THE EUTROPHICATION PHENOMENON IN GOLEŞTI LAKE - ROMANIA

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ABSTRACT. – Eutrophication on worldwide scale, as an effect of the anthropic impact, is one of the most serious problems that affect the quality of the water. Existence of a large percentage of lakes with eutrophication problems, demands a predictive tool for the quality of these ecosystems.
This study present the qualitative analysis of such an ecosystem, based on ecological modelling. This paper proposes an ecological model (nutrient-phytoplankton) that describes the biochemical behaviour of a eutrophic reservoir. The 1D model developed allows the estimation of nutrients concentration and algae biomass and nutrient limited evidence on algal growth rate. The model was calibrated and validated with data from 2008 and 2009 in Goleşti Lake. The model reproduces spatial and temporal concentration distribution of water quality constituents.

Keywords: lake, eutrophication, ecological model, nutrients, water quality.

1. INTRODUCTION

The study of water quality in lake or reservoirs is important in controlling the eutrophication phenomenon. Eutrophication of lakes is caused by the inflow of nutrients, in particular nitrogen and phosphorus that are released especially from human activities. A number of physicochemical and biological changes may occur as a result of eutrophication. Thus, the concentration of nutrients increase so the primary production of organic matter rise and thus the amount of organic material in a state of decomposition in water increase, all those processes having major effects on lake water quality. Typical symptoms of eutrophication are the increase of water turbidity and sedimentation rates, which will reduce the amount of light reaching submerged plants, appearance of flowering water, lush development of higher aquatic plants, formation of a film of floating algae, unpleasant smell of water, reduced transparency, oxygen deficiency in bottom layer of water, followed by formation of hydrogen sulphide and massive death of fish (Dumitran& Vuţă, 2010). So, accumulation of predisposing factors conditions can generate excessive biological productivity growth, leading to imbalances in the matter and energy flows (Bryhn, & Håkanson, 2009).

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The quality of the main lakes in Romania in terms of trophicity degree reveals the following aspects regarding nutrients concentrations in 92 monitored lakes: 6.32 % corresponded to ultra and oligotrophic category, 23.16 % - mesotrophic category, 36.24 % - eutrophic and 34.28 % - hypereutrophic. Concerning the phytoplankton biomass, 38.95 % of Romanian lakes corresponded to ultra and oligotrophic category, 23.16 % - mesotrophic, 15.79 % - eutrophic and 22.1 % - hypereutrophic (Iliescu, 2009).

The purpose of this study was to develop a model for Goleşti Lake that could simulate water quality, help develop an understanding of the processes affecting water quality, and predict changes in water quality. In recent years some water quality problems in the Goleşti Lake were found and the concentration of eutrophication indicators placed the water lake in the eutrophic category. Having the evolution of quality indicators from the lake as a starting point, a theoretical study will be carried out, that will refer to the elaboration of a model, which refers to the way a lake ecosystem works.

2. DESCRIPTION OF THE MODEL

Aquatic trophic chains are complex system which can be schematized by matter and energy transfer processes. The lakes dynamic is characterized by energy and mass exchange processes. Dominant flow of energy comes from the kinetic energy of wind and thermal energy produced by solar radiation. The vertical profile of temperature/density established in a lake results by superposing these two energy contributions.

The energy transfer over the different trophic chains starts with solar energy intake by primary producers and its absorption at the chlorophyll level. A part of the gross primary production is loss by respiration, but the net primary production is used by the next trophic level for alimentation. Thus, the primary consumers absorb this energy. The part of primary production which is not used is consumed by bacteria. Assimilated fractions correspond to secondary production and represent the energy flux which crosses the primary consumers trophic level. The energy leaving the food chain goes directly to decomposition, due to dissipative processes (Popa, 1998).

The most important problem in developing high quality models is to identify the adequate mathematical formulae to describe the transformation processes for the considered level of trophic chain (Jorgensen ş.a. 1986). This paper presents an ecological model which describe the annual cycle of nutrients, phytoplankton and zooplankton for an aquatic ecosystem. The model presented in this paper is dealing only with the biochemical part of the process. For this model, four state variables are taking into account: two nutrients, phytoplankton and zooplankton biomass.

3. STUDY CASE

The study case concerns the Goleşti Lake, which is an accumulation lake on the interior waters of Romania. It was created after the completion of a dam built on the Argeş River and it has a complex use allowing the flood attenuation, generation of hydroelectricity, household and industrial water supply, and irrigation. The lake has a volume of 55 million m³ and a maximum depth of 32 m. This reservoir is a heavily modified water body. Its physical characteristics have been substantially changed and to achieve good surface water status it is necessary to changes its hydromorphological characteristics which would have a significant adverse impact on the water environment.

Experimental physicochemical and biological data for a period of two years, from 2008 to 2009, were available for the Golesti Lake. The measurement frequency of these indicators, according to European norms, is four times per year. Thus, it is observed that the mean water temperature varies between 2°C and 23°C and the values of dissolved oxygen concentrations between 6.91 and 13.3 mg/l (Fig. 1).

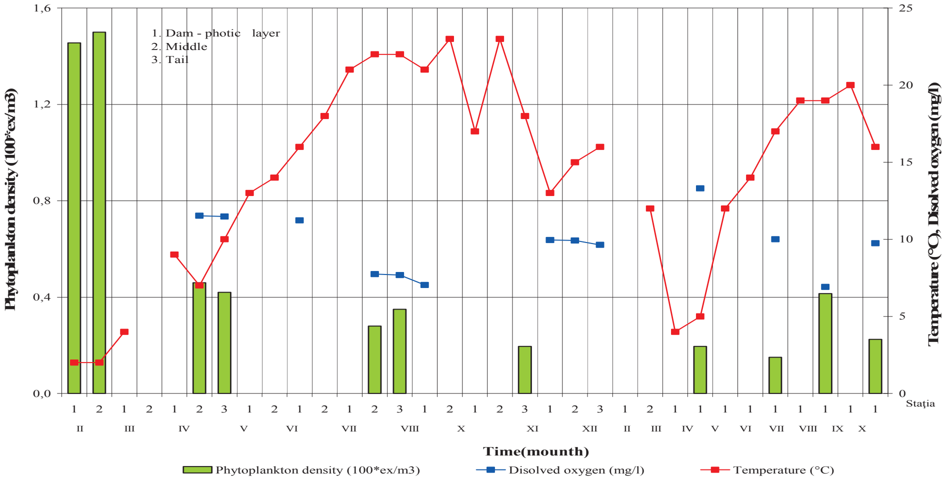

Figure 1. ***Experimental values of water temperature, dissolved oxygen and biomass concentrations.***

Concerning the time evolution of nutrients content, it is observed that the total mineral nitrogen concentration takes values between 0.2 and 1.18 mg/l, while the total phosphorus concentration changes from 0.044 to 1.43 mg/l. Also, in the Golesti Lake, the phytoplankton which is dominated by diatom and chlorophyta varies between 1.78 and 5.3 mg/l (Fig. 2).

One way to characterize the health of lake is by using phosphorus, chlorophyll a, and Secchi depth transparency data to calculate the Trophic State Index-TSI (Carlson 1977). This index provides a way to rate and compare lakes according to their level of biological activity on a scale from 0 to 100. This scale goes from 0 – 100, with 0 being the least trophic state (corresponding to an oligotrophic lake) and 100 being the most trophic (corresponding to a hypereutrophic lake).

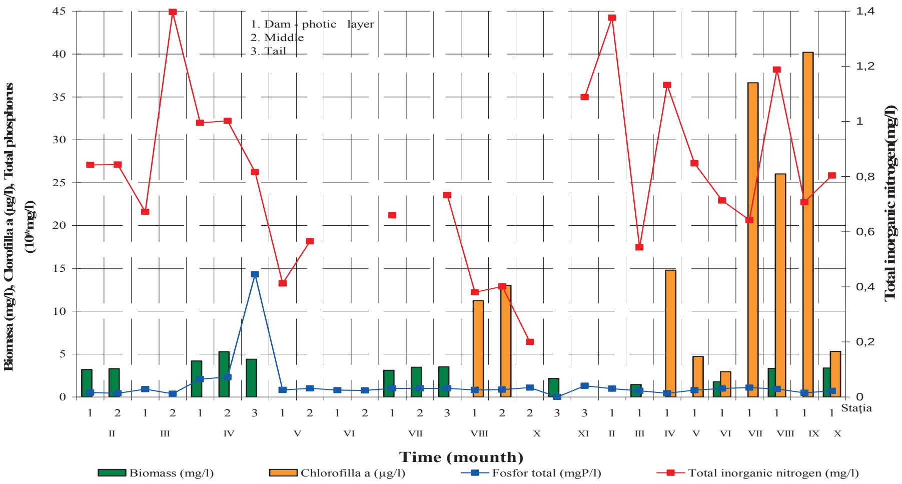

Figure 2. ***Experimental time variations of concentration values of phosphorus, nitrogen, chlorophyll a and phytoplankton biomass.***

The TSI values obtained for Goleşti Lake (Fig. 3) indicate that the lake is in large proportion in eutrophic status.

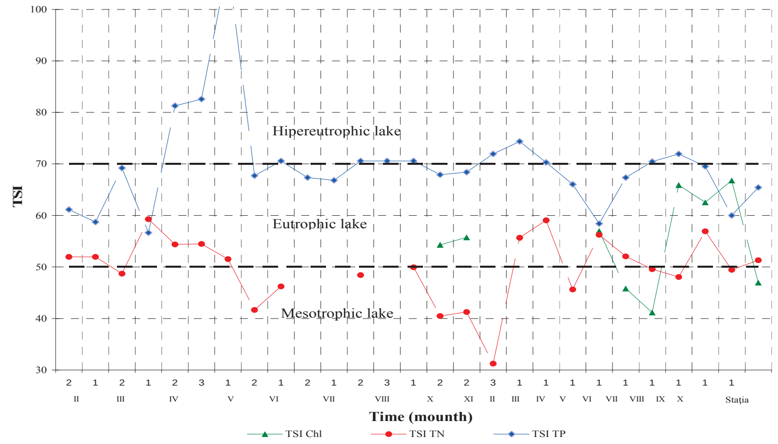

Figure 3. ***TSI values for Stanca Costesti Lake***

Thus, the resulting TSI values show that in the large majority of the study period the Goleşti Lake is placed in the eutrophic category. But also exist some exception; like in early summer 2008 the lake can be placed in the hypertrophic category if considering the phosphorus values and in 2009 the lake became mesotrophic for a short period regarding at the nitrogen and chlorophyll content.

4. MODELLING APPROACH

The most common modelling approaches of lake eutrophication are based mostly on steady-state input-output equations (Chapra, 1997). For the mass-balance, generally, the nutrient concentration is calculated from inputs, and chlorophyll *a* concentration or another indicator of phytoplankton biomass (Jorgensen, 1981) is predicted by correlation with the limiting nutrient.

The ecological model presented in this paper allows the simulating of four constituents: total inorganic nitrogen (TN), total phosphorus (TP), phytoplankton (A) and herbivore zooplankton (Z). Phytoplankton is considered as a pool of primary producers and is driven by the nutrient concentration and by the dynamics of grazers. It is described (eq. 1 Table 1), by the growth term, production, the loss by respiration and mortality terms, and by the grazing. In production term the optimal growth, growth$_{max}$, is multiplied by a dimensionless factor, which simulates limitation to growth due to sub-optimal levels of light intensity, temperature, and nutrient concentration. The limiting factors are computed following the standard formulations: the Michaelis Menten –Monod for nutrient limitation, the Steele formulation for the limitation due to light intensity, and an exponential relation for temperature. The evolution of the zooplankton (eq. 2 Table 1) is described by the grazing term –using the Holling type II relationship between phytoplankton and zooplankton concentration- and by the mortality term, which is described by a first order kinetic (Malmaeusa, 2004). Phosphorus and nitrogen are the main nutrients considered by the model (eq.3 and eq.4 Table 1).

Table 1. ***Differential equations for the state variables in ecological model***

$$\frac{\partial A}{\partial t} = (PP - loss)\times A - c_{za} \times A \times Z \qquad \text{(eq.1)}$$

$$\frac{\partial Z}{\partial t} = a_{ca} \times \varepsilon \times c_{za} \times A \times Z - k_{dz} \times Z \qquad \text{(eq.2)}$$

$$\frac{\partial TP}{\partial t} = a_{pa} \times (1-\varepsilon)\times c_{za} \times A \times Z + a_{pc} \times k_{dz} \times Z - a_{pa} \times Pp \times A + S_P \qquad \text{(eq.3)}$$

$$\frac{\partial TN}{\partial t} = a_{na} \times (1-\varepsilon)\times c_{za} \times A \times Z + a_{nc} \times k_{dz} \times Z - a_{na} \times Pp \times A + S_N \qquad \text{(eq.4)}$$

The parameter values found to give the best fit between simulated data and the lake's mean annual patterns are reported in table 2.

Table 2. ***The kinetics coefficients and value used in the model***

Parameter	Assigned value	Parameter	Assigned value
$grow_{max}$	0.85 day^{-1}	a_{ca}	40 mg C/mg Chla
$k_{sp\ P}$	5 mg/l	ε	0.6
$k_{sp\ N}$	15 mg/l	a_{pa}	1 mg P/mg Chla
c_{za}	5 mg/l	a_{na}	0.18 mg N/mg Chla

5. RESULTS AND DISCUTION

The model was calibrated and validated based on 2008 and 2009 data. The calibration procedure required a balance between phytoplankton growth and loss of available nutrients from the water column. Particular attention was placed on the dynamics of phosphate as this nutrient was the main one limiting phytoplankton biomass in Goleşti Lake. The ecological model was calibrated by tuning the model parameters within their observed literature ranges, as derived and used in the model sensitivity analysis.

The comparison between simulated and observed nutrient concentration values for the study lake is shown in figure 4.

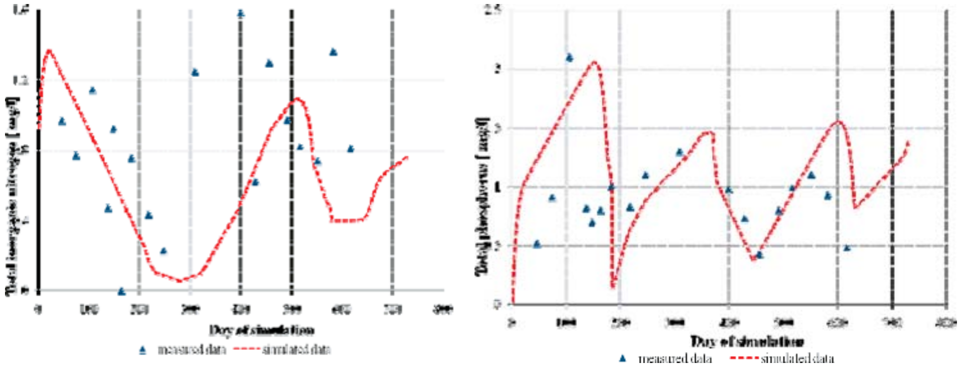

Figure 4. ***Comparison between observed and simulated data for the nutrients***

The predicted total phosphorus and total inorganic concentrations are in good agreement with empirical values for lake raported in scientifical literature.

In close correlation with lake ecosystem functioning, the model consider that algae flowering begins at the end of the spring mixing (75th day of the year). The nutrients concentration is in indirect correlation with the algal production. Due to algae bloom, the nutrients concentration starts to decrease, and, when the phytoplankton peak is reach, the decomposition processes, along with the resuspension ones, generate a growth of the nutrients concentration (especially on the phosphorous).

In Goleşti lake there are spring peaks in TP and chlorophill concetration, which are reproduced by our model. These peak concetration are explained by the mobilization of phosphorus from sediments due to spring turover and rapid growth of phytoplankton with concurrent zooplankton growth inhibited by the low water temperature. In the summer period the reactive soluble phosphorus is strongly assimilated by plants in the epilimnion layer and the primary production is the result of decreasing the amount of nutrients available.

Since just the herbivorous zooplankton is considered a delay between zooplankton peak and phytoplankton peak is natural to appear, as in fig.5.

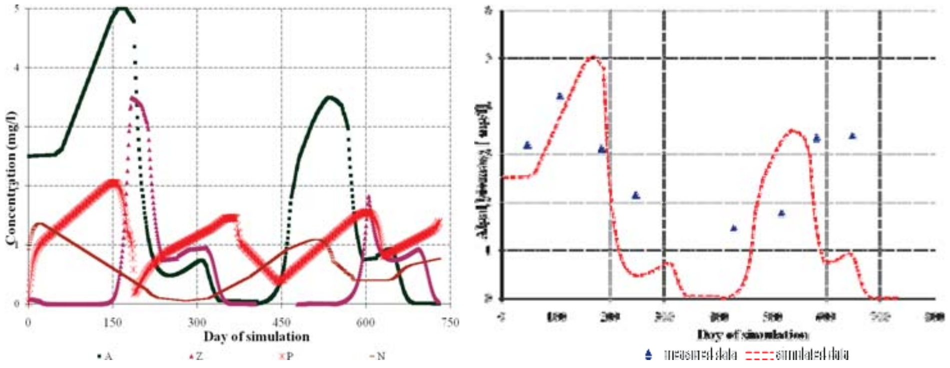

Fig. 5. *Numerical spatial distribution of TP, TN, A and Z concentration in Golesti Lake*

It can be seen that the model provides reasonable results for phytoplankton and zooplankton biomass, soluble reactive phosphorus and nitrogen concentrations. In order to quantitatively verify the model performance, the root mean square error (RMSE) was computed. The ideal value for RMSE is 0 and from the results, it was found that algae and phosphorus simulation had the largest error (1.61 respectively 1.59). For the nitrogen the RMSE was 0.52.

6. CONCLUSION

Water quality models are important tools to support the optimization of aquatic ecosystem rehabilitation programs and assess their efficiency. Management models for aquatic systems can be used to determine which measures in the watershed or in the water body have been effective and which one should be used in the future.

An ecological model was configured for the Golesti Lake from Romania and it was calibrated and validated with data from 2008 and 2009. The model simulates a simple food chain with only 3 levels (nutrients, primary producers and consumers). The choice of those state variables for the model represents a compromise between available data and the need to simulate the biochemical behaviour of the lake.

The results obtained agree well with the experimental data for the water quality constituents such as TP, TN, A and Z biomass. The values of the kinetic coefficients obtained from model calibration and validation analyses are consistent with the values reported in the literature. However, little discrepancies exist between the observed and simulated data.

From the verification, it was concluded that the developed model was capable to simulate the water quality dynamics of the studied area with a reasonable accuracy.

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