Soft sensor development for Cluj-Napoca wastewater treatment plant utilizing artificial neural network modelling

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Introduction. Nitrogen pollution is a serious problem for natural water bodies, as it has devastating effects, such as eutrophication. As a final pollution mitigation barrier, the efficient treatment of wastewater is essential [1]. From this perspective, wastewater treatments plants (WWTPs) need water quality prediction tools to support effective operation and informed decision making. By mapping the nonlinear functions of the complex processes behind the WWTPs, artificial neural networks (ANNs) are rapidly developing, allowing high prediction performance and compensating for the shortcomings of traditional modelling and control systems [2].

Methodology. The data used for training and testing the ANN model was collected from the Cluj-Napoca WWTP over a period of 7 months (Jan. to July 2025), at a 10 second interval. By averaging every 60 points, the data was reduced to a 10-minute interval and then the values were normalized. Two days' worth of data was separated for a second independent testing of the model, and the rest was used for developing the model. The development data was randomly divided by MATLAB into 3 sets: 70% for training, 15% for testing and 15% for validation. The model inputs consisted of date and time (converted to numerical values), recirculation flow, effluent ortho-phosphates concentration, effluent pH value, effluent organic substance concentration, dissolved oxygen concentration (from the aerobic bioreactor), and total suspended solids concentration (from the primary settler), while the model output is the effluent total nitrogen concentration. The process involved a trial-and-error methodology for the ANN configuration, until a satisfactory prediction performance result was achieved. The model's prediction performance was tested with multiple performance indicators: coefficient of determination (R^2); mean average percentage error (MAPE); and root mean squared error (RMSE).

Results and discussion. The best performing ANN model has an architecture of 2 hidden layers (with 10 and 9 neurons respectively, and logistic sigmoid transfer functions) with an input delay of 31 previous inputs (approximately 5 hours). All performance indicators (presented in Table 1) reveal good results on both the testing data from the development dataset and on the second independent test data, unknown to the model.

Table 1: Performance indicators for the best-performing ANN model.

Performance indicator	R^2	MAPE [%]	RMSE [mg/L]
Value for test data from the development set	0.9085	8.9134	0.6812
Value for the independent data	0.8253	14.1929	1.0080

The visual analysis of ANN predictions against WWTP measurements also revealed excellent model behavior in following the process dynamics (Fig. 1).

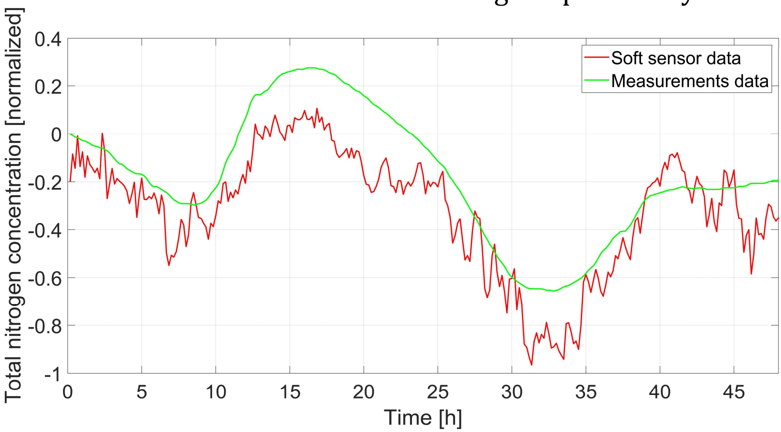

Fig. 1 Model results against measurements for the independent data: normalized nitrogen concentration dynamics.

The model can be used for monitoring or as an independent soft sensor in cases of faulty or missing hard sensors. This research also presents a future applicability for improving the process and nitrogen removal by integrating the ANN model in the WWTP control loop.

Conclusions. An ANN-based soft sensor for the effluent nitrogen concentration has been developed and verified against field data from the Cluj-Napoca WWTP.

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