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# THE INFLUENCE OF THE LAKE HYPOLYMNON DISCHARGE ON THE PHYSICO-CHEMICAL PARAMETERS OF THE RIVER

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***Abstract***

*The analysis of the evolution of water quality parameters over time is of interest to researchers and authorities because it provides information on long-term changes in the river basin and allows the evaluation of the effectiveness of pollution control measures in the context of national and international commitments. This study describes eutrophication as a process of degradation of Lake Kortowskie, Poland, summarizes the effects of lake hypolimnion discharge on the water quality of the Kortówka River, and presents, in tabular form, the statistical principles specific to factor analysis (ANOVA). Water quality was assessed by comparing temperature, pH, changes in oxygen concentration (DO), conductivity (EC) and redox potential (ORP) before the experiment, during and after the experiment.*

***Key words**: eutrophication, nutrients, restoration techniques, statistical analysis, water quality.*

## INTRODUCTION

Eutrophication has become the main water quality issue for most of the world's freshwater ecosystems (Tandyrak et al., 2016). Research shows that eutrophication occurs mainly in lakes where water circulation is reduced during the summer, when nutrient concentrations (total nitrogen and total phosphorus) increase at high temperatures (Şalaru et al., 2007).

In general, increasing the concentration of nitrogen and phosphorus causes a massive development of aquatic vegetation and, therefore, an increase in the amount of organic matter (Szymanski et al., 2013) which decomposes and accumulates in sediments (Ilechukwu et al., 2020) leading to the depletion of oxygen in hypolimnion and, at the same time, to the decrease of water quality (Bryant et al., 2011).

Improving water quality in lakes can be achieved by discontinuing external sources of pollution, but in most cases this method is not sufficient (Mientki & Teodorowicz, 1996), and the use of restoration techniques that include methods to reduce the phosphorus recycling rate is necessary, without physically removing phosphorus from the lake, dredging sediment or evacuating hypolimnion (Dunalska et al., 2007; Dunalska et al., 2014). Discharged hypolimnion should be aerated and mechanically treated before discharge into downstream rivers (Nürnberg et al., 1987).

The first restoration technique was used by Olszewski in Lake Kortowskie, Poland, in 1956 and continues to this day. This method is based on removing the hypolimnion, a deep layer of oxygen-free, low-light, low-phytoplankton water. Removal of hypolimnion is an efficient, simple method that works without consuming electricity, does not affect epilimnion, and the effects of eutrophication on the lake are eliminated to restore a normal oxygen concentration (Mientki & Teodorowicz, 1996), but downstream the effects of the eutrophication are felt, depletion of oxygen and release of toxic substances (hydrogen sulphide, ammonia) from the air into the air which influence the formation of the characteristic odour by microbiological processes of decomposition of organic matter (Tandyrak et al., 2016).

The effects of hypolimnion evacuation on physicochemical conditions suggest that this method restores nutrient balance, directly influencing the growth of phytoplankton biomass and increasing the water temperature in hypolimnion, weakening the thermal stratification (Dunalska et al., 2014). Moreover, this method is suitable for lakes that are stratified during the summer when favorable conditions for sulfate reduction are created, under anaerobic conditions and in the presence of organic substances. In the case of lakes these conditions are created in hypolimnion (Tandyrak et al., 2016).

In some lakes, the evacuation of hypolimnion is used to prevent the warming of downstream waters (Nürnberg, 2007), because the high temperature affects the photosynthesis process of aquatic plants and the metabolic rates of aquatic organisms, increases the energy consumption of living things and reduces dissolved oxygen levels (Sandu, 2018). Due to low oxygen levels and high ammonia levels in the hypolimnion, it is necessary to treat the discharged water to prevent adverse effects downstream, especially in low flow rivers. (Nürnberg, 2007).

We consider that there is limited information regarding how the discharge of the hypolimnion may influence the water quality of the downstream river and how parameters vary before and after discharge. Our objective is to understand how these processes interact with the river ecosystem. This information can be utilized for developing strategies to protect aquatic ecosystems.

## MATERIALS AND METHODS

### *Study Site*

Lake Kortowskie is located in the town of Olsztyn, Poland, covers an area of 89.7 ha and is fed by five streams. The maximum length of the lake is 1,660 m and the maximum width is 715 m (Rybak & Rybak, 1985). In the south-east, the Parkowy stream collects water from the nearby valley, but with a very low flow the amount of nutrients introduced into the lake is negligible.

The Starodworski stream has a catchment area of 0.55 $km^2$ and receives pollutants from a section of a building, feeding the lake to the south. In the southwest it flows into the Leśny stream, collecting water from an area of 11.3 $km^2$ (64.5% of this area includes forests, 18.5% arable land and 17% pastures and meadows). To the south, 300 m from the entrance of the Leśny stream, a drainage pipe discharges the collected water from an area of 0.5 $km^2$ (Dunalska, 2002). The only surface outlet of the reservoir is the Kortówka River (Szymanski et al., 2013) which is also the outlet of the pipe for the removal of hypolimnion (Dunalska, 2002).

The aim of the study was the Kortówka River, which crosses the campus of the University of Warmia and Mazury in Olsztyn, from where the river has its source in Lake Kortowskie (the exit of the Olszewski pipeline) to the confluence with the Lyna River (Figure 1). The river has a maximum width of 2 m. It is very shallow, about 0.3 m, and slow flowing.

The measurements were performed at a distance of 1,695 m at six points as follows: 30 m downstream of the hypolimnion exhaust pipe (P1), gymnasium bridge (260 m) (P2), stadium bridge (425 m) (P3), bridge of the Faculty of Environmental Sciences, Department of Environmental Engineering (605 m) (P4), Volvo service bridge (1,220 m) (P5) and the last point 10 m upstream of the confluence with the river Lyna (1,685 m) (P6).

Two measurements were made on the Lyna River: upstream (30 m) (P7) and downstream (55 m) (P8) confluence.

The following parameters were measured in situ using the YSI 6600 V2 probe: temperature, dissolved oxygen (DO), pH, redox potential (ORP) and conductivity (EC). Additional measured parameters include: flow, salinity, turbidity, total dissolved solids, chlorophyll and blue-green algae, but these will not be discussed in this article.

### *Description of the "Kortowskie" experiment*

One of the methods used to restore the lakes is the Olszewski method, also called the Kortowskie experiment, used to improve the water quality of Lake Kortowskie in Olsztyn (Wysocka et al., 2014). The method involves the selective discharge of water from the deep part of the lake together with the decanted organic particles, as well as the substances and microorganisms released from the sediments (Tandyrak et al., 2016).

In 1950, studies of Lake Kortowskie showed significant degradation of the water body, and in 1952 water in the southern section of the lake was deficient in oxygen for 134 days and hydrogen sulphide was present 5 m below the water surface.

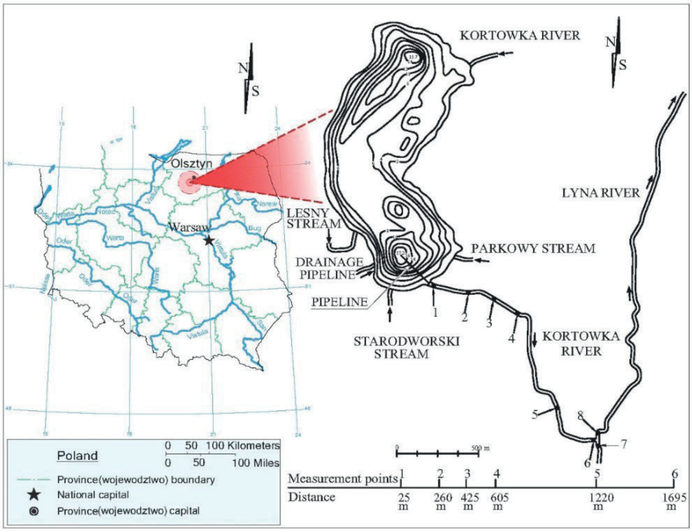


Figure 1. Lake Kortowskie and the location of the measurements at the Kortowka River

Between 1956 and 1967, the hypolimnion was evacuated in the summer, and in 1968 it was evacuated in the summer and winter (Dunalska et al., 2007).
Due to technical problems in 1973, the experiment was closed. Since then, the years 1956-1973 have been considered the first stage in the process of restoring Lake Kortowskie. The second stage began in 1976, and the new pipeline was built of fiberglass and polyester (Mientki & Teodorowicz, 1996).
The parameters of the pipeline are as follows: length 250 m, diameter 600 mm and maximum flow 0.25 $m^3/s$. It is located in the southern section of the lake, being equipped with a device set on the outlet flow that allows the closure, opening and regulation of the amount of water discharged, because hypolimnion must be eliminated when the amounts of nutrients that accumulate are maximum (Dunalska, 2002).
Highly polluted waters are directed to the Kortowka River, which disturbs the chemical and biological balance in the original part of the river (Dunalska et al., 2007).
Changes in environmental factors lead to the development of aquatic plant and animal communities, the structure and functions of aquatic ecosystems with a number of different responses depending on the nature of these changes, their intensity and duration of action.
Aquatic ecosystems, through their internal self-regulation mechanisms, succeed in a self-purification process involving filtration, sedimentation, dissolution, dilution and oxygenation, to restore the affected components naturally (Momeu et al., 2018).

## RESULTS AND DISCUSSIONS

The measurements performed for this study were divided into three stages as follows: before the experiment - stage I (March-June 2018), during the experiment - stage II (July-September 2018) and after the experiment - stage III (October 2018-May 2019).
From Figure 2 it can be seen that the water temperature changes with the season. The maximum temperature is 10.2°C in stage I, 18.6°C in stage II and 10.3°C in stage III; the lowest temperature is 9.7°C in stage I, 14.5°C in stage II and 8.2°C in stage III.
The effects of climatic conditions varied considerably from one season to another, and the greatest influences on the thermal regime of the water were observed in summer and autumn. The discharge of the cold water of the hypolimnion from the lake is discharged with an accentuated thermal exchange, weakening the thermal stratification and facilitating the mixing of the water column (Ying et al., 2012; Weber et al., 2017).
The increase in temperature in P7 and P8, measurements made on the Lyna River, may be due to the fact that the studied river segment is

lighter and deeper, thus allowing more heat exchange with the atmosphere (Chatanga et al., 2019).

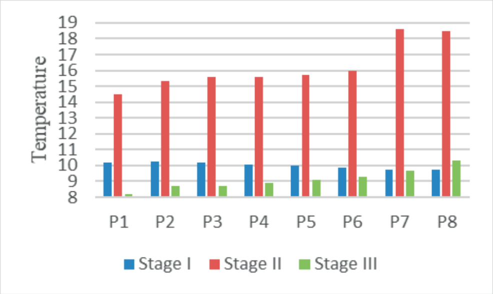


Figure 2. Seasonal temperature fluctuations in the Kortowka River and the Lyna River

The values of EC varied before the experiment from 401 µS/cm to 480 µS/cm, during the experiment from 367 µS/cm to 547 µS/cm, and after the experiment from 387 µS/cm to 524 µS/cm. EC values are useful for estimating the concentration of total dissolved solids (TDS) in water (Rostom et al., 2017).
TDS values ranged from 260 mg/L to 312 mg/L before the experiment, from 239 mg/L to 356 mg/L during the experiment, and from 263 mg/L to 365 mg/L after the experiment.
From Figure 3, in the Kortowka River higher values can be observed during the experiment than before the experiment. Usually, the EC in surface waters is influenced by dissolved ions of natural and anthropogenic origin. Higher EC values during the experiment are a likely indication that significant proportions of dissolved ions were transported to the river during the evacuation of the hypolimnion from Lake Kortowskie (Chatanga et al., 2019; Miyittah et al., 2020).
As shown in Figure 4, during the experiment the pH values ranged from 7.07 to 7.98. The highest pH value was recorded at measurement P2, 260 m downstream of the hypolimnion discharge line, and the lowest at P6 and P8.
Before the experiment the maximum pH (7.32) was recorded in P2, while the minimum pH (7.26) was recorded in P5, and after the experiment the pH values increase, varying from 7.57 downstream of the hypolimnion drainage pipe, up to 7.63 downstream of the confluence of the Kortowka and Lyna rivers.

ORP values ranged from 32.47 mV to 53.77 mV before the experiment, from -158.08 mV to 5.27 mV during the experiment, and from -31.54 mV to 36.41 mV after the experiment, as shown in Figure 5.

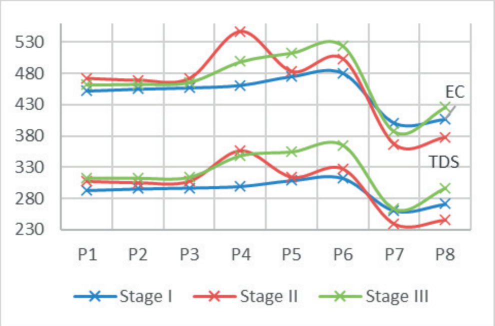


Figure 3. Seasonal changes in EC and TDS recorded in the Kortowka River and the Lyna River

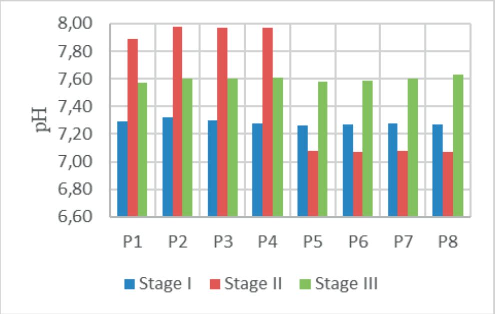


Figure 4. Seasonal variations in pH recorded in the Kortowka River and the Lyna River

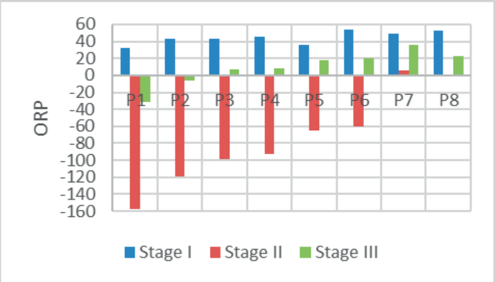


Figure 5. Seasonal variations in ORP in the Kortowka River and the Lyna River

The ORP is measured in addition to dissolved oxygen, as it can provide additional information about water quality and pollution (Rostom et al., 2017). In healthy waters, the ORP should be between 300 and 500 mV (Selim et al., 2023). In

this study, low ORP values were obtained in the waters of the Kortowka River due to the removal of hypolimnion from Lake Kortowskie.
The values obtained for the DO index measured in the eight points for the experimental period, respectively March 2018 - May 2019, recorded averages located in the intervals:

- 8.1-11.2 mg/L for measurements made in the first stage;
- 0.4-1.91 mg/L for measurements made in the second stage;
- 4.66-10.81 mg/L for measurements made in the last stage.

As shown in Figure 6, before the experiment, the dissolved oxygen values showed a decreasing trend, except for the values in P4 (Kortowka river) and P8 (Lyna river), where an upward trend is observed.
The lowest values are recorded during the experiment. The decrease in DO concentration is closely linked to the increase in and accumulation of organic matter in water and is caused by the evacuation of hypolimnion from Lake Kortowskie (Kunz et al., 2013; Momeu et al., 2018).
It is observed that after the experiment the DO values showed an upward trend along the Kortowka River. On the Lyna River at P8, downstream of the Kortowka River, the value of DO decreases, being associated with the presence of nutrients such as nitrates and phosphates (Ying et al., 2012).

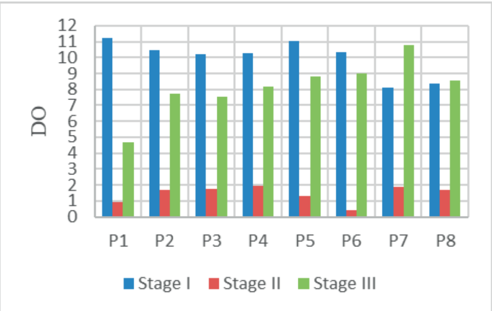


Figure 6. Seasonal variations in DO recorded in the Kortowka River and the Lyna River

The data set analysis was performed using correlation analysis to assess the relationship between the analyzed variables (Ilechukwu et al., 2020). A coefficient close to -1 or 1 means a strong negative or positive relationship between two variables, and its value closest to 0 means that there is no linear relationship between them at a significant level with p-values less than 0.05 (Kothari et al., 2021; Sadeghi, 2022; Mehmood et al., 2024). As we can see, between the variables, occurs both a positive and a negative correlation, due to the significance of each variable analyzed. The correlation analysis is presented in Table 1.

Table 1. Correlation coefficient for the analyzed parameters

| Parameters | T | EC | pH | ORP | DO |
|---|---|---|---|---|---|
| T | 1 | | | | |
| EC | -0.151 | 1 | | | |
| pH | -0.418 | 0.089 | 1 | | |
| ORP | -0.603 | -0.354 | 0.291 | 1 | |
| DO | -0.842 | -0.071 | 0.467 | 0.835 | 1 |

The data were further verified by performing the Kaisere Meyere Olkin (KMO) and Bartlett tests to verify that the variables could be factorized efficiently (Table 2) (Balata et al., 2022).
The KMO index compares the values of the correlations between the variables and those of the partial correlations. In general, this index should be greater than 0.5 for a satisfactory analysis of the factors (Lyon et al., 2012; Samian et al., 2015).
In this study, the KMO had a value of 0.629. The value of the Bartlett's Test of Sphericity (66.742, Sig = 0.000) is small enough to reject the hypothesis that the variables are uncorrelated, as a result there is a strong relationship between the data (Ajtai et al., 2023; Chen et al., 2023; Xue et al., 2023). These values indicate the presence of one or more common factors which motivate the application of a factor reduction procedure.

Table 2. KMO test and Bartlett test

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy | | 0.629 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 66.724 |
| | df | 10 |
| | Sig. | 0.000 |

Table 3 shows the Rotated Component Matrix, which transforms the principal factors to find the relationship between them and reduce the data variability. When all component rotations are performed, a new cycle of rotations begins, and the process repeats until a maximum number of iterations is reached; in our case, rotation converges in just 3 iterations (Weide & Beauducel, 2019; Rahman et al., 2021; Tiwari et al., 2023).

Table 3. Rotated Component Matrix

| | Component | |
|---|---|---|
| | 1 | 2 |
| Dissolved oxygen | 0.951 | -0.178 |
| Temperature | -0.903 | -0.097 |
| ORP | 0.780 | -0.523 |
| pH | 0.643 | 0.245 |
| Electrical conductivity | 0.062 | 0.944 |
| Extraction Method: Principal Component Analysis. | | |
| Rotation Method: Varimax with Kaiser Normalization. | | |
| a. Rotation convergent in 3 iterations. | | |

The factor structure for the analyzed variables is:

- the first factor is made up of the variables DO (0.951), ORP (0.780) and pH (0.643);
- the second factor consists only of the variable EC (0.944).

Using this type of factor analysis, we can obtain useful information on the factors that have a great influence on water quality, giving statisticians the opportunity to track its upward or downward evolution (Elkorashey, 2022).

## CONCLUSIONS

This study highlights the usefulness of applying the method of analyzing key components in the field of water and environmental sciences, with the ultimate goal of identifying those factors that significantly influence water quality in the current context of globalization and accelerated development.

The immediate effect of this type of application may be the ability to analyze, test and improve those factors that are directly responsible for the level of water quality. Knowing and analyzing these factors, programs can be initiated to bring water quality to a higher level.

DO values were, on average, less than 6.5 mg/L throughout the experimental period, suggesting that the river was in low oxygen conditions, leading to anaerobic decomposition of excess organic matter.

Significant changes in all parameters except pH can be attributed to the evacuation of hypolimnion from Lake Kortowskie.

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