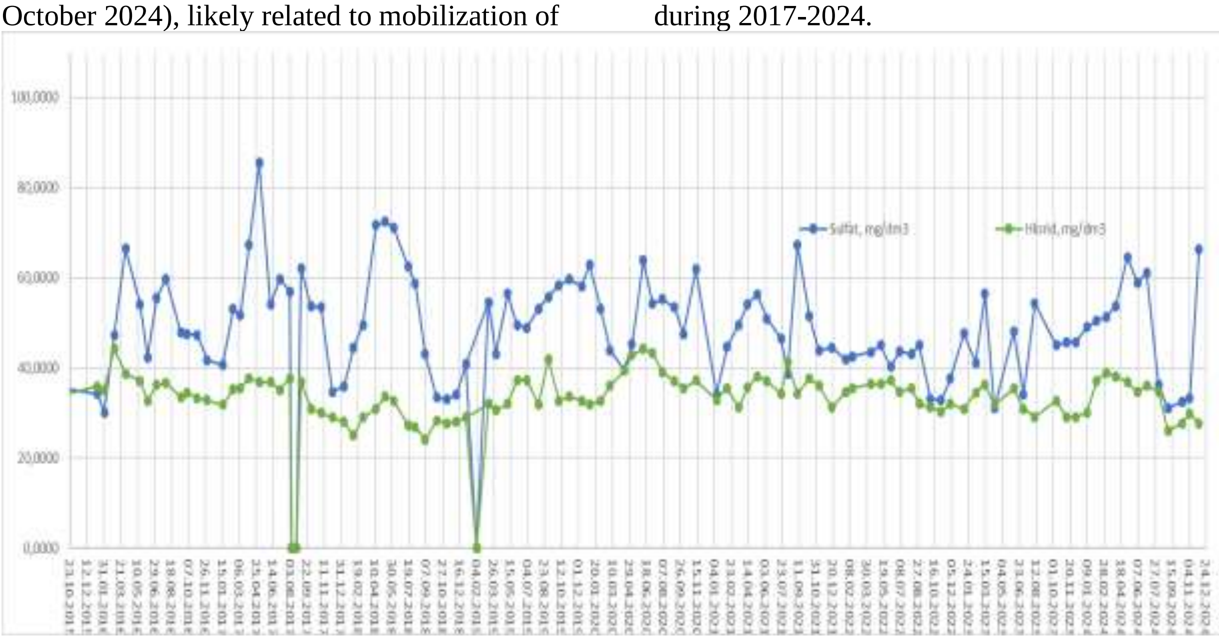

Fig. 2 – Dynamics of sulfate and chloride ion content in Dnipro River surface waters in Zaporizhzhia during 2017-2024

The graph demonstrates fluctuations in sulfate and chloride ion concentrations in river water, which are indicators of mineralization, degree of anthropogenic load, and hydrochemical stability of the aquatic environment.

Throughout the entire period, sulfate concentrations (blue line) fluctuate within 30-90 mg/dm³, with notable peaks in certain months (e.g., 05.2021, 10.2021, 09.2022, 11.2023, 11.2024). Such anomalous increases may be related to local wastewater discharges or active oxidation of organic matter during changes in hydrochemical regime. Increased sulfates may also result from microbiological decomposition of biota, particularly during periods of algae death, or active sulfate reduction with subsequent release of sulfur-containing compound oxidation products.

Characteristically, sulfate ions demonstrate higher variability, which is typical for ions that can actively come from anthropogenic sources - industrial enterprises, storm and domestic runoff. Particularly sensitive fluctuations are observed in 2022-2023, which may reflect the impact of military actions and disruption of wastewater treatment facilities.

Unlike sulfates, chloride ions (green line) have more stable concentration, maintained in the range of 25-40 mg/dm³. This corresponds to the nature of chlorides as conservative ions that are not actively involved in biogeochemical processes and have high solubility. However, short-term decreases (e.g., in 07.2021 and 04.2022) may result from technical errors or local water dilution, for example, after severe floods or increased water exchange.

Overall, comparison of dynamics for both ions indicates increased reactivity of sulfates in the river water system, while chlorides remain a stable indicator of overall mineralization level. Increased sulfates with unchanged chloride levels may indicate activation of biochemical processes - particularly, oxidation of SPAR or hydrogen sulfide formation with subsequent oxidation to SO_4^{2-} under variable oxygen regime conditions.

Figure 3 presents the results of analysis of dissolved oxygen concentration dynamics and biochemical oxygen demand over 5 days in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

The graph depicts the dynamics of two key indicators of aquatic environment condition: dissolved oxygen concentration and biochemical oxygen demand over 5 days (BOD_5). Both parameters are closely related to the intensity of biochemical processes and are primary markers of water body self-purification and its ecological state.

During the period from 2017 to 2022, typical seasonal dynamics are observed; in summer, dissolved oxygen levels decrease, which is due to reduced solubility at elevated water temperatures and activation of microbiological decomposition of organic matter. During this time, BOD_5 values increase, as elevated temperature and organic load stimulate metabolic activity of aerobic bacteria, increasing oxygen consumption. In autumn and winter, conversely,

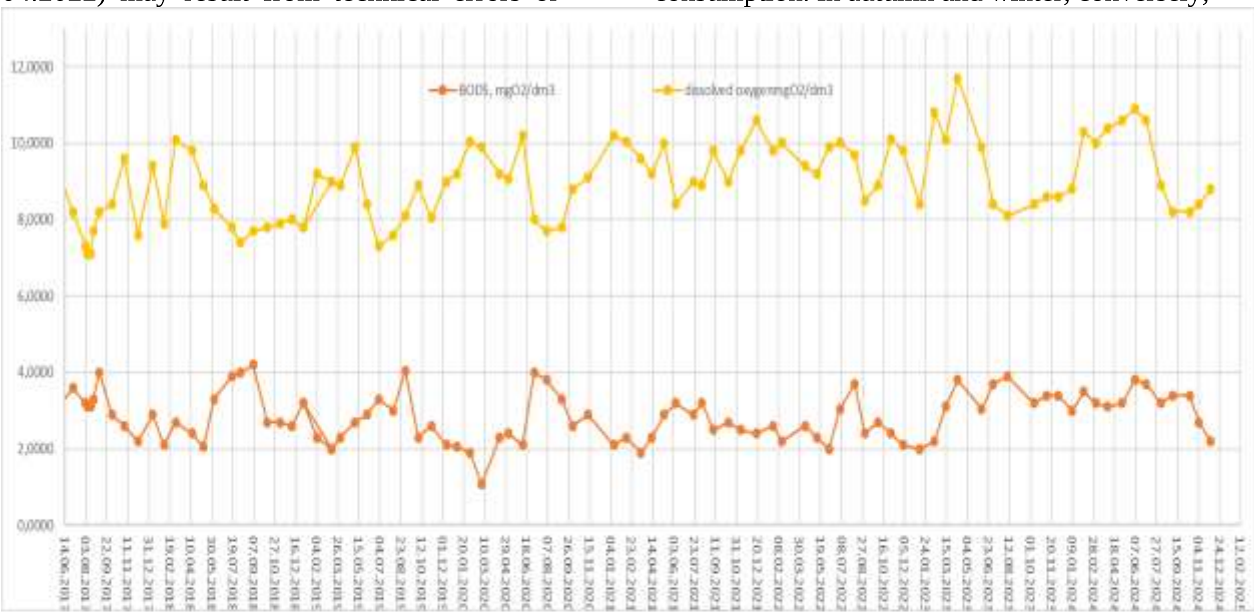

Fig. 3 – Dynamics of dissolved oxygen concentration and biochemical oxygen demand over 5 days in Dnipro River surface waters in Zaporizhzhia during 2017-2024

there is an increase in dissolved oxygen concentration and decrease in BOD_5 - the result of slowed biochemical processes and improved oxygen solubility.

However, beginning in 2023, this clear seasonal rhythm is disrupted. The graph shows a significant decrease in dissolved oxygen during the summer and autumn period of 2023, while BOD_5 values remain relatively stable, without corresponding growth. This may indicate oxygen deficit caused by hydrological regime disruption due to destruction of the Kakhovka HPP (06.2023) and reduced flow velocity, limiting water mixing and oxygen saturation from the atmosphere.

Continued organic matter decomposition under conditions of limited oxygen access in 2023-early 2024 explains the low DO level with relatively unchanged BOD_5 - available organic substances decompose with slowing, and oxygen access is limited. During the summer period of 2024, increased DO indicates partial restoration of aeration, possibly through improved weather conditions or reduced anthropogenic load (particularly organic matter), which is also evidenced by stability or even slight decrease in BOD_5.

Overall, the graph confirms the effect of "biochemical paradox": when high dissolved oxygen levels correspond to low BOD_5 (ecosystem capable of self-purification), and its decrease without accompanying BOD_5 growth indicates disruption of natural organic matter oxidation due to reduced flow and decreased atmospheric diffusion. Such changes demonstrate reduced adaptive potential of the aquatic ecosystem under the influence of hydrotechnical and climatic factors.

For overall assessment of anthropogenic load levels from pollutants and their impact on BOD_5 levels and dissolved oxygen concentration, distribution histograms were constructed for the period 2015-2024.

Figure 4 presents a histogram of phosphate ion concentration distribution in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

The distribution histogram of phosphate ion concentrations in Dnipro River water demonstrates an asymmetric (right-skewed) character with a modal interval of 0.36-0.44 mg/dm³, indicating predominance of moderate phosphate loading levels. Approximately 80% of values are concentrated within 0.22-0.50 mg/dm³ - typical for water bodies with regular impact from wastewater and agricultural runoff. Such concentrations can support increased aquatic ecosystem productivity but promote phytoplankton biomass accumulation, especially during summer periods, increasing the risk of eutrophication development. Individual high values (>0.65 mg/dm³) are likely related to local unauthorized discharges or episodic ferti-

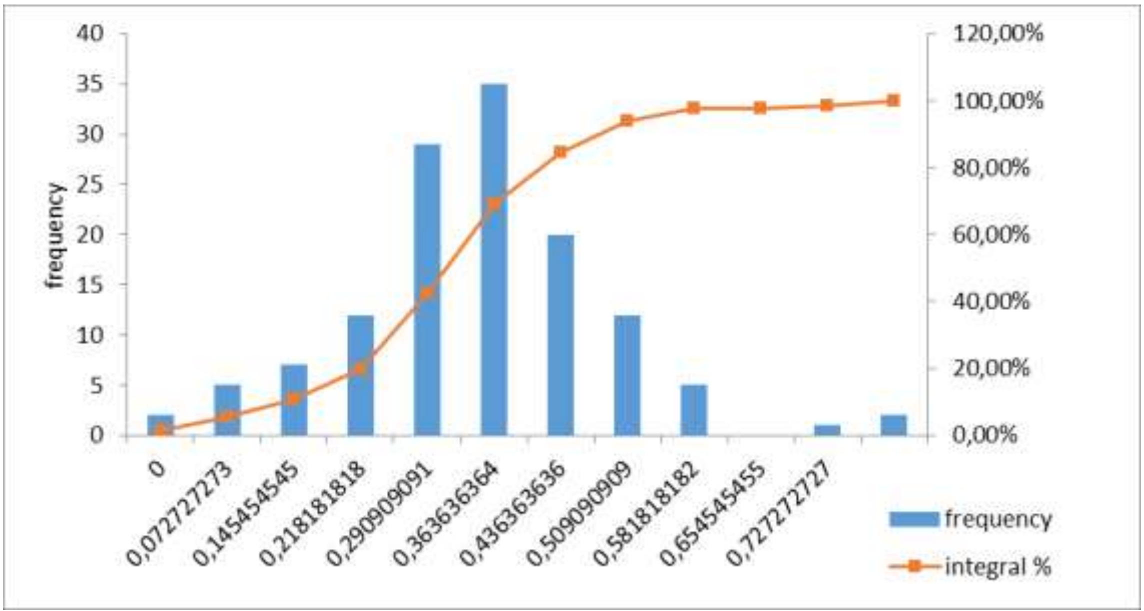

Fig. 4 – Distribution histogram of phosphate ion concentrations in Dnipro River surface waters in Zaporizhzhia during 2017-2024

lizer washout, and indicate disruption of the water body's buffer capacity. This distribution profile indicates the need for systematic monitoring and ecological control of phosphate loading sources.

Figure 5 presents a histogram of ammonium ion concentration distribution in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

The histogram demonstrates frequency distribution of ammonium ion concentrations, which has a pronounced right-skewed distribution with a maximum in the 0.31-0.39 mg/dm³ range. The main portion of values (over 80%) is

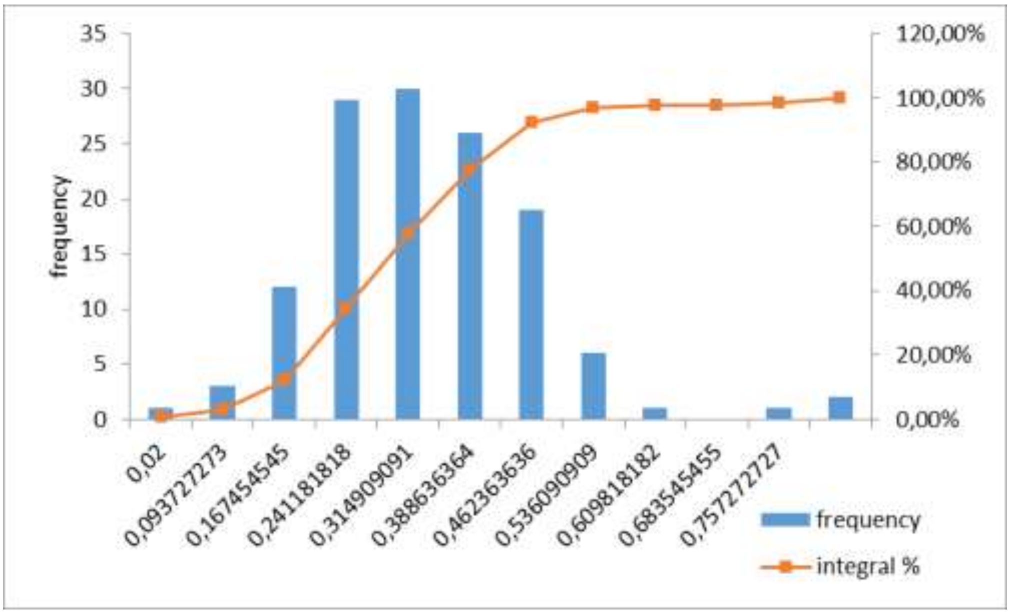

Fig. 5 – Distribution histogram of ammonium ion concentrations in Dnipro River surface waters in Zaporizhzhia during 2017-2024

concentrated within 0.24-0.53 mg/dm³, indicating the presence of a persistent ammonium pollution source, likely of domestic or agricultural origin. The cumulative curve (integral %) confirms predominance of average values, characteristic of aquatic systems with regular anthropogenic load but still capable of self-purification. Ammonium is an intermediate product of organic matter mineralization and an important indicator of oxygen regime. With sufficient dissolved oxygen levels, NH_4^+ undergoes nitrification to nitrites and further to nitrates, so this distribution form indicates relatively aerobic conditions.

At the same time, individual emissions with concentrations above 0.60 mg/dm³ (outliers on the right) indicate episodic overloads or reduced aeration - likely due to local discharges or flow reduction due to hydrotechnical changes (e.g., dam destruction or seasonal low water). This distribution profile is typical for waterways affected by anthropogenic factors but still maintaining buffer capacity for self-purification. At the same time, the presence of even occasional high concentrations requires enhanced control, as NH_4^+ is toxic to aquatic biota under high pH and temperature conditions characteristic of summer periods.

Figure 6 presents a histogram of sulfate ion concentration distribution in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

The distribution of sulfate concentrations has a normal distribution character with a maximum within 56-66 mg/dm³, corresponding to the natural mineralization level for large river systems with moderate technogenic load. The main mass of values (over 80%) is concentrated in the 46-75 mg/dm³ range, confirmed by the smooth cumulative curve. This indicates a stable source of sulfate influx - particularly from natural minerals (gypsum, sulfides), as well as from domestic and industrial wastewater.

Sulfates are indicators of the water body's oxidative regime, and high values may indicate active organic matter decomposition processes or influx of sulfur-containing compounds. Individual cases of concentrations above 84 mg/dm³ may result from local pollution, desorption processes from bottom sediments, or atmospheric runoff impact.

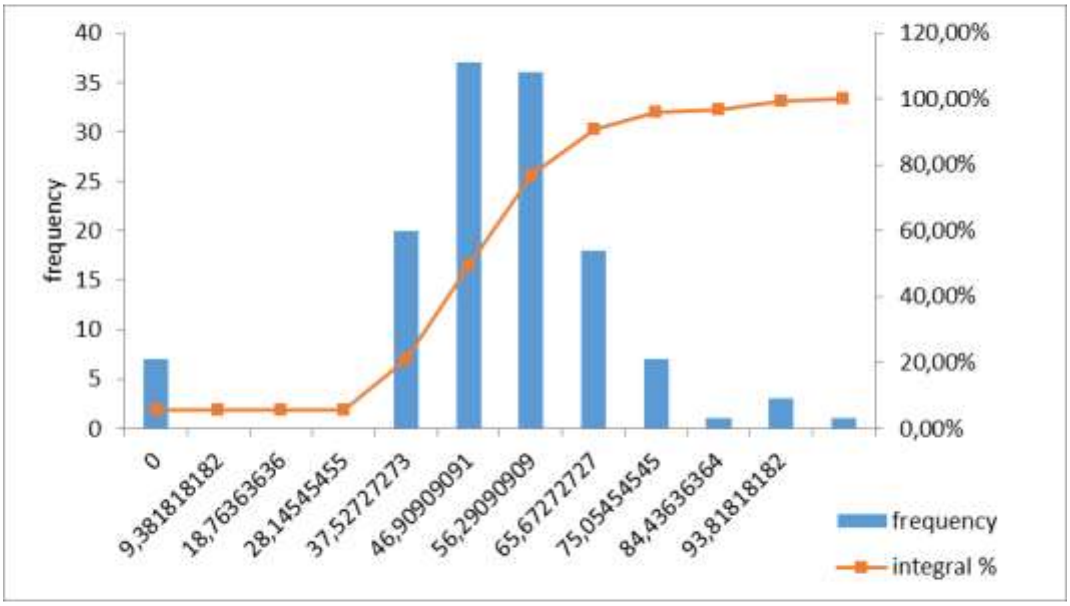

Fig. 6 – Distribution histogram of sulfate ion concentrations in Dnipro River surface waters in Zaporizhzhia during 2017-2024

This distribution profile is typical for river systems experiencing seasonal changes and having both natural and anthropogenic sources of SO_4^{2-} influx. High concentrations at low oxygen levels can also serve as a substrate for sulfate reduction with hydrogen sulfide (H_2S) formation, which is potentially toxic to aquatic biota.

Figure 7 presents a histogram of chloride ion concentration distribution in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024. The chloride ion distribution histogram is characterized by left-skewed asymmetry with a modal class in the 36.2-40.3 mg/dm³ range, indicating predominance of moderate mineralization levels. Over 80% of observations are concentrated within 28-44 mg/dm³, typical for freshwater river systems with background hydrogeochemical regime and minimal anthropogenic load.

Chlorides, as inert conservative ions, do not participate in the biogeochemical cycle and are not adsorbed by bottom sediments, so their distribution serves as a marker of hydrochemical background stability. The absence of pronounced extreme values in the right tail of the distribution indicates minimal influence of point

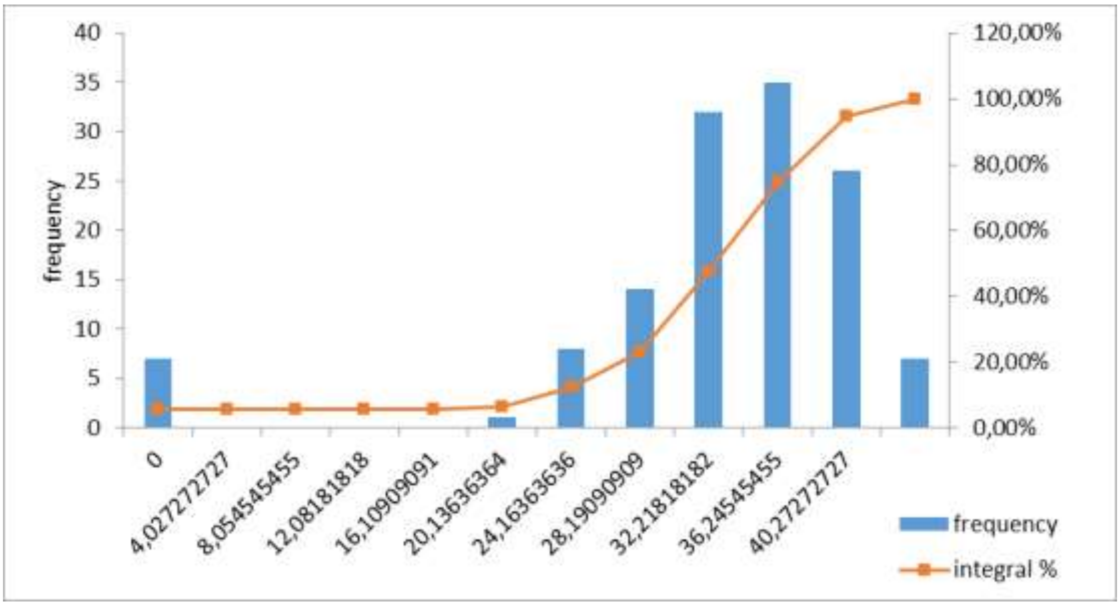

Fig. 7 – Distribution histogram of chloride ion concentrations in Dnipro River surface waters in Zaporizhzhia during 2017-2024

pollution sources - particularly domestic or industrial effluents characteristic of urbanized territories.

The presence of individual low values in the left part of the histogram (below 12 mg/dm³) may result from water dilution by flood or atmospheric precipitation or seasonal reduction in mineralization.

Thus, Cl^- distribution reflects hydrochemical stability and can be used as an indicator of background conditions when assessing changes in more reactive aquatic environment components.

Figure 8 presents a histogram of BOD_5 value distribution in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024.

The distribution of BOD_5 values has an asymmetric form with a maximum in the 2.7-3.1 mgO_2/dm^3 range, indicating predominance of moderate organic pollution. Most values (≈80%) are within 2.3-3.8 mgO_2/dm^3, corresponding to the level of weak to moderate anthropogenic load according to water quality ecological assessment classification. This profile is typical for water bodies with biodegradable organic matter of domestic and agricultural origin. The BOD_5 indicator is an integral biochemical indicator characterizing the oxygen requirement of aerobic microorganisms for oxidation of dissolved organic matter. Stable peak position in the medium range indicates conditions for natural self-purification and relatively aerobic environment. The presence of individual high values (>3.8 mg/dm³) indicates periodic local organic matter influx, likely from effluents without proper treatment. The cumulative percentage distribution curve (integral %) confirms uniform transition from background to elevated values, indicating absence of sharp anthropogenic emissions.

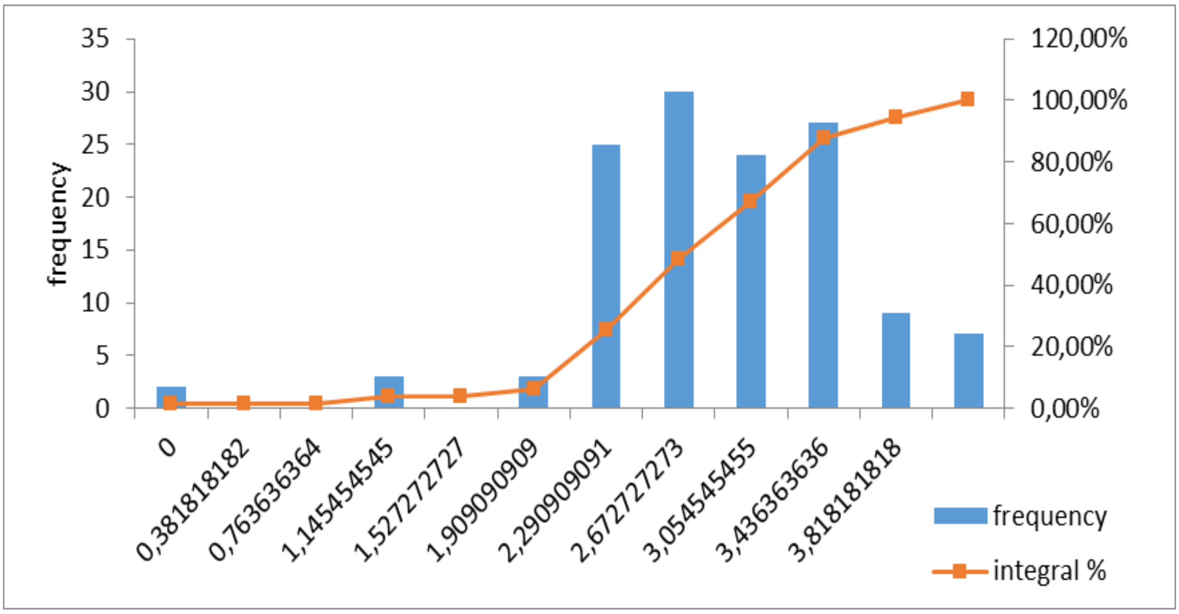

Fig. 8 – Distribution histogram of BOD_5 values in Dnipro River surface waters in Zaporizhzhia during 2017-2024

Figure 9 presents a histogram of dissolved oxygen concentration distribution in the surface waters of the Dnipro River in Zaporizhzhia during 2017-2024. The distribution of dissolved oxygen concentrations has a clearly defined modal interval of 9.7-10.4 mgO_2/dm^3, where the largest number of observations are concentrated. Over 80% of all values are within 8.2-11.2 mgO_2/dm^3, indicating the aerobic nature of the environment, favorable for aquatic biota functioning. This level of oxygen saturation corresponds to good ecological conditions, characteristic of water bodies with moderate organic loading and active oxygen diffusion from the atmosphere. It also indicates effective self-purification through aerobic oxidation of organic matter. The presence of a small number of values above 12 mgO_2/dm^3 may be related to intensive photosynthetic activity of algae during daytime, especially in summer. At the same time, the absence of a significant number of low values (<7 mg/dm³) indicates stable oxygen regime and absence of critical phenomena related to oxygen deficit (hypoxia), usually observed in reservoirs with reduced flow or excessive eutrophication.

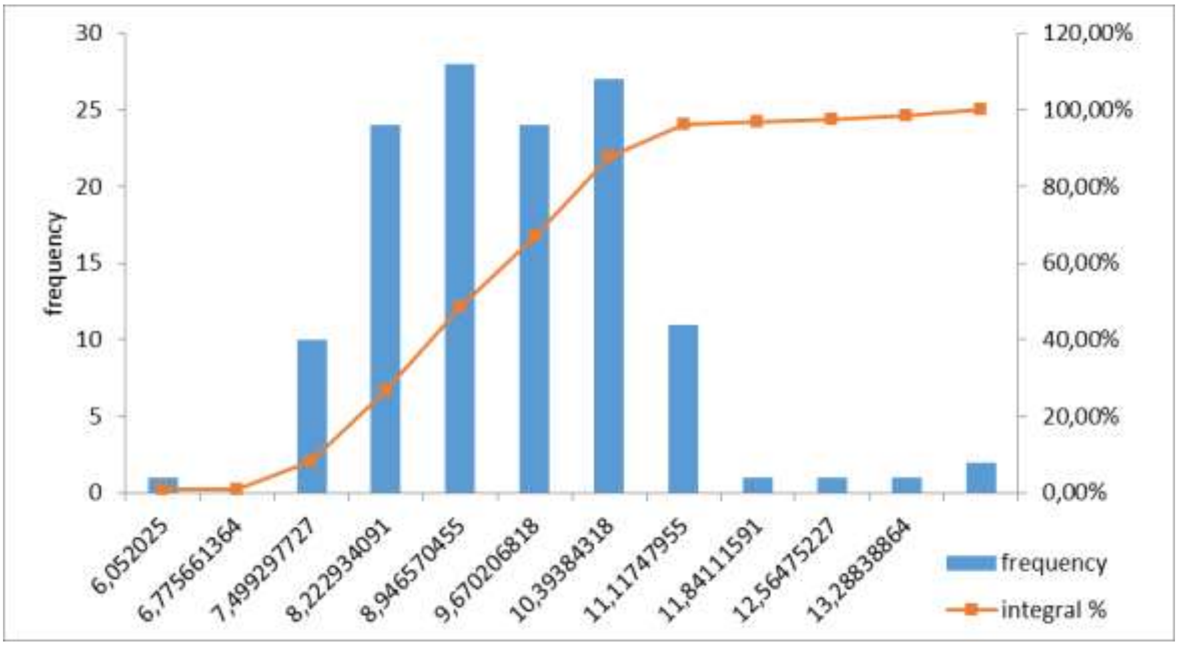

Fig. 9 – Distribution histogram of dissolved oxygen concentrations in Dnipro River surface waters in Zaporizhzhia during 2017-2024

The obtained distribution is an indicator of stable hydrobiological state, allowing maintenance of natural self-purification mechanisms and providing conditions for aerobic transformation of organic and inorganic pollutants.

To determine dynamics of anthropogenic load level changes on Dnipro River surface waters (DWS-1 station) and subsequent forecasting in the context of individual pollutants, corresponding regression equations were constructed. Annual average values of harmful substance emissions were used in their construction (i.e., seasonality of pollution was leveled).

Figure 10 presents the dynamics of phosphate and ammonium ion concentration changes in water during 2013-2024 and corresponding approximating curves.

Regression equation of the identified dependence for phosphate ions:

$$y = 5 \times 10^{-8}x^6 - 6 \times 10^{-4}x^5 + 2.7458x^4 - 6.8999 \times 10^3x^3 + 1 \times 10^7x^2 - 7 \times 10^9x + 2 \times 10^{12},$$

approximation reliability – $R^2 = 0.8047$.

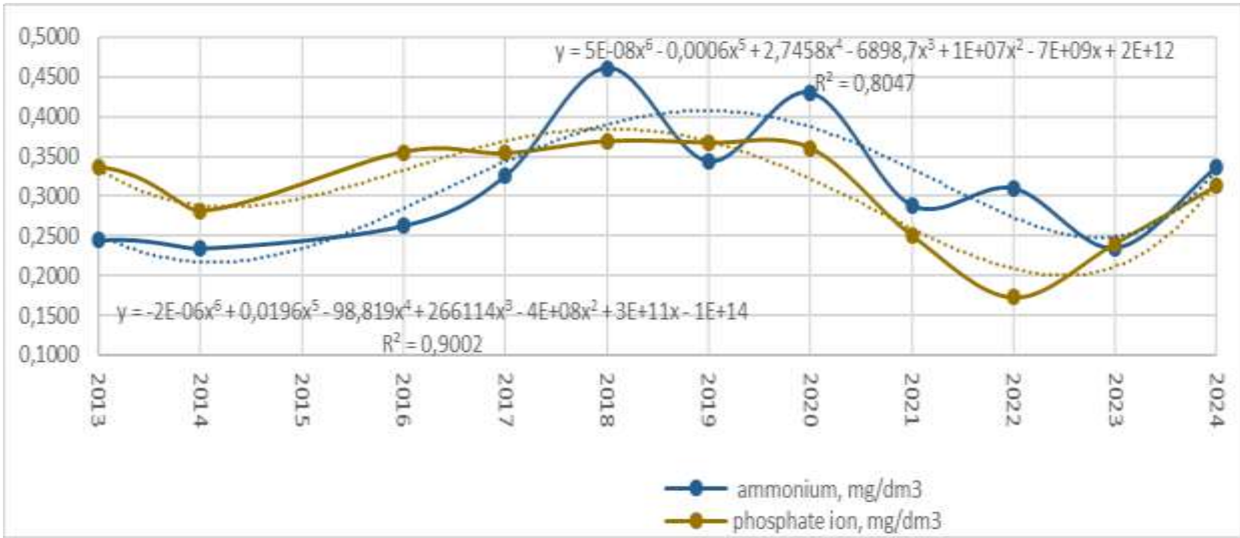

Fig. 10 – Dynamics of phosphate and ammonium ion concentration changes in water during 2013-2024 and corresponding approximating curves

The identified dependencies indicate that phosphate ion content reduction in water occurs periodically, namely being minimal in 2014 and in 2022.

Regression equation of the identified dependence for ammonium ions:

$$y = -2 \times 10^{-6}x^6 + 1.96 \times 10^{-2}x^5 - 98.819x^4 + 2.66114\times \times 10^5x^3 - 4 \times 10^8x^2 + 3 \times 10^{11}x - 1 \times 10^{14},$$

approximation reliability – $R^2 = 0.9002$.

The identified dependencies indicate that ammonium ion content reduction in water also occurs periodically, being at low levels during 2013-2015, and then in 2019, 2021, and in 2023.

This provides grounds to confirm the assumption regarding the main impact factor - fertilizer application, as reduction in application of some fertilizers is compensated by others. Additionally, from 2016 to 2021, general situation deterioration was observed, as average content of phosphate and ammonium ions in water increased. After situation improvement during 2022-2023 (due to reduced fertilizer application), in 2024 there was a return to previous trends.

Figure 11 presents the dynamics of sulfate and chloride ion concentration changes in water during 2013-2024 and corresponding approximating curves.

Regression equation of the identified dependence for sulfate ions:

$$y = 3 \times 10^{-4}x^6 - 3.0774x^5 + 1.5511 \times 10^4x^4 - 4 \times 10^7x^3 + 6 \times 10^{10}x^2 - 5 \times 10^{13}x + 2 \times 10^{16},$$

approximation reliability – $R^2 = 0.7549$.

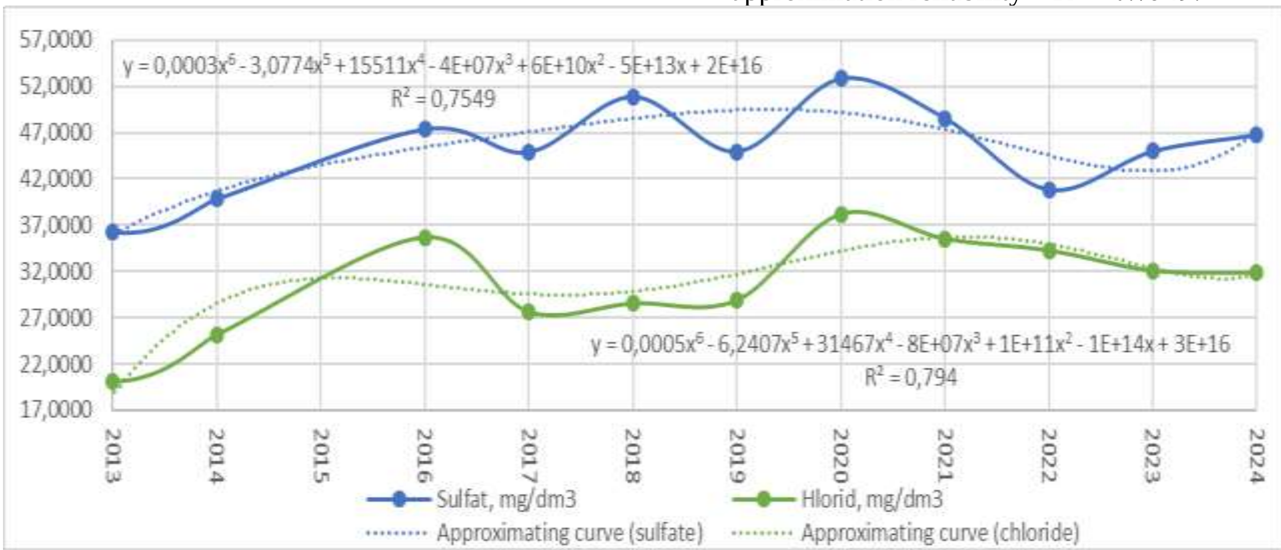

Fig. 11 – Dynamics of sulfate and chloride ion concentration changes in water during 2013-2024 and corresponding approximating curves

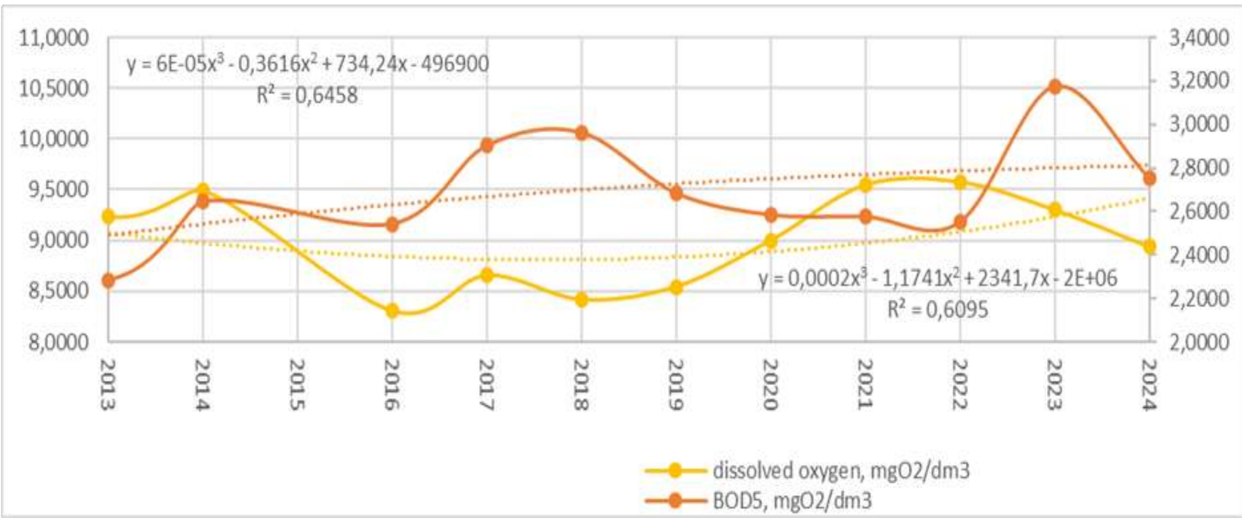

Fig. 12 – Dynamics of BOD_5 and dissolved oxygen concentration changes in water during 2013-2024 and corresponding approximating curves

Regression equation of the identified dependence for chloride ions:

$y = 5 \times 10^{-4}x^6 - 6.2407x^5 + 3.1467x^4 - 8 \times 10^7x^3 + + 1 \times 10^{11}x^2 - 1 \times 10^{14}x + 3 \times 10^{16}$,

approximation reliability – $R^2 = 0.794$

The identified dependencies indicate that chloride ion content changes in water are also insignificant. As can be seen, sulfate and chloride ion content during 2013-2016 increased, while in subsequent years it fluctuates around a certain average level.

Figure 12 presents the dynamics of BOD_5 and dissolved oxygen concentration changes during 2013-2024 and corresponding approximating curves.

Regression equation of the identified dependence for BOD_5:

$y = 6 \times 10^{-5}x^3 - 0.3616x^2 + 7.3424 \times 10^2x - 4.969 \times 10^5$,

approximation reliability – $R^2 = 0.6458$.

The identified dependencies indicate that maximum indicator levels were in 2017-2018 and in 2023 (significant increase) with practically unchanged level in other years.

Regression equation of the identified dependence for dissolved oxygen:

$y = 2 \times 10^{-4}x^3 - 1.1741x^2 + 2.3417 \times 10^3x - 2 \times 10^6$,

approximation reliability – $R^2 = 0.6095$.

The identified dependencies indicate that minimum indicator levels were in 2016-2019 and in 2024, with maxima observed in 2014 and during 2021-2022.

Therefore, opposite trends exist for BOD_5 and dissolved oxygen, as should be expected. The obtained results provide grounds to confirm the assumption about the existence of self-purification capacity despite existing anthropogenic influences.

Conclusions

The study covered the period 2013-2024 and was conducted in the context of the following indicators: phosphate ions, ammonium ions, sulfate ions, chloride ions, BOD_5, and dissolved oxygen.

It was established that the main anthropogenic load is created by industry, agriculture, and municipal enterprises. The consequences of war were also assessed, namely the destruction of the Kakhovka HPP dam (destruction of the Kakhovka Reservoir) and cessation of Dnipro HPP operations. Considering that indicators of surface water ecological state are BOD_5 and dissolved oxygen level, special attention was given to these indicators.

It was established that during 2017-2022, typical seasonal dynamics of indicators were observed. Since 2023, the clear seasonal rhythm changed due to disruption of hydrological regime through destruction of the Kakhovka HPP (06.2023) and reduced flow velocity, limiting water mixing and oxygen saturation from the atmosphere. Nevertheless, reduced pollution levels by phosphate and ammonium ions since the beginning of war has provided the possibility for self-purification of Dnipro River surface waters.

For overall assessment of anthropogenic load levels from pollutants and their impact on BOD_5 levels and dissolved oxygen concentration in Dnipro River surface waters, distribution histograms were constructed for the period 2015-2024.

Forecasting of anthropogenic load levels for main pollutants was carried out using regression equations, and predicted levels of BOD_5 and dissolved oxygen concentration in Dnipro River surface waters were determined.

Conflict of Interest

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ЕКОЛОГІЧНА ОЦІНКА ТА ПРОГНОЗУВАННЯ СТАНУ ПОВЕРХНЕВИХ ВОД РІЧКИ ДНІПРО У ЗАПОРІЖЖІ

Мета. Надати комплексну екологічну оцінку та прогнозування стану поверхневих вод річки Дніпро в межах Запорізької області з акцентом на динаміку основних показників якості води у 2013–2024 роках. Особлива увага приділяється антропогенним факторам, зокрема наслідкам військових дій і руйнування Каховської гідроелектростанції, що суттєво змінили гідрологічний режим і вплинули на екологічну рівновагу річки.

Методи. Системний аналіз, методи статистичної обробки, аналіз розподілу та регресійне моделювання для оцінки динаміки у ретроспективі та прогнозування майбутніх тенденцій.

Результати. Використано багаторічні дані моніторингу, отриманих з Лабораторії моніторингу вод Басейнового управління водних ресурсів річок Приазов'я. Основна увага приділялася оцінці шести ключових показників якості води: фосфатів, амонійних, сульфатних і хлоридних іонів, біохімічного споживання кисню протягом п'яти діб ($БСК_5$) та концентрації розчиненого кисню для оцінки екологічного стану поверхневих вод річки Дніпро в межах Запорізької області, зокрема у районі водозабору питної води (ДВС №1) у верхньому б'єфі Дніпровської ГЕС. Концентрації фосфатів і амонію демонструють періодичні коливання, зумовлені сезонними чинниками та використанням добрив. Рівень сульфатів відзначається високою мінливістю як природного, так і техногенного походження, тоді як концентрації хлоридів залишаються порівняно стабільними. Дані про розчинений кисень і $БСК_5$ свідчать про сезонну динаміку, яка порушується з 2023 року внаслідок руйнування Каховської дамби. Аналіз підтвердив здатність річки до часткового самовідновлення, особливо за умов зниженого антропогенного навантаження в період війни. Для прогнозної оцінки рівнів забруднення та екологічних ризиків було розроблено регресійні моделі.

Висновки. Визначено основні екологічні проблеми річки Дніпро, зокрема органічне й мінеральне забруднення, порушення гідрологічного режиму та зниження рівня кисню. Руйнування гідротехнічної інфраструктури, пов'язане з війною, загострило ці проблеми. Попри це, річка демонструє здатність до природного самовідновлення, особливо завдяки зменшенню навантаження фосфатами та амонієм. Відновлення екологічного балансу потребуватиме системного моніторингу, реконструкції водогосподарської інфраструктури та контролю за джерелами забруднення. Розроблені моделі можуть бути використані для прогнозування та управління якістю поверхневих вод як у мирний час, так і в період повоєнного відновлення.

КЛЮЧОВІ СЛОВА: *річка Дніпро, наслідки війни, поверхневі води, екологічний моніторинг, фосфати, амоній, сульфати, хлориди, розчинений кисень, БСК$_5$, антропогенний вплив, прогнозування*.

Конфлікт інтересів

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Автори заявляють про відсутність конфлікту інтересів щодо публікації цього рукопису. Крім того, автори повністю дотримувалися етичних норм, включаючи уникнення плагіату, фальсифікації даних та дублювання публікацій.

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