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DISSOLVED OXYGEN CONCENTRATION WATER DYNAMICS WITH DISCHARGE OF THE NUCLEAR POWER PLANT UNDER THE INFLUENCE OF TEMPERATURE EFFECT

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This article presents the results of studies on the dynamics of changes in the concentration of dissolved oxygen (DO) in the river in the zone of influence of water discharge from a nuclear power plant (NPP). Water is use in the power generation cycle of a NPP, mainly for cooling to remove heat. Moreover, the operation of the cooling system of a NPP requires a large amount of water, and meanwhile, the removal of heat from the systems and components of a NPP results in the discharge of cooling system effluent with an increased temperature, which can affect the chemical quality of the water body. One of the main chemical quality indicators used to determine the ecological status of a water body is DO concentration, but this indicator is highly dependent on temperature. After all, the discharge of water from a NPP with a temperature effect is highly susceptible to affect DO concentration. The popuse of this study is to determine the spatial and temporal changes in the concentration of DO with the establishment of variability factors and correlations between the concentration of DO and water temperature of the Styr River in the area affected by the temperature effect of the Rivne NPP. Overall, the studies conducted indicate that there is no negative impact of the nuclear power plant wastewater discharge.

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INTRODUCTION

Dissolved oxygen (DO) is an important chemical indicator of the ecological status of water bodies. Changes in the DO concentration of water bodies show significant fluctuations over a wide range of spatial and temporal scales and are primarily dependent on water temperature [1]. In addition, this dependence can change under the influence of natural and anthropogenic factors [2]. Nuclear power plant (NPP) consume large amounts of water for cooling, and the discharge of cooling water from NPP cooling systems has an elevated temperature [3]. Therefore, national standards set temperature limits for NPP water discharges [4]. Regular discharges from NPP pose a risk of persistent surface heat plumes in aquatic ecosystems, which could affect the environment of adjacent territories, which is one of the most important issues in the context of considering the risks associated with nuclear energy [5]. It is generally accepted that the DO content in water bodies is regulated by interacting and competing factors [6]. The absorption of oxygen from the atmosphere and its release by plants during photosynthesis are processes that enrich the water of natural objects with oxygen. Processes that deplete oxygen include biochemical oxidation of organic matter and chemical oxidation of reducing agents (Fe^{2+}, Mn^{2+}, NO_2^-, H_2S, et al.) [7]. However, the known studies of the influence of factors on the DO content have insufficient data and spatial and temporal inconsistency of water quality [8]. It should be noted that the influence of the main processes involved in the formation of DO also includes the interaction of water with air, in particular aeration and diffusion of oxygen, oxygen supply and accumulation by plant photosynthesis and oxygen consumption by respiration of aquatic organisms, as well as decomposition of organic matter and nitrification [9]. Thus, among factors, temperature is the main determinant of DO dynamics, with illumination in second place and flow having a minimal effect [10]. The highest oxygen saturation of surface waters is observed at 14…15 h, the lowest at 4…6 h, which is related to the productivity of photosynthesis [11]. DO concentrations can therefore vary by 2…3 mg/dm^3 during the day [12].

The combination of natural factors with anthropogenic activities makes it difficult to link and control environmental factors in river flow [13]. It has been shown [14] that the determined temperature dependence of DO concentration of water bodies varies significantly depending on the total dissolved salts (TDS). Thus, depending on the temperature, the TDS of surface waters affects the DO concentration, reducing it by 0.04…0.08 mg/dm^3 per 1 g of dissolved salts, this effect is clearly visible at mineralisation above 1 g/dm^3 and decreases with decreasing temperature. It is known that the effluent has an increased salinity due to concentration and evaporation processes in the design cooling systems used [15]. This requires individualisation of studies of the dynamics of changes in factors affecting DO concentration in a particular water body and consideration of the separate water effects of the effluent. Moreover, according to the environmental standards for water bodies to meet the drinking, household and other needs of the population (H) [16], the DO content should not be less than 4 mg/dm^3 at any time of the year in a sample taken before 12 noon. For waters used for fishing (F) [17], the DO content should not be less than 4 mg/dm^3 in winter (with ice cover) and less than 6 mg/dm^3 in summer. According to Ukrainian requirements [18], the DO content in the effluent should not be less than 4 mg/dm^3 and the temperature difference between the effluent and the surface water should not exceed 3 °C.

Our research focuses on the potential influence and relationship of river water temperature on DO content with the study of the temperature effect of nuclear power plant effluents. The aim of this study is to determine the spatial and temporal consistency of DO content, to identify the factors of variability and correlations between DO and water temperature in the zone of influence of the temperature of nuclear power plant effluents. The relevance of this study is to investigate the thermal impact of cooling water discharges from nuclear power plants on water bodies.

METHODOLOGY AND METHODS

The study was carried out using the Rivne NPP cooling system as an example. The process water at the Rivne NPP is taken from the Styr River to feed the open circuit cooling system, and the return water is discharged into the Styr River. The scheme location of water sampling in the Styr River before water intake (A) and water discharge (B) of Rivne NPP is shown in Fig. 1. Sampling and monitoring of parameters was carried out by the certified laboratory of weekly monitoring of the Rivne NPP in 2020–2022. A standard method for measuring DO concentration in water was used to control the concentration (Table 1).

The following methods were used in the study: mathematical modelling to substantiate the parameters, classification and generalisation; systems analysis to develop the methodological basis for the evaluation; analysis and technical calculations; computational and statistical methods. Statistical processing of the study results involved determining the range of data series (min-max), arithmetic mean (M), standard deviation (±SD) and coefficient of variation (CV) of the respective sample.

Table 1

Characterization of methods for measuring DO concentration in the study

Indicator	CI*	CI* and relative measurement error δ, %	Method
DO, mgO_2/dm^3	0.5… 50	0.5 to 5: δ = ± 25; 5 to 20: δ = ± 20; 20 to 50: δ = ± 10	MVV 081/12-0008-01

Note: *CI is the measurement range.

Fig. 1. Location of sampling sites of the Styr River: before water intake (A) and water discharge (B) of Rivne NPP

RESEARCH RESULTS AND DISCUSSION

The data of DO concentration monitoring in the Styr River water in the area of influence of the Rivne NPP discharges shows a wide range of concentration fluctuations (Fig. 2).

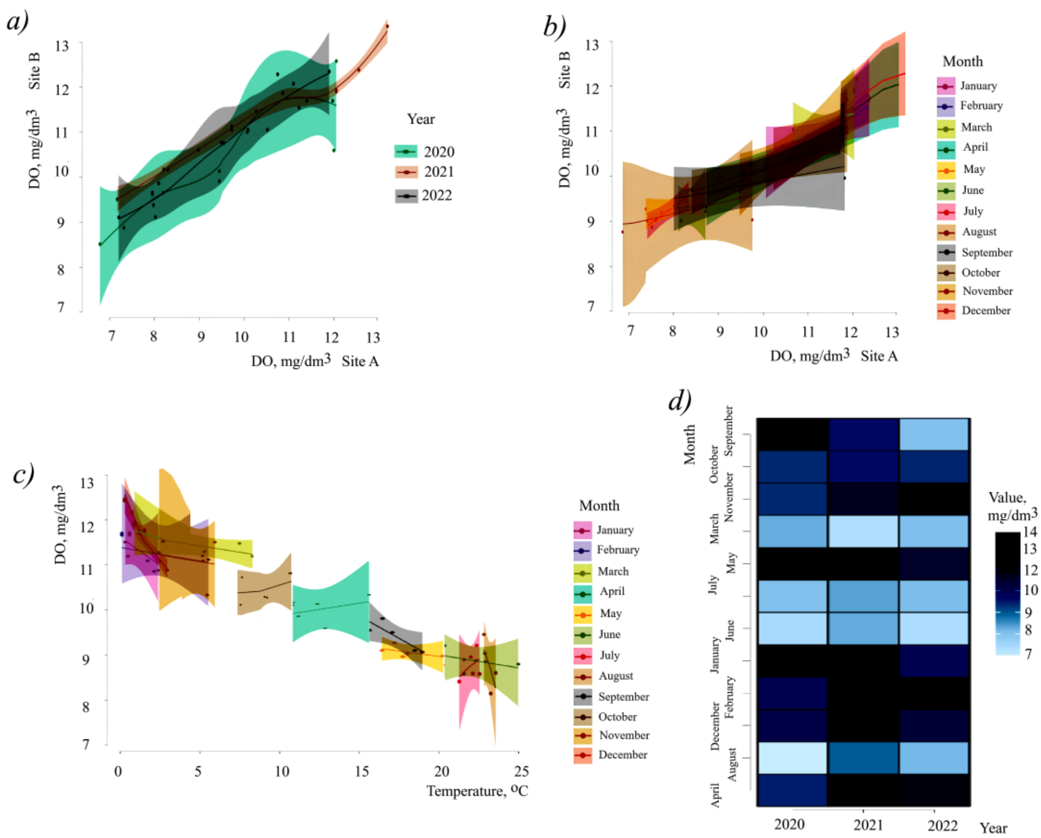

Fig. 2. Dissolved oxygen dynamics depending on the water temperature of the Styr River in the Rivne NPP discharge zone (a – distribution during 2020–2022; distribution by months: b – 2020, c – 2021, d – 2022)

Consequently, with increasing water temperature in the Styr River, DO concentration decreases (see Fig. 2,c), with higher DO concentrations observed in winter months and lower concentrations in summer months (see Fig. 2,d). In particular, during 2020–2022, the DO concentration varied in the range of min-max 6.40…13.53 mgO_2/dm^3, M = 9.31 mgO_2/dm^3, SD = ± 2.95 mgO_2/dm^3, CV = 31.7%.

In the locations before the water intake (Fig. 3,a) and after the water discharge (see Fig. 3,b) of the Rivne NPP of the Styr River water, the environmental standards F and H for the actual DO concentration are not exceeded, and the DO concentration does not decrease below 6 mgO_2/dm^3.

The concentration of DO in the water of the Styr River after discharge is lower than before the Rivne NPP intake. In fact, it was found that the decrease is observed: M = 0.47 mgO_2/dm^3, SD = ± 0.13 mgO_2/dm^3, CV = 27.7%. Therefore, this can be explained by the impact of the Rivne NPP heated return water discharge, which is why the Styr River water temperature is observed to increase in the sites before the intake (see Fig. 3,c) and after the water discharge (see Fig. 3,d). The temperature increase does not exceed the normalised value of 3 °C according to [18] and is 1.07 °C; SD = ± 0.64 °C; CV = 73.55%.

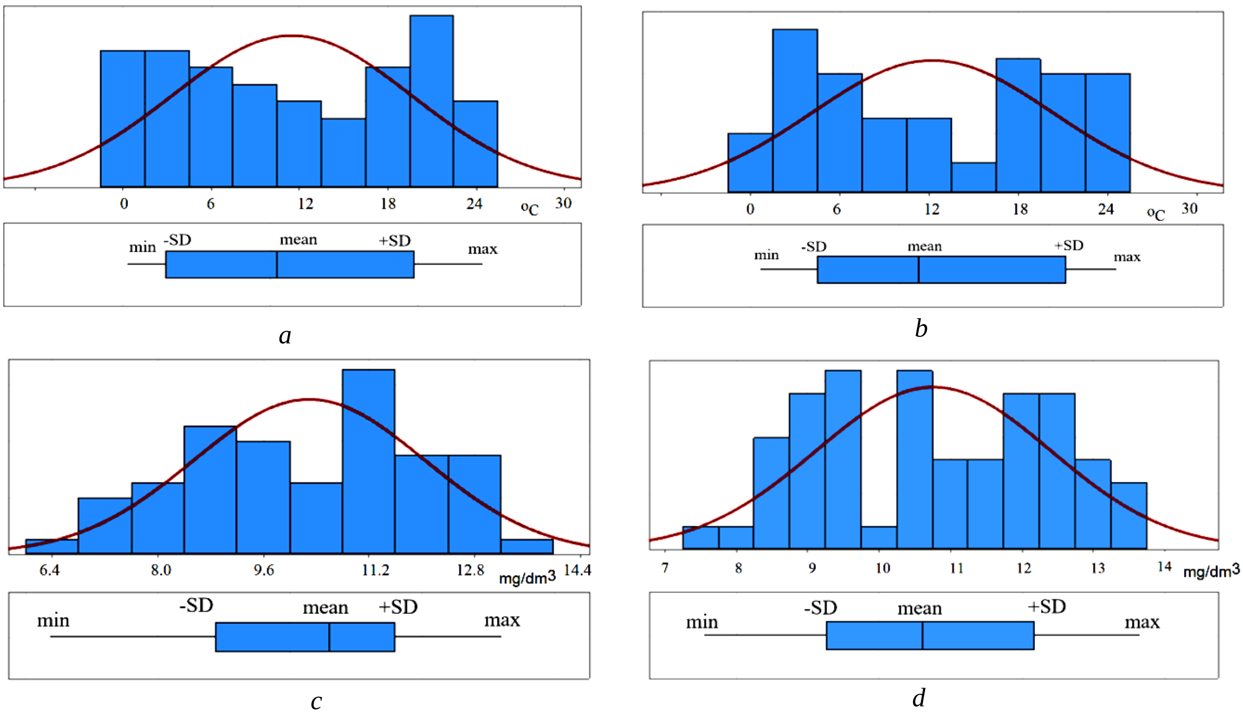

Fig. 3. Dissolved oxygen and water temperature of the Styr River in the area of influence of the Rivne NPP water discharge during 2020–2022 (water temperature: a – before intake, b – after discharge; dissolved oxygen concentration in water: c – before intake, d – after discharge)

It is well known [19] that a high pH level of water can inhibit algal photosynthesis, which in turn leads to a decrease in DO concentration. Thus, in winter, the pH level of the Styr River water decreases to 7.5…8.0 units, and in summer it increases to 7.8…8.5 units [23]. It can also be argued that the increase in the pH level in the summer period of the year has led to a decrease in the seasonal DO concentration in water the Styr River. Moreover, the natural decrease of DO concentration according to [20] in water bodies is explained by biochemical processes of aerobic oxidation of organic nitrogen and phosphorus compounds by microorganisms (1) and the nitrification reaction by nitrifying bacteria (2).

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 106O_2 \rightarrow 106CO_2 + 16NH_3 + H_3PO_4 + 106H_2O, \quad (1)$$

$$NH_4^+ + 1.83O_2 + 1.98HCO_3^- \rightarrow 0.0210C_5H_7NO_2 + 0.979NO_3^- + 1.04H_2O + 1.88H_2CO_3. \quad (2)$$

It is well known [10] that the decrease in DO concentration in water of water bodies also occurs due to the physical effect of temperature, since its increase reduces the solubility of oxygen. However, since the processes of increasing water temperature are accompanied by intensification of biological processes with increased photosynthesis [9], it is possible to assume further increase of DO concentration with the establishment of the initial equilibrium of its content in the water of the Styr River after the water discharge of the Rivne NPP. In the sites of the Styr River before the water intake and after the Rivne NPP water discharge, DO concentrations differ most (up to 15%) for the minimum values (Table 2), which determines the greatest impact of the water discharge at low DO concentrations and is observed in the warm season. The median DO concentration (see Table 2) practically does not differ in the controlled areas, which may indicate [21] the absence of a significant temperature effect of water discharge on DO concentration in the Styr River in the area of the Rivne NPP discharge.

Table 2

Minimum and median DO concentrations and their distribution at sites before and after the Rivne NPP water discharge

Indicators	Before intake, mg/dm^3	After discharge, mg/dm^3
Minimum:	7.56	6.40
5th percentile	8.36	7.21
25th percentile	9.26	8.87
Median:	10.61	10.59
75th percentile	12.18	11.99
95th percentile	13.53	13.37

The method of multiple linear regression [22, 23] was used to determine the relationship between DO concentration and water temperature (Fig. 4). The obtained equation (3) describes the dependence of DO concentration and water temperature in the area of influence of the Rivne NPP water discharge with the value of the coefficient of determination R-sq = 0.98. The relationship between the indicators is characterised by a p-value of 0.001 and a strong relationship with a Pearson's coefficient of r = 0.76. The obtained parameters of regression dependence (see Fig. 4) R-sq, p, r allow to predict changes in DO concentration as a function of water temperature in the range from 0 to 25 °C in the zone affected by water discharge from the Rivne NPP.

$$\text{DO, mg/dm}^3 = 12.32 - 0.1759 \cdot \text{T, °C}. \quad (3)$$

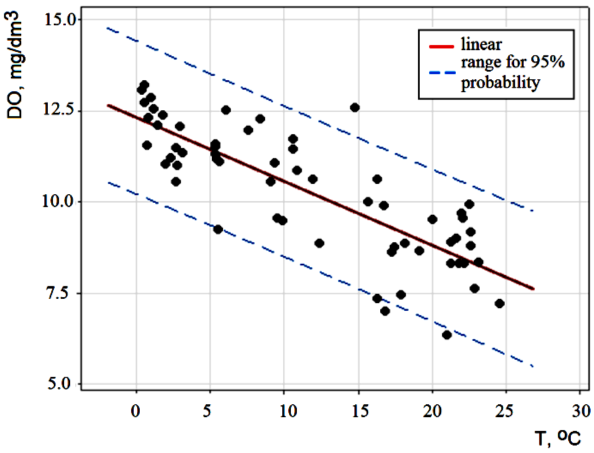

Fig. 4. The regression relationship of dissolved oxygen concentration and water temperature of the Styr River in the zone of influence of the Rivne NPP discharge

To generalise, it is known [24] that the oxygen regime of a river depends primarily on seasonal variations in temperature, flow and trophic status. It can be concluded that the oxygen regime of the Styr River is primarily dependent on seasonal temperature fluctuations, and the systemic effect of the temperature discharge from the Rivne NPP [25] on DO concentration is not observed. Furthermore, the results indicate that the highest DO concentrations observed in winter, as reported in previous studies, are due to low water temperatures [26]. Conversely, both physical and biological factors influence processes over spatial and temporal scales of DO concentration and are therefore important for experimental research [27].

CONCLUSIONS

This study investigated the dynamics of changes in DO concentration in the Styr River in the zone of influence of the Rivne NPP water discharge. DO concentration varied in the range of min-max 6.40…13.53 mgO_2/dm^3. As a result, it was found that the water discharge of the Rivne NPP with an increased level of temperature has no influence on the DO concentration in the Styr River. In addition, a slight decrease of up to 15% of DO concentration in the Styr River after the Rivne NPP water discharge is observed in winter. A seasonal natural increase of the DO concentration in the Styr River before and after the water discharge from the Rivne NPP was observed in winter. In general, according to the results of this study, the impact of the Rivne NPP water discharge does not exceed the environmental standards in terms of the temperature effect of the discharge and the impact of the discharge on the DO concentration in the water body. Therefore, in the area affected by the water discharge of the Rivne NPP, the influence of temperature on the dynamics of DO concentration proves that there are no changes in the oxygen balance of the Styr River. Moreover, the regression dependence obtained from the study results allows to predict the DO concentration in the Sty River water under the temperature effect of the water discharge, which is important and can be used to limit the temperature effect of the NPP water discharge.

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ДИНАМІКА КОНЦЕНТРАЦІЙ РОЗЧИНЕНОГО КИСНЮ ПІД ВПЛИВОМ ТЕМПЕРАТУРНОГО ЕФЕКТУ СКИДУ АТОМНОЇ ЕЛЕКТРОСТАНЦІЇ

П.М. Кузнєцов, О.О. Бєдункова

Представлено результати досліджень динаміки змін концентрації розчиненого кисню у річці у зоні впливу водних скидів атомної електростанції. Вода використовується у циклі виробництва електроенергії атомної електростанції, в основному, для охолодження і відведення тепла. Крім того, експлуатація системи охолодження атомної електростанції потребує великої кількості води. У той же час відведення тепла від систем та елементів атомної електростанції призводить до скидання зворотних вод охолоджуючої системи з підвищеною температурою, що може вплинути на хімічні показники якості водного об'єкту. Одним з найважливіших хімічних показників якості, що визначає екологічний стан водного об'єкту, є концентрація розчиненого кисню, але цей показник значною мірою залежить від температури. Зрештою, скидання води атомної електростанції з температурним ефектом дуже схильне до впливу на концентрацію розчиненого кисню. Метою цього дослідження є визначення просторово-часових змін концентрації розчиненого кисню зі встановленням факторів мінливості та кореляційних зв'язків між концентрацією розчиненого кисню та температурою води річки Стир у зоні впливу температурного скиду Рівненської атомної електростанції. В цілому, проведені дослідження свідчать про відсутність негативного впливу скидання зворотних вод атомної електростанції.