



University of Pannonia
Chemical Engineering and Material Sciences Doctoral School

**Analysis of nutrient cycling changes in wetlands
driven by bird migration**

DOCTORAL Ph.D. THESIS

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Introduction

Clean water is a vital resource, vulnerable to both natural changes and human activities. To effectively protect water quality, solutions that allow for rapid and long-term analysis are needed. The limitations of current sampling and measurement methods mean that this research focuses on machine learning analysis of real-time sensor and remote sensing data.

The analyses cover the status of mountain streams and wetlands, the relationship between waterbird populations and water quality, and the identification of anomalies. Models developed from real-time water monitoring data have demonstrated that waterbirds can serve as indicators of changes in nutrients, while the presence and abundance of bird species are correlated with phosphorus and nitrogen concentrations.

The installation and adaptation of real-time water quality monitoring systems has led to more accurate predictive models. The established PCR water quality prediction model provided accurate predictions of the water quality index of the study area, achieving an R^2 value of 0.81 and a mean squared prediction error of 0.17 during the analyses.

An autoregressive integrated moving average (ARIMA) model was developed to estimate the variation of water chemistry parameters, which supported the prediction of surface freshwater status and chemistry parameters through time series analysis.

The dissertation focuses on the importance of adapting the indicators calculated from the water chemistry parameters established by the Water Framework Directive, taking into account seasonal variations in water quality, exploring the ecological links between wetlands, and developing intervention strategies that allow for immediate and informed decision-making.

Applied Methods

During my doctoral research, I implemented real-time water quality monitoring systems, whose data enabled the identification of immediate problems and the tracking of long-term trends. For processing sensor data, I applied machine learning analyses, while remote sensing data were used for analyzing and evaluating identified anomalies. Laboratory measurements were utilized to achieve more accurate determination of water chemical parameters.

The analysis of more than 10 years of water quality data, the monitoring of migratory waterbirds, the determination of site-specific pollution profiles, and the selection of nutrient-indicator bird assemblages were also part of the research. Using principal component analysis

(PCA) and regression, I investigated the relationships between waterbirds and water quality indicators.

For predictive modeling, I used a PCR model, which demonstrated an R^2 value of 0.81 and a mean squared prediction error (MSPE) of 0.17. The evaluation of identified anomalies was conducted through the analysis of remote sensing data (NDVI and surface temperature). Furthermore, I developed ARMA and ARIMA models, which can be applied for 30-day time-series water quality forecasting of surface freshwater.

The analyses were based on data from real-time monitoring stations at the Kis-Balaton Water Protection System and the Szúnyogszék Lakes. These methods enable effective water quality monitoring across geographically distant yet ecologically connected wetlands, facilitating the understanding of ecological relationships and the development of rapid response measures.

Theses

I. The seasonal nutrient contribution of waterbirds and their role in the trophic dynamics of wetlands

1. I confirmed that bird migration is correlated with nutrient availability in the Szúnyogszék (Dumbrăvița) section of the Homoród stream through the role of waterbirds in phosphorus and nitrogen cycling. I demonstrated that the contribution of waterbirds to phosphorus at the outflow of the pond system into the stream can reach 6.6% of the total annual phosphorus load. Although the contribution of nitrogen from herbivorous goose species in the Szúnyogszék Lakes is up to 0.7%, a strong correlation between bird load and nutrients was observed during a period when water quality in the oligotrophic stream-supplied pond was still in the good category. The nutrient contribution of waterbirds should therefore be taken into consideration when planning sustainable water management measures, especially in shallow wetlands.

Related publications: 2, 9, 14.

II. Impact of bird migration on water quality: principal component analysis and regression modelling

2. Principal Component Analysis (PCA) was used to demonstrate the relationship between water quality parameters and nutrient transport by birds. Based on the results of the PCA, regression analysis confirmed that the presence of migratory birds is associated with the seasonal variations in the Water Quality Index (WQI). The developed PCR model demonstrated an R^2 value of 0.81 and a mean squared prediction error (MSPE) of 0.17, providing accurate predictions for the seasonal and interannual variations in the Water Quality Index (WQI). This indicates that waterbirds play a detectable role in the nutrient transport of the investigated wetland system. Based on this method, I developed a decision support algorithm capable of estimating the impact of birds' complex two-directional nutrient transport (e.g., excrement input and food uptake) on water quality, thereby aiding in the effective management of fluctuating nutrient loads.

Related publications: 2, 4, 9, 14.

III. The role of waterbird species in the nutrient cycling and water quality of the Szúnyogszék (Dumbăvița) lakes

3. I demonstrated that the PCA method is suitable for comparing the temporal relationships between waterbird species, water quality parameters, and nitrogen and phosphorus loads. Using Principal Component Analysis (PCA), I also showed that among the 12 most frequently observed and most abundant waterbird species, the black-headed gull (*Chroicocephalus ridibundus*), the great cormorant (*Phalacrocorax carbo*), the Eurasian teal (*Anas crecca*), the grey heron (*Ardea cinerea*), the great egret (*Ardea alba*), and the Caspian and yellow-legged gulls (*Larus cachinnans/Larus michahellis*) are associated with higher phosphorus concentrations. In contrast, the greater white-fronted goose (*Anser albifrons*), the common coot (*Fulica atra*), the common pochard (*Aythya ferina*), and the northern shoveler (*Anas clypeata*) are

observed in water bodies with higher nitrogen concentrations. This association reflects the trophic level-based feeding habits of these species and the availability of food resources. The analyses also revealed a correlation between the presence of waterbirds and higher values of suspended solids, total dissolved solids, and biological oxygen demand. These species contribute in a complex manner to the nutrient transport within lakes, influencing changes in phosphorus and nitrogen concentrations. Supporting this, the guild of importer-exporter species with two-way nutrient transport functions accounted for the largest share (60%) of the bird community population.

Related publications: 2, 4, 5, 7, 8, 14.

IV. Application of GIS and Remote Sensing Methods for detecting water quality loads in the Szúnyogszék Lakes

4. I demonstrated that the assessment of the condition of the Szúnyogszék Lakes can be effectively supported by the application of GIS and remote sensing methods (LANDSAT 7 and 8), providing a valuable tool for identifying environmental and anthropogenic anomalies based on surface temperature and Normalized Difference Vegetation Index (NDVI) values. The analyses revealed that decreases in minimum NDVI values on the water surface indicate a decline in vegetative activity, which has an adverse impact on water quality during dry periods. NDVI values of 0.2 indicate the presence of shallow, muddy, or silty water, which is often associated with rising surface temperatures, primarily due to the draining of the basins. Prolonged warm periods and lack of precipitation also contribute to declining water levels, lower dissolved oxygen (DO) concentrations, and the drying out of shallower parts of the lakebed. I demonstrated that linear regression and ARIMA models are reliable tools for predicting NDVI changes, enabling the timely identification of future water quality issues.

Related publications: 1, 4.

V. Development of time-series regression models for the prediction of water quality parameters in the Kis-Balaton Water Protection System

5. I investigated that time-series regression models developed for predicting water quality parameters of the Kis-Balaton Water Protection System, especially Autoregressive Moving Average (ARMA) models, can be effectively applied to estimate the temporal changes in dissolved oxygen, pH, redox potential, electrical conductivity and turbidity. I demonstrated that optimization of models using online physico-chemical sensor data significantly increased prediction accuracy, especially at 30-day intervals. The results confirmed that the models provide accurate trend predictions, although in the case of turbidity only the mean values were correctly predicted. I suggest the use of nonlinear methods (SVM, neural networks, SARIMA - Seasonal ARIMA) to manage such events. ARIMA models are a useful method for predicting water quality and detecting anomalies, which is essential for the conservation of the wetland habitat of Lake Kis-Balaton.

Related publication: 1.

Publications

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