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VARIATION OF BIOGENIC NUTRIENTS IN LAKE WATER UNDER DIFFERENT LEVELS OF ANTHROPOGENIC IMPACT

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Abstract. This article analyzes the water quality of three lakes under different anthropogenic influences. It examines seasonal changes in biogenic substance concentrations and pH, as well as the impact of environmental use on the ecological status of the lakes. A comparison of one year's water testing data for Lakes Girbys, Dauniškis, and Lydekis (Utena County) shows that the highest concentrations of biogenic substances and the most pronounced risk of eutrophication are characteristic of lakes affected by intensive agricultural activity. The lake located in an urbanized area is characterized by greater fluctuations in biogenic substances. The lake located in a natural, wooded environment is characterized by stable water quality and the least anthropogenic impact. The results of the study show that the water quality of lakes is determined not only by their natural characteristics, but also by the intensity and nature of environmental use.

Keywords: anthropogenic impact, water quality, biogenic substance, lakes.

1. Introduction

The accelerated growth of industry, manufacturing, and human activity, in conjunction with the irresponsible use of fertilizers and plant protection products in agriculture and rapid urbanization, has led to a marked increase in surface and groundwater pollution (Bijay-Singh & Craswell, 2021; Česonienė et al., 2020; Lawniczak et al., 2016; Grace, 2021; Liu et al., 2024). In order to ensure ecosystem stability and biodiversity, it is necessary to preserve the best possible conditions of surface water bodies and their water quality. The primary factors contributing to the degradation of all open water bodies, including lakes, are the increasing anthropogenic load and excess of biogenic substances, particularly nitrogen and phosphorus compounds. These elements have a significant impact on the deterioration of water quality (Schindler, 1977; Carpenter et al., 1998; Smith et al., 1999; Schindler et al., 2016). Intensive human activity has been shown to deplete water resources and exert a negative effect on the environment.

International scientific research shows that the nature of agricultural use and other anthropogenic activities related to farming and livestock breeding have a significant impact on the entry of biogenic substances into water bodies. In areas of intensive agricultural activity, nitrates, ammonium nitrogen, and phosphates often enter lakes through surface and underground runoff, especially during periods of heavy rainfall (Withers & Haygarth, 2007; Zhang et al., 2017). In urban areas, the leaching of biogenic substances is associated with the rapid growth of the urban population, the expansion of built-up areas, surface runoff from cities, and increasingly overloaded sewage systems (Paul & Meyer, 2001; Wang et al., 2023). Observations have revealed that wooded areas are distinguished by more balanced and stable biogeochemical processes, with minimal anthropogenic impact, which contributes to the preservation of water quality (Allan, 2004; Locke, 2024; Caldwell et al., 2023).

When evaluating the quality of lake water, it is necessary to take into account the seasonal variation in biogenic substances and their concentrations. Scientific research has indicated that increased phosphorus concentrations are frequently observed during the spring months, a phenomenon attributable to a combination of factors, including soil eutrophication processes, soil particle leaching, and increased precipitation intensity.

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During the summer season, biogenic substance concentrations in surface waters remain stable due to intensive plant growth, while in autumn and winter, nitrogen compounds may accumulate due to reduced uptake (Jeppesen et al., 2005; Huang et al., 2024; Bradulienė et al., 2024). These processes determine not only short-term changes in water quality, but also long-term eutrophication trends.

Despite extensive international research and regional-scale analyses comparing lakes under different anthropogenic conditions and covering all seasons of the year, the following issues remain relevant (Zhang et al., 2017). The objective of this study is to evaluate the water quality of lakes under different anthropogenic impacts. To this end, seasonal changes in biogenic substance concentrations and pH will be analyzed. Additionally, the impact of environmental use on the ecological status of lakes will be determined. This will be accomplished by taking into account the current methodology for assessing surface water bodies.

2. Research subject and methodology

The research study was conducted in accordance with the following research schema presented in Figure 1.

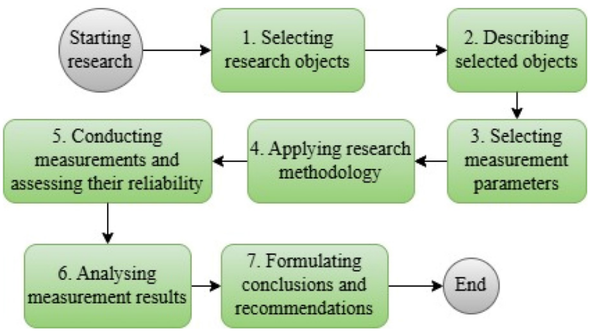

Figure 1. Research methodology to evaluate the water quality of lakes

Lithuania has over 2.600 lakes larger than 0.05 hectares. The country's total lake coverage index is 1.35%. The Utena district has the highest natural lake coverage index in the country at 5.8%. Considering this, three open bodies of water were selected for the study: lakes located in the region with the highest lake density in Lithuania. The government does not engage in systematic oversight of the lakes under study. The lakes under study are comparable in size; however, their respective environments differ. A substantial amount of agricultural activity is observed in the vicinity of lake Lydekis (Figure 2). The surface area of the lake is 14.41 hectares. The shoreline, which measures 1.78 km in length, exhibits a pronounced sinuous. The body of water is bordered by meadows and agrarian fields, which collectively encompass an area of over 200 hectares within a radius of two kilometers.

Figure 2. Lake Lydekis and its area

Lake Girbys is surrounded by forests, with no anthropogenic activity in the vicinity (Figure 3). The lake covers an area of 10.9 hectares. It is oval in shape. The length of the shoreline is 1.23 km. The surrounding forest covers an area of 920 hectares. The forest is dominated by pine trees (64%) and spruce trees (24%).

Figure 3. Lake Girbys and its area

Lake Dauniškis is distinctive in that it is the only one of the three located in an urbanized, densely populated area in the city of Utena (Figure 4). The lake's surface area is measured at 12.89 hectares. The shoreline extends for a distance of 1.6 kilometers. A recreation park has been constructed near to the lake.

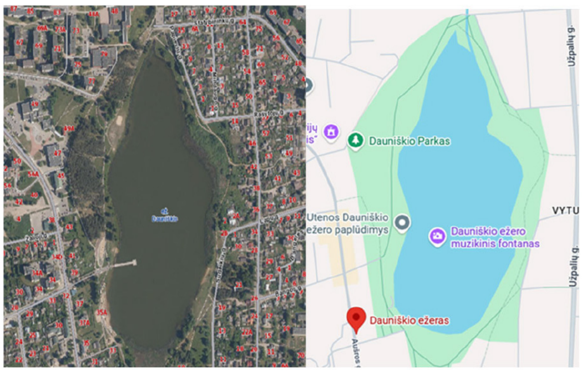

Figure 4. Lake Dauniškis and its area

Water samples were collected from the lakes under investigation on a monthly basis from January to

December in the 2024–2025 period. This frequency enables the monitoring and analysis of changes in the parameters under investigation, both during the investigation period and in relation to the potential influence of seasonality. Water for laboratory tests was taken into a one-liter container, filling it so that there were no air gaps. Then it was transported to the Vilnius Tech Environmental Engineering laboratory. The samples from the lakes under investigation were tested for pH, total nitrogen (N_t), ammonium nitrogen (NH_4), nitrate (NO_3), nitrite (NO_2) and phosphate phosphorus (PO_4–P) concentrations. The pH of the water sample was measured using an ionomeric method. The measurement of nitrite, nitrate, ammonium nitrogen, and phosphate phosphorus was conducted using a molecular absorption spectrometric method, with a Merck Nova 60 A spectrophotometer employed for data acquisition. The determination of nitrates is governed by the provisions stipulated in LAND 65:2005, while the quantification of nitrites is delineated by the parameters established in LST EN 26777:1999. The assessment of ammonium nitrogen is specified by the parameters delineated in ISO 7150-1:1984 and the determination of phosphate phosphorus is governed by the parameters stipulated in ISO 6878:2004. The results of these parameters allow the water quality and ecological status to be determined. Total nitrogen is calculated using the formula:

$$N_t = (NO_3^-) + (NO_2^-) + (NH_4^+), \text{mg/l}. \quad (1)$$

Based on the total nitrogen value, the water body is classified into one of five classes of lake ecological status: very good (<1.00 mg/l); good (1.00–2.00 mg/l); average (2.01–3.00 mg/l); poor (3.01–6.00 mg/l); very poor (>6 mg/l). (Lietuvos Respublikos Aplinkos ministras, 2019). In order to statistically evaluate the accuracy of lake water quality indicators and the reliability of measurements, 95% confidence intervals were calculated for each parameter studied. This calculation was performed using Student's t-method (Britannica Editors, 2026). These intervals demonstrate the range of values within which the true population mean resides with a 95% probability.

3. Results

In order to visually assess the distribution of water quality indicators, their trends, dispersion, and possible exceptions, as well as to identify indicators with the greatest fluctuations and possible negative impact on the aquatic ecosystem, box and whisker plots of the parameters under study were created.

Analyzing the box-and-whisker plot for lake Lydekis (Figure 5) reveals stable pH values. The median was 8.1, and the average was 8.01. The 95% confidence interval is 7.83–8.21. Most measurements fell within the range of a slightly alkaline environment. Nitrite concentrations were low (average: 0.046 mg/l; median: 0.038 mg/l), though one exceptional value of 0.11 mg/l was recorded. The 95% confidence interval is 0.033–0.061 mg/l. Nitrate concentrations remained fairly constant (median: 2.4 mg/l; average: 2.6 mg/l). The 95% confidence interval is 2.34–2.84 mg/l The greatest variability was observed in phosphate and ammonium concentrations, whose averages exceeded the medians: PO_4-P 2.06 and 1.9 mg/l; NH_4 0.22 and 0.15 mg/l. These results suggest episodic increases in biogenic substance concentrations and a higher risk of eutrophication throughout the year. Phosphate phosphorus (PO_4-P) concentrations were moderately stable, with a mean of 2.06 mg/l and a 95% confidence interval of 1.89–2.25 mg/l, suggesting relatively consistent concentrations during most of the observation period.

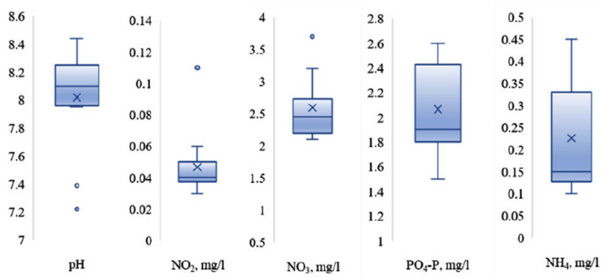

Figure 5. Box-and-whisker plots of the investigated parameters of lake Lydekis

An analysis of the box-and-whisker plot of water quality in lake Girbys revealed that the pH values ranged from 6.5 to 8.1, with a median of approximately 7.6 and a 95% confidence interval of 7.25–7.87. This finding indicates that the environment is slightly alkaline and relatively stable (Figure 6). Nitrite concentrations were found to be generally low, with a median of approximately 0.03 milligrams per liter (mg/l) and an average of 0.035 mg/l and a 95% confidence interval of 0.026–0.044 mg/l. However, isolated peaks up to 0.08 mg/l were observed, indicating short-term increases. The nitrate concentrations demonstrated stability, exhibiting a range from 1.2 to 2.2 milligrams per liter (median approximately 2.0 milligrams per liter, average 1.95 milligrams per liter).

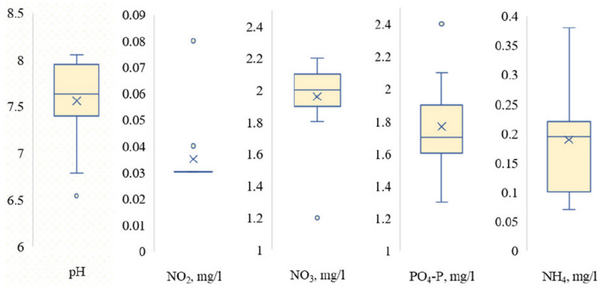

Figure 6. Box-and-whisker plots of the investigated parameters of lake Girbys

The 95% confidence interval of 1.79–2.13 mg/l. Conversely, phosphate and ammonium concentrations demonstrated greater variability, with a median PO_4-P of approximately 1.7 mg/l, including an outlier of up to 2.4 mg/l, and a median NH_4 of ~0.195 mg/l, with a single increase of up to ~0.38 mg/l recorded. The 95% confidence interval for PO_4-P is 1.58–1.95 mg/l.

The pH values of lake Dauniškis were fairly stable, ranging from 6.2 to 8.6. The median was approximately 8.15, and the average was 7.96 and a 95% confidence interval of 7.63–8.30. These values are characteristic of slightly alkaline conditions (Figure 7). Nitrite concentrations were generally low, with a median of ~0.02 mg/l and an average of 0.032 mg/l. The narrow 95% confidence interval of 0.029–0.036 mg/l reflects stable concentrations throughout the observation period. However, one exceptional value of ~0.10 mg/l was recorded, indicating a short-term pollution episode. The median nitrate concentration was 1.7–1.8 mg/l; the average was 1.84 mg/l, with isolated increases to 2.6 mg/l. The 95% confidence interval is 1.60–2.08 mg/l. The greatest variability was observed in phosphate and ammonium concentrations. The median PO_4-P was approximately 1.75 mg/l, with an average of 1.71 mg/l. The 95% confidence interval of 1.55–1.89 mg/l suggests that the concentrations were relatively constant, with little variability. The median NH_4 was approximately 0.25 mg/l, with an exception of approximately 0.60 mg/l, which indicates possible episodic sources of pollution. Ammonium nitrogen (NH_4) exhibited a broader confidence interval, with a 95% confidence interval ranging from 0.14 to 0.34 milligrams per liter. This finding signifies a considerable degree of variability and suggests the potential for seasonal or environmental influences.

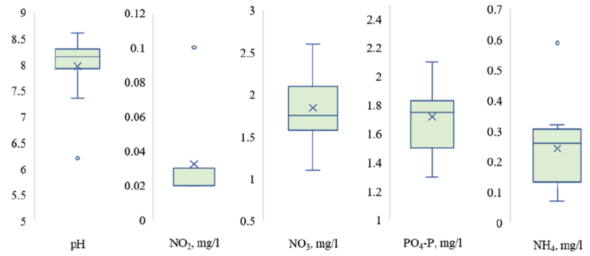

Figure 7. Box-and-whisker plots of the investigated parameters of lake Dauniškis

The narrow confidence intervals (NO_3, NO_2, PO_4-P) suggest that these parameters were accurately estimated and that their concentrations remained nearly constant over time. Meanwhile, wider intervals of (NH_4) reflect significant seasonal or environmental changes. The confidence interval enabled an objective evaluation of which parameter measurements were more stable and which were characterized by greater natural variability. Considering these factors, the study data are reliable enough to evaluate seasonal and annual changes in biogenic substances in lakes, even with a small sample size.

After creating a radar chart (Figure 8) that reflects the data on biogenic substance concentrations over the years studied, it is evident that lake Lydekis has the highest nutrient concentrations (NO_3, NO_2, PO_4-P, and NH_4) and the greatest fluctuation in their levels. This indicates a more pronounced anthropogenic impact and a higher risk of eutrophication. Lake Girbys has the most stable and lowest levels of nitrite and phosphate, so it can be considered more ecologically resistant and less affected by external factors. In contrast, lake Dauniškis is characterized by large fluctuations in pH and ammonium levels, suggesting that it is sensitive to external factors and may experience episodic pollution. This may be related to more intensive urban or recreational activities. Of the three lakes, Lydekis is the most eutrophic, Girbys is the most ecologically stable, and Dauniškis is the most unstable.

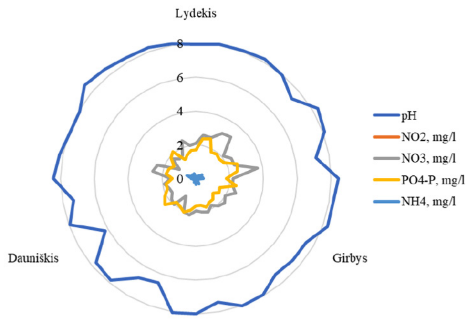

Figure 8. Changes in the concentrations of biogenic substances during the study years

These results underscore the advantages of multidimensional monitoring for rapid assessment of ecological status and evaluation of the impact of biogenic substances on aquatic ecosystems.

Seasonal research results showed that lake Lydekis had the highest concentrations of biogenic substances throughout the year. In spring, the concentrations were as follows: NO_3 2.60 mg/l; NO_2 0.11 mg/l and PO_4-P 2.50 mg/l. In summer, the concentrations were as follows: NO_2 0.06 mg/l, NO_3 2.50 mg/l, PO_4-P 2.40 mg/l and NH_4 0.45 mg/l. This can be attributed to intensive farming taking place in the vicinity of the lake. During the spring, excess nitrogen and phosphorus fertilizers from cultivated fields enter lake Lydekis through precipitation. In the summer, substances that plants did not absorb could more easily enter the lake water along with runoff. The highest concentrations of nitrates (up to 3.70 mg/l), nitrites (up to 0.05 mg/l), and ammonium (0.31 mg/l) were recorded in lake Lydekis in autumn and winter. These higher concentrations indicate a possible accumulation of substances on the ground surface in the fall and their subsequent washout into the lake at the beginning of winter, particularly after thaws or snowmelt. The lowest concentrations of NO_2 (0.02 mg/l), NO_3 (1.60 mg/l), and PO_4-P (1.30 mg/l) were found in lake Dauniškis. However, the highest NH_4 value

(0.59 mg/l) was recorded here in winter. Despite its location in an urbanized area, the low concentrations may be associated with the well-organized drainage of rainwater. The lake's natural self-cleaning processes and the constant maintenance of its shores also limit the amount of pollutants that enter the lake.

The pH values in all lakes ranged from 6.20 to 8.61, indicating a predominantly slight alkaline tendency. The substantial seasonal fluctuation in pH and biogenic substances signifies the occurrence of dynamic biochemical processes and fluctuating levels of anthropogenic influence on the lakes. The larger amplitudes of fluctuations indicate active biochemical processes occurring even when light and photosynthesis are reduced.

According to the values presented in the methodology for determining total nitrogen concentrations and the condition of surface water bodies, it can be stated that lake Girbys meets the criteria for a very good ecological status of lakes, with (N_t) values not exceeding the limit (<1.00 mg/l). The lakes Lydekis and Dauniškis are classified as having a very good (<1.00 mg/l) and good (1–2 mg/l) ecological status, respectively. However, given the increased concentrations of biogenic substances that have been detected, the condition of lake Lydekis should be monitored and protective measures considered. It is evident that the urbanized environment exerts a more substantial impact on the ecosystem of lake Dauniškis, despite the absence of overt sources of pollution (Figure 9).

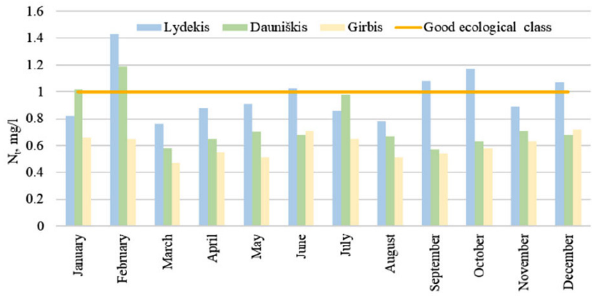

Figure 9. Distribution of total nitrogen concentrations during the study period

A comparative analysis of one-year water sample tests from three lakes in the Utena district – Girbys, Dauniškis, and Lydekis – discloses discernible disparities associated with the magnitude of environmental use. The highest concentrations of nitrates, phosphates phosphorus, and ammonium nitrogen were measured in lake Lydekis (intensive agricultural activity) during all months of the year, indicating the most pronounced signs of eutrophication risk. The concentrations of biogenic substances in lake Dauniškis, located in an urbanized area, show fluctuations in these parameters. Lake Girbys, characterized by its natural, wooded environment, is regarded as a site with minimal anthropogenic impact, exhibiting balanced ecological parameters and low levels of pollutants. The analysis of the three lakes indicated that water quality is influenced by both natural characteristics and the nature and intensity of environmental use.

4. Conclusions

The study confirms clear differences between lakes located in areas of varying intensity of anthropogenic impact. The nature of environmental use emerges as the main factor determining lake water quality, their ecological status, and the dynamics of biogenic substances.

The highest concentrations of biogenic substances were identified in lake Lydekis, situated within an area characterized by intensive agricultural practices, across all seasons of the year. This indicates a significant risk of eutrophication.

Lake Girbys, situated within a forested environment and exhibiting minimal anthropogenic influence, had the lowest levels of pollutants and the highest ecological stability.

The lake Dauniškis, situated within an urbanized area, exhibited distinctive characteristics, including heightened parameter variability and episodic spikes in pollution levels. These phenomena point to the occurrence of episodic pollution events and the impact of the urban environment on the aquatic ecosystem.

Based on total nitrogen concentrations, lake Girbys was found to be in very good ecological status (N_t < 1.00 mg/l), while lakes Lydekis and Dauniškis were classified as being in good ecological status (1.00–2.00 mg/l). Nevertheless, the status of these lakes must continue to be monitored due to fluctuations in biogenic substances and the potential risk of eutrophication.

In future research, we plan to continue lake water quality studies by expanding the number of lakes studied and the measurement period to better capture long-term trends and annual variability in nutrient dynamics and ecological status under different land use pressures.

Increased sampling frequency, particularly in urban and agricultural catchments, is needed to identify episodic pollution events and quantify the contribution of diffuse and point-source inputs. Integrating biological quality elements and hydro-morphological indicators with physicochemical parameters would allow a more comprehensive assessment of ecological status in accordance with the Water Framework Directive. In addition, modelling approaches linking land-use practices, climate variability, and nutrient loading could support scenario-based management and inform targeted measures to prevent eutrophication and deterioration of lake status.

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