УДК 621.039
doi.org/10.31717/2311-8253.23.3.6

P. M. Kuznietsov[1, 2], **O. O. Biedunkova**[1]

[1] *National University of Water and Environmental Engineering, 11, Soborna st., Rivne, 33028, Ukraine*
[2] *SS Rivne NPP, 1, Promyslova st., 34400, Varash, Ukraine*

Study of Temperature Impact of Discharges and Balance of Biogenic Elements in the Water of the Styr River in the Impact Zone of the Rivne NPP

Keywords:
nuclear power plant,
temperature influence,
discharges,
biogenic elements

Regardless of the type of cooling cycle, all nuclear power plants (NPPs) have a cooling water discharge with residual heat energy. Significant volumes of water are circulated in the cooling system of an NPP, which is withdrawn and discharged into a natural water body, thus transferring heat from the power plant to the water body. Changes in the content and balance of biogenic substances in surface waters under the influence of water discharges from an NPP can be considered as important indicators of water and environmental reactions to heat emissions from an NPP. The study aims to determine the dynamics of changes in the content of biogenic elements for the coexisting forms of nitrogen (N), phosphorus (P), and carbon (C) with the establishment of variability factors and correlations between their forms in the water of the Styr River, which is in the zone of water discharges influence from the Rivne Nuclear Power Plant (Rivne NPP). According to the results of the study, it was determined that the content of P (orthophosphate ions PO_4^{3-}), C (biochemical oxygen demand for 5 days BOD5 and chemical oxygen demand COD) and N (ammonium nitrogen $N\text{-}NH^3$, nitrate ions NO_3^-) in the water of the Styr River in the zone of influence of water discharges from the Rivne NPP has seasonal dynamics. The correlation of the balance content of nutrients in the water of the Styr River before water intake and after discharge by the Rivne NPP was estimated. Regression statistical dependencies were established, which allow predicting the content of nutrient forms depending on the temperature by environmental and technical factors of temperature influence. In general, the research results indicate that there is no negative impact of the Rivne NPP water discharges on the balance of nutrients, and therefore no manifestation of the Styr River water-ecological reactions to the Rivne NPP heat release.

Introduction

The temperature regime of a water body is a crucial factor for the quality of the ecosystem, and the temperature impact on water bodies caused by the discharge of cooling water from nuclear power plants can have a significant impact on the aquatic environment [1]. The temperature effects of water discharges are determined by direct and indirect effects: direct effects include increased activity with acceleration of digestion, increased demand for food, disruption of reproduction, destruction of sensitive tissues of the nervous system of aquatic organisms; indirect effects cause negative changes in aquatic and ecological processes, including imbalance of nutrients [2]. Many scientific studies have been carried out on the effects of cooling water discharges on aquatic ecosystems, but only the spatial and temporal interpretation of temperature has been studied in real sites. The technological aspect, which relates the power output of a nuclear power plant to the temperature of the cooling water, has also been studied. However, in addition to thermal emissions, aquatic ecosystems also face the impact of chemicals discharged by NPPs with cooling water, which should also be considered. Our study focuses on the potential impact and relationship of cooling water temperature on chemical discharges, as well as on assessing the impact of temperature.

The thermal effects of power plants, which raise the temperature of natural waters by more than 4 °C, cause a shift in the N: P balance, and a temperature increase of 10 °C causes changes in the structural communities and the number of aquatic organisms [3, 4]. In particular, the introduction of warm wastewater contributes to biological metabolic productivity. Environmentally significant is the excess temperature released (temperature difference), which describes the difference between the temperature and the ambient temperature in the river [5]. Thus, changes in the nutrient content of surface waters under the influence of nuclear power plant effluents can be considered as important indicators of aquatic and ecological responses to nuclear power plant heat generation [6].

Our research focuses on the potential influence and interrelationship of cooling water temperature on chemical effluents, and an assessment of the temperature effect on possible changes in chemical elemental balances due to thermal pollution with study of the temperature effect of power plant cooling water on the cycling of biogenic elements (N, P, and C) has not been considered to date. The purpose of the study is the determination of the dynamics of changes in the content of biogenic elements — forms of N, P, and C with the establishment of variability factors and correlations between them in the zone of influence of temperature discharges of the Rivne NPP. The relevance of the study lies in the investigation of the thermal impact of the cooling water discharges from the nuclear power plant on the water bodies, since the thermal regime of the reservoir is a decisive factor for the quality of the ecosystem.

Method

The research is carried out on the example of the cooling system of the Rivne NPP. The Rivne NPP process water is supplied by the Styr River, an open recirculating cooling water system (RCWS) with a return water discharge to the Styr River. Sampling and monitoring of parameters were carried out by the Rivne NPP's certified measuring laboratory. To control the concentration, standard measurement methods were used (Table 1) and the measurement results for 2018–2022 are presented in [7]. The scheme of sampling of the Styr River water before intake (A-) and after discharge (B-) of the Rivne NPP cooling water is shown in Fig. 1. The methodology of this study involved the use of mathematical modelling, classification and generalisation, system analysis and technical calculations, calculation and statistical methods. The results of the study are initial data for further monitoring of possible abnormal changes in the content of biogenic elements C, P, and N and the trends of changes in the cycle of these elements in the water of the Styr River, including changes due to the influence of anthropogen-

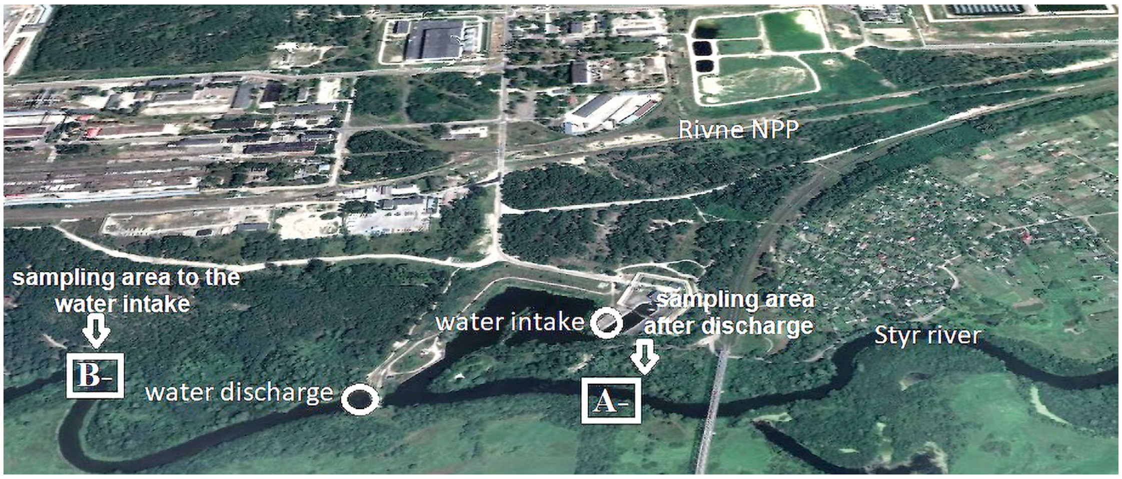


Fig. 1. Location of the Styr River water sampling and monitoring sites in the pre-intake (A-) and post-discharge (B-) areas of the Rivne NPP (see Figs 1–11 in color on the journal website)

Table 1. Characterization of methods for measuring the concentration of biogenic elements in the study (CI is the measurement range)

Indicators	CI	Relative measurement error δ, %	Method of measurement (Standard in Ukraine)
Carbon compounds			
BOD5, mgO_2/dm^3	0.5–15	0.5 to 2: δ = ±(90–27); 2 to 5: δ = ±(27–11); 5 to 15: δ = ±(11–5)	KND211.1.4.024-95
COD, mgO/dm^3	5–100	5 to 10: δ = ±(65–34); 10 to 30: δ = ±(34–14); 30 to 100: δ = ±(14–9)	KND211.1.4.021-95
Nitrogen compounds			
Nitrate ions, mg NO_3/dm^3	0.5–1,000	0.5 to 100: δ = ±25; 100: δ = ±16	MVV 081/12-0651-09
Ammonium nitrogen, mgN/dm^3	0.5–10	0.1 to 0.5: δ = ±20; 0,5: δ = ±9	MVV 081/12-0106-03
Phosphorus compounds			
Orthophosphate ions, $mgPO_4^{3-}/dm^3$	0.05–100	0.05 to 0.5: δ = ±15; 0.5: δ = ±10	MVV 081/12-0005-01

ic factors of discharge waters. The practical value of the study is planning and implementing appropriate water management strategies and focusing on water quality and pollution sources to prevent water pollution in water bodies and can be used to assess the non-radiological impact of discharges from nuclear power plants.

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 and statistical analysis of the data using the Minitab software package (Version 21.4.1, Minitab, LLC).

Results and Discussion

The Styr River water flows varied in the range from 10 to 63 m^3/s, M = 27 m^3/s, SD = ±18 m^3/s, CV = 51,36%. According to the terms of the Permit [8], the flows of recharge of the Rivne NPP cooling system should not exceed 2.79 m^3/s (88 $mln.m^3/year$), the actual flows of recharge of the Rivne NPP cooling system (see Fig. 1, b) depends on the season and is to 2,63 m^3/s in the warm season and up to 1.56 m^3/s in the cold season. The average value of water intake from the Styr River to feed the cooling system of the Rivne NPP was 1.68 m^3/s, SD = ±0.41 m^3/s, CV = 27.92%. The flow rate of cooling return water of the Rivne NPP cooling system is from 15–22% from the flow of intake of water and does exceed the normalised value under the terms of the Permit [8] up to 0.7 m^3/s (18.36 $mln.m^3/year$). The flow rate of the cooling system water of the Rivne NPP depends on the season of the year to 0,65 m^3/s in the warm season and up to 0.37 m^3/s in the cold season. The average flow rate of the cooling system water of the Rivne NPP was 0.31 m^3/s, SD = ±0.22 m^3/s, CV=45.63%.

The change in the temperature of the Styr River water in the zone of influence of the Rivne NPP discharges ranges from 0.3 °C to 24.6 °C (Fig. 2), the difference in Styr River water temperature before and after the discharge does not exceed the permitted increase limit under the terms of the Permit [8] in 3 °C (see Fig. 2) and makes up the average value of 1.07 °C, SD = ±0.64 °C, CV = 73.55%. The amount of water taken from the Styr River to replenish the cooling system of the Rivne NPP depends on the season of the year, with higher flows in the warmer months due to an increase in ambient temperature and consequently greater evaporation of water from the cooling system. The change

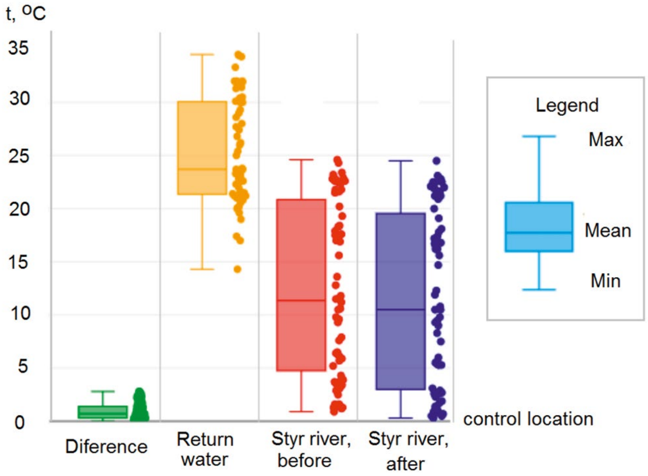


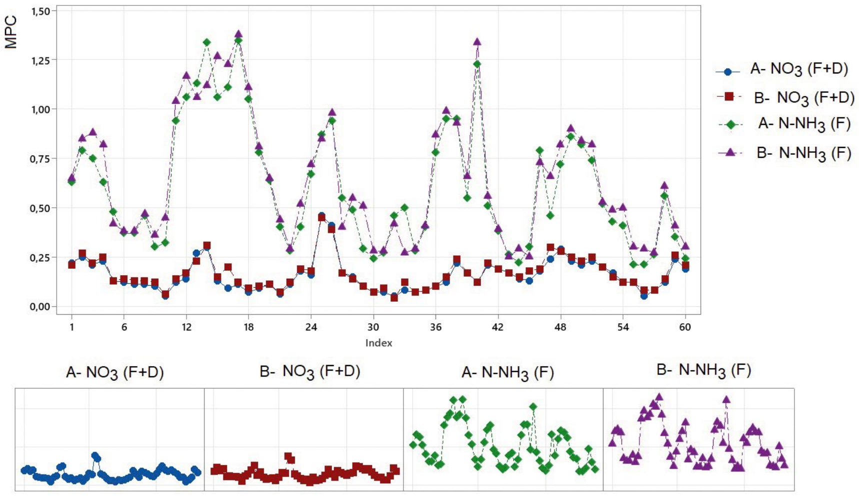
Fig. 2. Dynamics of changes in the temperature of RCWS return water from the Rivne NPP and Styr River water at the sites before water intake (A–) and after discharge (B–) of the Rivne NPP and their difference for 2018–2022

in the temperature of the Styr River at the Rivne NPP intake reflects the known seasonal increase in temperature in summer and decrease in winter.

The change in the concentration of the control indicators in the water of the Styr River in the area of influence of the Rivne NPP discharges shows a wide range of fluctuations in the concentration of the indicators. Thus, during 2018–2022, the NO_3^- concentration (Fig. 3) varied in the range of min-max 2.03–20.07 mg/dm^3, at M = 5.81 mg/dm^3, SD = ±0.49 mg/dm^3, CV = 52,74%; N-NH_3 (Fig. 3) — min-max 0.25–2.13 mg/dm^3, M = 0.56 mg/dm^3, SD = ±2.17 mg/dm^3, CV = 59.17%; COD (Fig. 4) — 17.6–83.2 mgO/dm^3, M = 45.7 mgO/dm^3, SD = ±22.5 mgO/dm^3, CV = 46.9%; BOD5 (Fig. 4) — min-max 0.86–3.87 mgO_2/dm^3, M = 1.32 mgO_2/dm^3, SD = ±0.17 mgO_2/dm^3, CV = 23.4%; PO_4^{3-} (Fig. 5) — 0,09–0,590 mg/dm^3, M = 0.295 mg/dm^3, SD = ±0.134 mg/dm^3, CV = 35.9%.

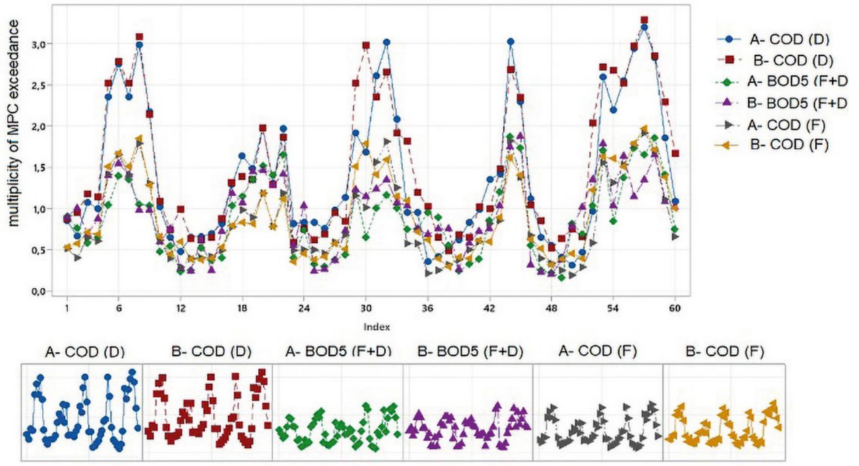
The concentration of control indicators in the area of influence of the Rivne NPP water discharges meets environmental standards. There are occasional exceedances of the maximum permissible concentration (MPC) for domestic (D) and fishery (F) standards for COD, BOD5, NO_3^- (F and D) and PO_4^{3-} (F), which are not related to the activities of the Rivne NPP, but are caused by an increase in the concentration of substances in the Styr River upstream (section A before the intake).

The dynamics of seasonal changes in indicators shows their variability for COD, BOD5 with a maximum in the warm season, which is explained by production and destruction processes and high photosynthetic activity of phytoplankton. The peak concentrations of NO_3^-, N-NH_3 are observed in spring and autumn, which may be related to the anthropogenic load during agricultural activities, and fluctuations in the content of phosphorus compounds are also observed with a maximum in the warm season.



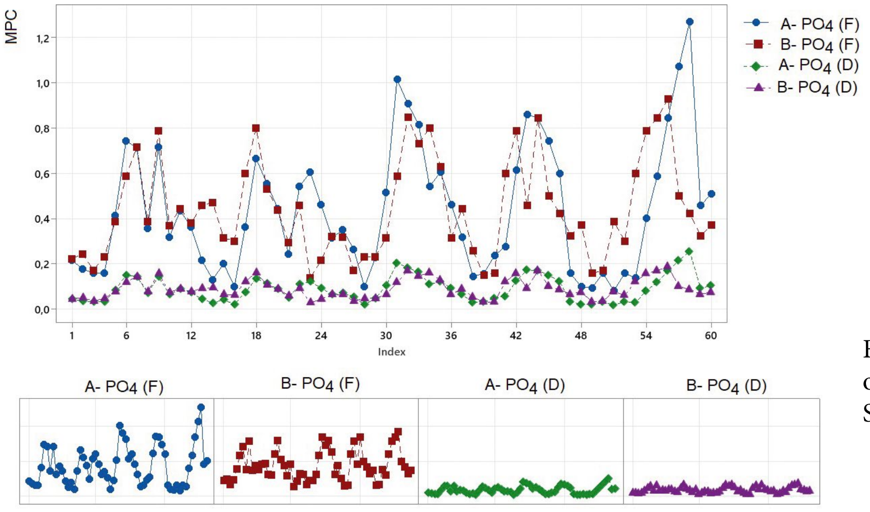
MPC — maximum permissible concentration, MPC (F) — fishery, MPC (D) — domestic

Fig. 3. Dynamics of changes in the content of nitrogen compounds in the water of the Styr River in relation to the MPC for 2018–2022



MPC — maximum permissible concentration, MPC (F) — fishery, MPC (D) — domestic

Fig. 4. Dynamics of changes in the content of carbon compounds in the water of the Styr River in relation to the MPC for 2018–2022



MPC — maximum permissible concentration, MPC (F) — fishery, MPC (D) — domestic

Fig. 5. Dynamics of changes in the content of phosphorus compounds in the water of the Styr River in relation to the MPC for 2018–2022

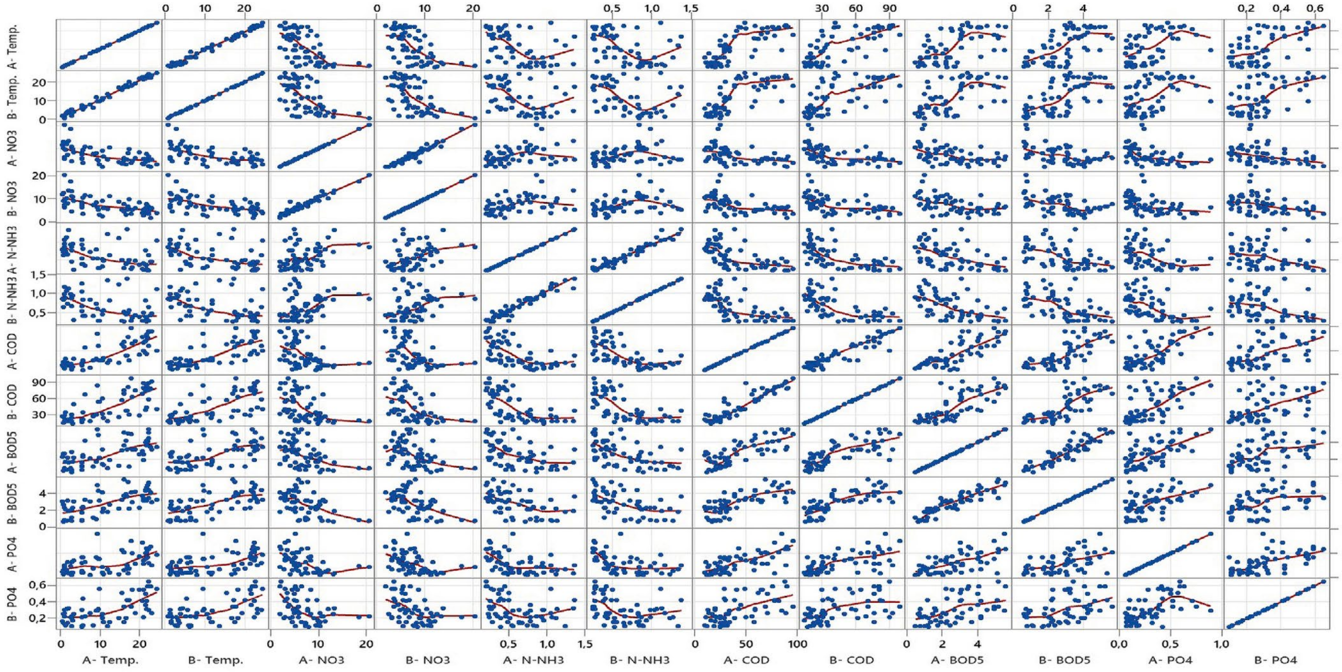


Fig. 6. Matrix plot for indicators of the Styr River in the impact zone of the Rivne NPP for 2018–2022

Dataset analysis was performed using the Pearson correlation analysis in order to evaluate the relationship between water quality variables [9]. This minimizes the effect of between-stations correlations and between-sampling campaigns relationships. A correlation coefficient near –1 or 1 means a strongest or negative or positive relationship between two variables and its value close to 0 means no linear relationship between them [10].

The correlation between the control indicators is shown in a matrix plot (Fig. 6), the indicators can be grouped by three characteristics:

correlation by water temperature: with positive correlation between control parameters and temperature for COD, BOD5, PO_4^{3-} and negative between control parameters and temperature for NO_3^-, N-NH_3;

correlation between chemical indicators: negative correlation between nitrogen compounds and COD, BOD5 compounds and between nitrogen compounds (NO_3 vs. N-NH_3), positive correlation between PO_4^{3-} and COD, BOD5, between carbon compounds (COD vs. BOD5);

correlation between before/after water discharge: positive for all controlled indicators.

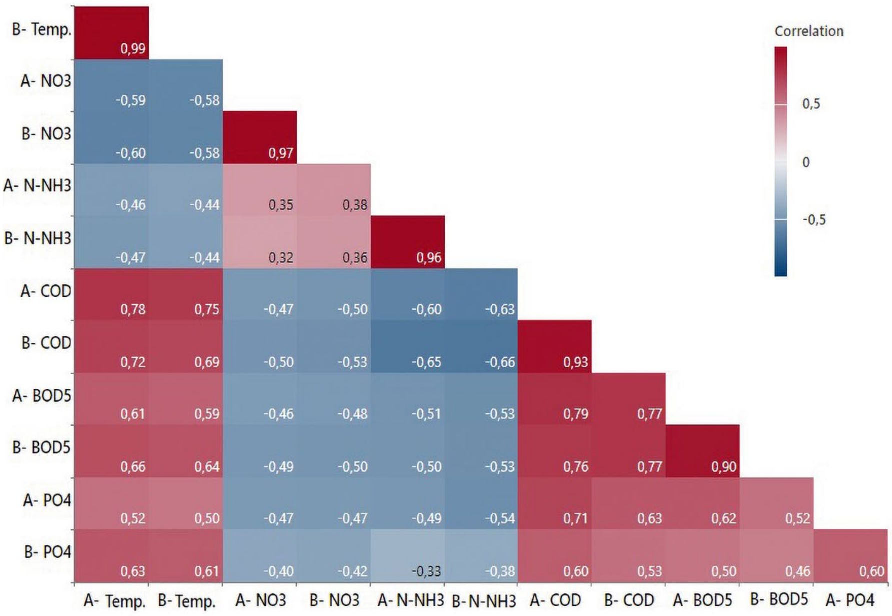


Fig. 7. Correlation coefficient r-Pearson for indicators of the Styr River in the impact zone of the Rivne NPP for 2018–2022

Correlation coefficient r-Pearson (Fig. 7) for indicators can also be systematised according to the characteristics of:

correlation by water temperature: strong and average correlation between control parameters and temperature, excluding N-NH$_3$;

correlation between chemical indicators: weak correlation between compounds of the nitrogen group (N-NH$_3$, NO$_3^-$), strong correlation between organic compounds for COD, BOD5;

very strong correlation between all controlled indicators for before/after water discharge.

For all parameters tested, distributions were centered and reduced prior to clustering. The result is illustrated by a dendogram (Fig. 8) presenting the clusters and their proximity [11] with a reduction in dimensionality of the original data. In cluster analysis the proximity between two clusters is the increase in the squared error, it is the most common method to categorize groups more accurately [12]. The cluster analysis of variables shows the distribution of indicators for water sampled in the sampling locations, the indicators on the dendrogram are grouped according to indicators with appropriate sampling locations, which reflects the correlation of control indicators before water intake and after discharge of the Rivne NPP (see Fig. 8). Generated cluster graph of data analysis does not separate the parameters before water intake and after discharge, the data are grouped into clusters according to indicators (Fig. 9).

The Principal component analysis (PCA) was applied efficiently on our data (Fig. 10) to identify underlying interrelationship amongst the parameter. PCA was applied on reduced standardized data sets to extract information about correlation among variables analyzed

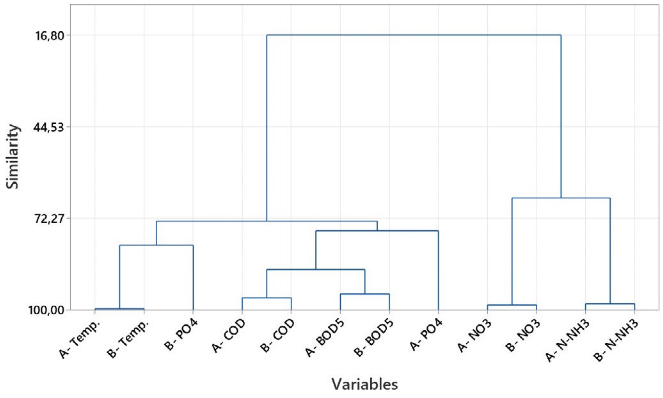


Fig. 8. Dendrogram connections of control indicators of the Styr River in the impact zone of the Rivne NPP for 2018–2022

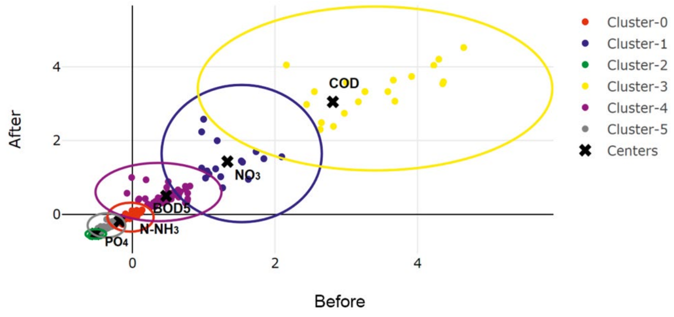


Fig. 9. Generated cluster graph of control indicators of the Styr River in the impact zone of the Rivne NPP for 2018–2022

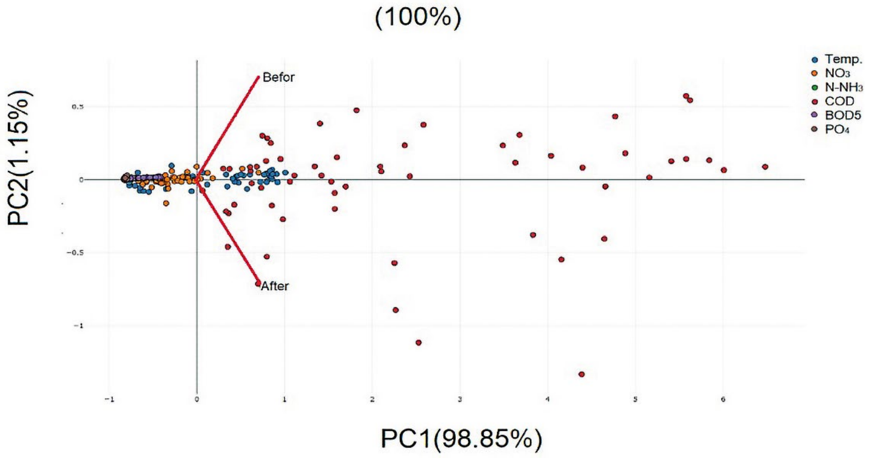


Fig. 10. Principal component analysis biplot of control indicators of the Styr River in the impact zone of the Rivne NPP for 2018–2022

in the water samples [13]. Calculation was achieved based on the correlation matrix of measured parameters, and the PCA scores were obtained from the standardized variables data. The normalized object scores and variable loading on each PC were scaled proportionally to the root of the variance accounted for by that PC as shown in the PCA plot: the percentage of total variance explained by the first principal components (PC1,2) are 98.85 % and 1.15 % (see Fig. 10). Indicators of the Styr River after discharge of the Rivne NPP samples has also shared similar of indicators connect and positively correlated with the first PC. The data projection on the space of the second PC showed a correlation between the samples collected.

Multiple linear regression was used as a statistical technique to determine factors that contributed to control indicators. Partial least-squares regression (PLSR) is a multivariate regression method that specifies a linear relationship between a set of dependent response variables, X, and a set of predictor variables, (Y, Z) [14].

The correlations of the temperature effect were determined by the PLSR method for two types of:

ecological impact, which is caused by natural seasonal changes in temperature;

ecological and technological impact, based on temperature differences.

The correlations between water temperature (oC) and biogenic elements contents (mg/dm^3) were assessed using the results of control for samples taken at site A, namely before the Rivne NPP water intake (1–2), and by temperature difference (Dif.Temp), using the results of control for samples taken at sites A- and B- of the Styr River before the water intake and after the Rivne NPP discharge (3–6).

$$(B\text{– Temp.}) = 32.25 - 0.885\,(B\text{– }NO_3) - 15.7\,(A\text{– N-}NH_3) - 21{,}1\,(B\text{– N-}NH_3) + 20.3\,(A\text{– N-}NH_3)(B\text{– N-}NH_3) \quad (1)$$

$$(B\text{– Temp.}) = -7.91 + 0.3679\,(A\text{– COD}) + 0.1652 \times (B\text{– COD}) + 4.01\,(B\text{– BOD5}) - 0.092\,(B\text{– COD})\text{^}2 \quad (2)$$

$$(B\text{– }NO_3) = 0.922 - 0.238 \cdot (\text{Dif.Temp}) + 0.9368\,(A\text{– }NO_3) + 0.193\,(A\text{– }NO_3)\text{^}2 \quad (3)$$

$$(B\text{– N-}NH_3) = -0.0085 + 1.064\,(A\text{– N-}NH_3) + 0.0758 \times (\text{Dif.Temp}) - 0.092\,(A\text{– }NH_3)(\text{Dif.Temp}) \quad (4)$$

$$(B\text{– COD}) = -9.73 + 0.862\,(A\text{– COD}) + 6.01 \times (\text{Dif.Temp}) + 0.1453\,(A\text{– COD})(\text{Dif.Temp}) \quad (5)$$

The obtained equations (1–2), which characterise the purely ecological impact of the dependence of water temperature and nutrient content in the water of the Styr River, show models with high acceptance and a high level of correlation (R-sq > 70 %). For the content of phosphorus compounds, no significant correlation with temperature was found, which may be due to the predominance of anthropogenic factors.

The determined equations (3–5), characterising the environmental and technological impact and the content of nitrogen compounds (NO_3^-, N-NH_3) and organic carbon (COD) in the water of the Styr River at the discharge of the Rivne NPP, depending on the initial content (site A–) and the difference in water temperature before/after the discharge (sites B– and A–), show models with high acceptance and high level of correlation (R-sq > 70%). Models with low acceptance (R-sq less than 50%) were identified for BOD5 and PO_4^{3-}, because BOD5 depends on microbial contamination and PO_4^{3-} depends on the anti-scaling treatment used, additional variables are needed for model simulation.

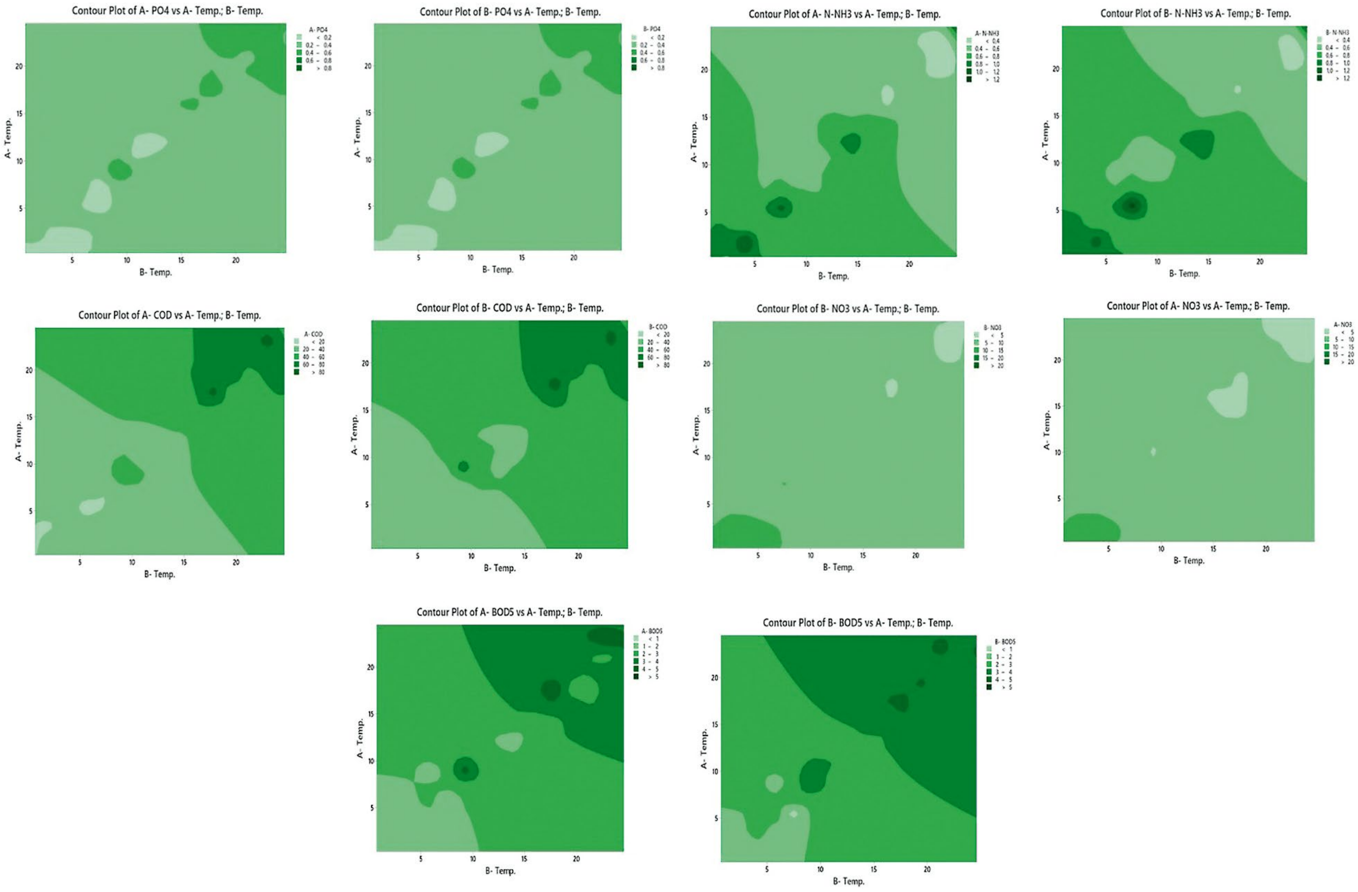


Fig. 11. Colorogram of changes in water control indicators of the Styr River before/after the return water discharge of the Rivne NPP for 2018–2022

The content of biogenic components forms demonstrates satisfactory comparability of the control data in the water of the Styr River before water intake and after discharge of the Rivne NPP (Fig. 11), which indicates that there is no negative impact of the Rivne NPP discharges on the balance of biogenic elements.

Conclusions

The discharge of NPP return water at elevated temperatures in combination with a complex of natural factors can cause negative changes in water and ecological processes, in particular, disturbance of the nutrient balance. The temperature effect of the Rivne NPP outflow, normalised by the temperature difference of the Styr River water before and after the outflow, does not exceed the normalised value of 3 °C. The concentration of the studied forms of biogenic elements in the area of influence of the Rivne NPP effluents meets the environmental standards, with periodic exceedance of the MPCs for COD, BOD5, $NO_3^{-,}$ PO_4^{3-}, which is not related to the activity of the Rivne NPP, but is due to an increase in the concentration of substances in the Styr River. The seasonal variability of COD, BOD5 in the water of the Styr River is noted, with an increase in content in the warm season, which is associated with the intensification of natural biological processes, and peak concentrations of NO_3^-, N-NH_3 in the cold season. The obtained correlation dependencies show strong and medium relationships between COD, BOD5, NO_3^-, N-NH_3 and water temperature in the Styr River. The obtained dependencies are the initial data for further monitoring of the possible negative impact on the nutrient balance due to the water discharge of the Rivne NPP. A strong correlation between the indicators is observed for the results of the monitoring before and after the water discharge of the Rivne NPP, which may indicate that the discharge does not affect changes in the biogenic elements balance. For forecasting and possible limitation of the discharge, correlation dependencies were obtained that determine the concentrations of NO_3^-, N-NH_3, COD in the Styr River water after the discharge, taking into account the difference in water temperature and their concentration before the discharge. To establish correlation dependencies for predicting the discharge for BOD5, PO_4^{3-}, it is necessary to take into account microbiological indicators (BOD5) and technological processes of reagent dosing during corrective treatment (PO_4^{3-}), which will be the result of further work.

References

1. Madden N., Davis M., Lewis A. (2013). Thermal effluent from the power sector: an analysis of once-through cooling system impacts on surface water temperature. *Environmental Research Letters,* vol. 8 (3), pp. 1–8.
2. Webb B. W., Nobilis F. (2007) Long-term changes in river temperature and the influence of climatic and hydrologic factors. *Hydrological Sciences Journal,* vol. 52, pp. 74–85.
3. Hutchins D. A., Zhang Y., Warner M. E., Feng Y. (2007). CO_2 control of Trichodesmium N2 fixation, photosynthesis, growth rates, and elemental ratios: Implications for past, present, and future ocean biogeochemistry. *Limnology and Oceanography*, vol. 52, pp. 1293–1304.
4. El-Ghorab E. A. S. (2013). Physical model to investigate the effect of the thermal discharge on the mixing zone (Case Study: North Giza Power Plant, Egypt). *Alexandria Engineering Journal*, vol. 52, pp. 175–185.
5. Kaushal S. S., Likens G. E., Jaworski N., Pace M. L., Sides A. M., Seekell D., Belt K. T., Secor D. H., Wingate R. L. (2010). Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment*, vol. 8, pp. 461–466.
6. Kuznietsov P. N., Biedunkova O. O., Yaroshchuk O. V. (2023). Experimental study of transformation of carbonate system components cooling water of Rivne Nuclear Power Plant during water treatment by liming. *Problems of Atomic Science and Technology*, vol. 144, pp. 69–73.
7. Reports on the assessment of the impact of non-radiation factors on the environment of the “Rivne NPP” for the years 2019–2022. (in Ukr.)
8. Permit for special water use of SS Rivne NPP No. 53/RV/49d-20. (2020). Retrieved from https://e-services.davr.gov.ua. (in Ukr.)
9. Barakat A., Baghdadi M., Rais J., Aghezzaf B., Slassi M. (2016). Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. *International Soil and Water Conservation Research*, vol. 4, pp. 284–292.
10. Hajigholizadeh M., Melesse A. M. (2017). Assortment and spatiotemporal analysis of surface water quality using cluster and discriminant analyses. *Catenia*, vol. 151, pp. 247–258.
11. Shankar K., Aravindan S., Rajendran S. (2010). GIS based Groundwater Quality Mapping in Paravanar River Sub-Basin, Tamil Nadu, India. *International journal of Geomatics and Geosciences*, vol. 1, pp. 282–296.
12. Zi C., Zhou Q., Lv J., Jiang Y., Yang H., Yang H., Mei S., Jia Z., Zhang H., Jin Y. (2023). Assessment of Groundwater Quality Using APCS-MLR Model: A Case Study in the Pilot Promoter Region of Yangtze River Delta Integration Demonstration Zone, China. *Water*, vol. 15, p. 225.
13. Yu L., Zheng T., Yuan R., Zheng X. (2022). APCS-MLR model: A convenient and fast method for quantitative identification of nitrate pollution sources in groundwater. *Journal of Environmental Management*, vol. 314, art. 4797.
14. Kahaer Y., Tashpolat N. (2019). Estimating Salt Concentrations Based on Optimized Spectral Indices in Soils with Regional Heterogeneity. *J. Spectrosc*, vol. 15, art. 2402749.

П. М. Кузнєцов[1, 2], О. О. Бєдункова[1]

[1] Національний університет водного господарства
та промисловості, вул. Соборна, 11, Рівне, 03028, Україна
[2] ВП «Рівненська АЕС», вул. Промислова, 1, Вараш,
34400, Україна

Дослідження температурного впливу скидів та балансу біогенних елементів у воді р. Стир у зоні впливу Рівненської АЕС

Незалежно від типу охолоджувального циклу, всі атомні електростанції (АЕС) мають скидні зворотні води з залишковою кількістю теплової енергії. У системі охолодження АЕС циркулюють значні об’єми води, яка відбирається та скидається в природну водойму, через що відбувається передача тепла від електростанції до водойми. Зміни вмісту та баланс біогенних речовин поверхневих вод під впливом водних скидів АЕС можуть розглядатись як важливі індикатори водно-екологічних реакцій на тепловиділення АЕС. Метою дослідження є визначення динаміки змін вмісту біогенних елементів для співіснуючих форм азоту (N), фосфору (P), вуглецю (C) з встановленням факторів мінливості та кореляційних зв’язків між їх формами в воді р. Стир, що відбувається в зоні впливу температурних водних скидів Рівненської АЕС (РАЕС).

За результатами дослідження визначено, що вміст сполук P (ортофосфат-іонів PO_4^{3-}), C (біохімічне споживання кисню протягом 5 діб БСК5, хімічне споживання кисню ХСК) та N (азоту амонійного $N\text{-}NH_3$, нітрат іонів NO_3^-) у воді р. Стир у зоні впливу водних скидів РАЕС має сезонну динаміку. Оцінена кореляція балансового вмісту біогенних елементів у воді р. Стир до водозабору та після скиду РАЕС. Встановлені регресійні статистичні залежності, що дозволяють прогнозувати вміст форм біогенних елементів, залежно від температури за екологічним та еколого-технічним факторами температурного впливу. У цілому результати досліджень свідчать про відсутність негативного впливу водних скидів РАЕС на баланс біогенних елементів, а отже й відсутність прояву водно-екологічних реакцій р. Стир на тепловиділення РАЕС.

Ключові слова: атомна електростанція, температурний вплив, скиди, біогенні елементи.

Надійшла 21.10.2023
Received 21.10.2023