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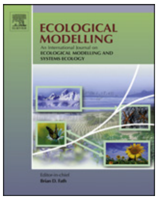

Neural network modeling of dissolved oxygen in the Gruža reservoir, Serbia

Vesna Ranković[a,*], Jasna Radulović[a], Ivana Radojević[b], Aleksandar Ostojić[b], Ljiljana Čomić[b]

[a] *Department for Applied Mechanics and Automatic Control, Faculty of Mechanical Engineering, University of Kragujevac, 34000 Kragujevac, Sestre Janjić 6, Serbia*
[b] *Institute of Biology and Ecology, Faculty of Science, University of Kragujevac, 34 000 Kragujevac, Radoja Domanovića 12, Serbia*

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ABSTRACT

The objective of this study is to develop a feedforward neural network (FNN) model to predict the dissolved oxygen in the Gruža Reservoir, Serbia. The neural network model was developed using experimental data which are collected during a three years. The input variables of the neural network are: water pH, water temperature, chloride, total phosphate, nitrites, nitrates, ammonia, iron, manganese and electrical conductivity. Sensitivity analysis is used to determine the influence of input variables on the dependent variable. The most effective inputs are determined as pH and temperature, while nitrates, chloride and total phosphate are found to be least effective parameters. The Levenberg–Marquardt algorithm is used to train the FNN. The optimal FNN architecture was determined. The FNN architecture having 15 hidden neurons gives the best choice. Results of FNN models have been compared with the measured data on the basis of correlation coefficient (r), mean absolute error (MAE) and mean square error (MSE). Comparing the modelled values by FNN with the experimental data indicates that neural network model provides accurate results.

1. Introduction

Water quality measurements include a variety of physical, chemical, and biological parameters. Basic problem in the case of water quality monitoring is the complexity associated with analyzing the large number of variables. Different multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA) are used for the interpretation of a complex data (Iscen et al., 2008).

The concentration of dissolved oxygen (DO) is important for the healthy functioning of aquatic ecosystems, and a significant indicator of the state of aquatic ecosystems.

The dissolved oxygen levels in aquatic systems probably reveal more about their metabolism than any other single measurement. Concentrations reflect the momentary balance between oxygen supply from the atmosphere and photosynthesis on one hand, and the metabolic processes that consume oxygen on the other hand (Kalff, 2002).

It is highly desirable to create a DO model for each major reservoir so that water quality can be optimized throughout a time horizon.

Different models have been developed and used to analyze dissolved oxygen. These are grouped into two general categories: deterministic (Stefan and Fang, 1994; Stefan et al., 1995; Ansa-Ansare et al., 2000; García et al., 2002; Hull et al., 2008; Shukla et al., 2008) and statistical/stochastic models (Boano et al., 2006).

Although the modeling of dissolved oxygen in aquatic ecosystems has been studied, many aspects of its dynamics are still unclear (Antonopoulos and Gianniou, 2003). The DO dynamics is highly nonlinear and many useful statistical theories cannot be implemented.

One of the successful soft computing methods applications is to model complex nonlinear systems. A number of authors have established that feedforward neural network (FNN), with a variety of activation functions, serve as universal approximators (Blum and Li, 1991; Hornik, 1991). The most important property of the neural network is its capability to learn from examples. ANN provides an effective tool to analysis and modeling nonlinear relationships in ecology (Lek et al., 1996).

The development and current progress of integration of various Artificial Intelligence techniques (knowledge-based system, genetic algorithm, artificial neural network, and fuzzy inference system) into water quality modeling are reviewed by Chau (2006). The artificial neural networks (ANNs) have been successfully used tools in the fields of water quality prediction and forecasting. FNN models were identified, validated and tested for the computation of DO (dissolved oxygen) (Dogan et al., 2009) and DO (dissolved oxygen) and BOD (biochemical oxygen demand) (Singh et al., 2009) of river water. Palani et al. (2008) demonstrated the application of neural network models for the prediction and forecasting of selected seawater quality variables. ANNs have been used intensively in the development of a reservoir water quality simulation

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[*] Corresponding author. Tel.: +381 34 335 990; fax: +381 34 333 192.
E-mail addresses: vesnar@kg.ac.yu, vesnar@kg.ac.rs (V. Ranković).

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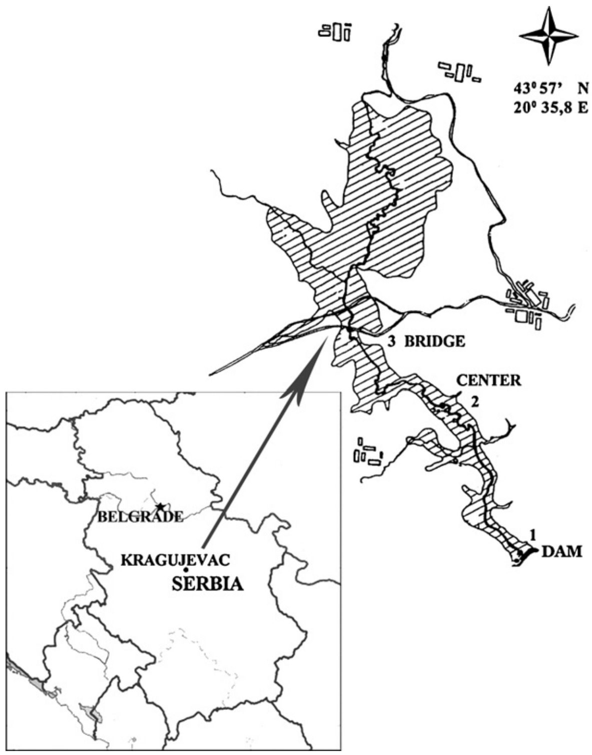

Fig. 1. The Gruža Reservoir and sampling points (1, Dam; 2, Center; 3, bridge).

model (Soyupak et al., 2003; Chaves and Kojiri, 2007; Kuo et al., 2007; Ying et al., 2007).

The aim of this paper is to construct a FNN model to predict the dissolved oxygen in the Gruža Reservoir, Serbia and demonstrate its application to identifying complex nonlinear relationships between input and output variables. The Gruža Reservoir has been chosen due to its importance in watersupply as well as its high trophic degree, which has been reached in less than twenty years. The need to create the model results from the fact that during the summer period in hypolimnion the conditions are anoxic. The proposed model may contribute to more efficient management as well as to preventive activities.

2. Materials and methods

2.1. Study area

The Gruža Reservoir was formed on the Gruža River for the purpose of supplying Kragujevac and the surrounding area with drinking water. The city of Kragujevac, Serbia, is the administrative, political, economic, educational and cultural hub of the District of Šumadija and the surrounding neighborhood districts (Fig. 1).

Construction of the dam began in 1979, and the reservoir was filled with water in 1985. It is located at an altitude of 238–269 m a.s.l., with a total water volume of $64.6 \times 10^6\,\mathrm{m}^3$, a surface area of 934 ha, and a drainage basin of 318 km^2. The maximum depth of the reservoir is 31 m, and the reservoir exhibits 3–5 m water level fluctuations. It has a hydraulic residence time of 22 months. More than two-thirds of the reservoir has all the characteristics of lowland reservoirs, with shallow depth (mean depth of reservoir is 6.5 m), an unfavorable ratio of trophogenic and tropholytic layers, and banks surrounded by meadows and cultivated land. The soil upon which the accumulation lake was made contains Fe and Mn. A special characteristic is a bridge crossing the reservoir, which carries frequent motor traffic, so that considerable amounts of exhaust fumes collect over the reservoir and enter the water by means of diffusion or with precipitation. The large surface in relation to the mean depth favors eutrophication (Ostojić et al., 2005).

The average values of trophic state parameters (9–200 μg L^{-1} total phosphorus, 3–99 μg L^{-1} chlorophyll-a, and 0.5–2 m Secchi transparency) indicate that water of the Gruža Reservoir is eutrophic according to three types of classification: Carlson (1977), OECD (1982), and Jones and Lee (1982). It is apparent that the Gruža Reservoir can be classified as a eutrophic water on the basis of total phosphorus content of chlorophyll-a and hypertrophic water with respect to transparency (Ostojić et al., 2005).

It is surrounded by farmland, and receives waste water from a number of neighbouring settlements. The reservoir exhibits thermal stratification from the end of April to the beginning of October (Comic and Ostojic, 2005).

2.2. Water quality data

The data set used in this study was generated through monitoring of the water quality of Gruža reservoir. Monthly sampling was carried out during the period from three years (2000–2003). Three permanent sampling sites were selected (Fig. 1). One was directly beside the dam, where the depth varied from 25 to 30 m, depending on the water level. The second was in the central part with a depth ranging from 14 to 17 m. The third was in the shallowest part, near the bridge, with a depth ranging from 5 to 9 m, about 200 m from its end, which is under water even when its level is lowest. Samples were collected at 3-m depth intervals during the thermal stratification period and at 5-m increments during the mixing period. For the analysis we selected 180 samples with complete data.

Physical and chemical analyses were performed using Standard Methods (APHA, 1995).

The parameters analyzed in this paper are based on variables that reflect the water quality and they can be divided into the following categories (Straškraba and Tundisi, 1999):

- water quality variables indicative of stratification which include temperature, dissolved oxygen, pH, Fe and Mn,
- water quality variables that indicate the trophic status and include total phosphorus and nitrogen,
- mineral budget: conductivity, chloride.

A data set including 180 data samples. The available set of data was divided into two sections as training and test set. In the training process of the FNN 152 samples were used. The ANN model was tested using 28 randomly selected data.

Basic statistics of the measured water quality variables in the Gruža Reservoir is presented in Table 1. The input variables of the neural networks model are denoted as x_i, $i = 1,2,\ldots,10$ and the output as y. Measured value of the output is denoted as y_m.

3. ANN model

3.1. ANN and training algorithm

Artificial neural networks are composed of a set of simple elements, the so-called artificial neurons. These elements are inspired by biological nervous systems. The model of a neuron represented in Fig. 2.

The output of a neuron can be expressed as:

$$out = f(n) \tag{1}$$