Application of computer models and Artificial Intelligence technologies to improve the quality of wastewater treatment

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Abstract. The article provides a brief overview of the use of computer simulation models and artificial intelligence technologies to predict the quality of wastewater treatment from agro-industrial enterprises, which have a complex composition, variable flow rate and require taking into account a large number of factors both at the design and operation stages. This predetermines the need to model complex systems and predict the quality of cleaning using computer models and artificial intelligence technologies. Based on the reviewed foreign and Russian publications, a conclusion was made about the most common types of models currently used to predict the quality of wastewater treatment.

1 Introduction

Modern agricultural holdings are multifunctional complexes equipped with modern technology for obtaining raw materials of animal and plant origin, processing raw materials to obtain materials and semi-finished products for the food industry or finished products for sale in retail chains.

Wastewater from agricultural holdings contains a significant amount of organic and inorganic impurities with variable composition and flow rate. The typical composition of wastewater may differ depending on which industry the processing enterprises included in agricultural holdings belong to [1]. In addition, wastewater pollution depends on the level of raw material losses, the quality of equipment and the competence of operating personnel.

Wastewater treatment facilities for agricultural holdings are designed based on an analysis of production processes, flow, uniformity of flow and composition of wastewater.

The complexity and instability of the composition of wastewater leads to the need for careful selection of initial data for design, selection of a whole complex of treatment facilities and does not always give satisfactory results [2]. Traditionally, the choice of wastewater treatment technologies is based on the sequential implementation of technological calculations of the pre-treatment stages, including rough treatment, settling and averaging, and the main stages - physical-chemical, biological treatment, deep cleaning and disinfection.

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The complex nature of treatment facilities determines the consideration of a large number of factors and necessitates automation of design. The use of mathematical models and regression algorithms to determine parametric relationships between various variables in complex systems, which are wastewater treatment plants, determines the feasibility of computer simulation modeling and, especially in the last decade, the use of artificial intelligence (AI) technologies, a brief overview of which is given in this article [3-4].

2 Materials and methods

The selection of literature sources on the use of computer models and artificial intelligence technologies in wastewater treatment was based on the following criteria: 1) search depth 10 years, earlier publications were not considered; 2) content of the article - the use of artificial intelligence in industrial, agricultural and municipal wastewater treatment technologies, the use of predictive analysis, the use of neural networks, the level of scaling of the impact of artificial intelligence in wastewater treatment, and 3) keywords.

The keywords chosen were wastewater treatment, treatment quality monitoring, simulation modeling, mathematical treatment model, artificial intelligence, neural networks, predictive analysis.

A total of 96 sources were considered, of which more than two thirds were cases related to predicting the quality of wastewater treatment in centralized wastewater disposal systems. For analysis, 31 publications were selected for the period from 2017 to 2023 (Table 1), related to the use of artificial intelligence in industrial wastewater treatment systems, including those from agricultural holdings.

Table 1. "Geography" of reviewed publications.

A country	Number of articles	A country	Number of articles
China	6	Taiwan	1
Iran	3	UAE	1
Saudi Arabia	3	Malaysia	1
Great Britain	2	Portugal	1
India	2	Romania	1
Pakistan	2	Egypt	1
Türkiye	2	Israel	1
Thailand	2	Taiwan	1
Australia	1		

To search for information, we used such resources as Semantic scholar, Research gate, MDPI – Publisher of Open Journal Access, Elsevier.

3 Results

For the purposes of simulation modeling of treatment facilities, software products are used that use theoretical formulas and empirical dependencies as predictive models. The following computer models are currently most widely used for the study of wastewater treatment plants: BioWin (EnviroSim Associates Ltd, Canada), STOAT (Water Research Center Limited, UK), Aspen HYSYS (Aspen Technology Inc., USA), WEST (MIKE by DHI, Denmark) and GPS-X (Hydromantis ESS, Inc, Canada). In modern European and Russian research, Aspen HYSYS and GPS-X software products are most often used [5-6]. For example, using the GPS-X model, you can study individual wastewater treatment processes, such as sedimentation, flotation, coagulation. biological treatment in an aeration tank and ozonation, as well as their combinations [5-10]. Analysis of publications shows that computer modeling is used mainly for biological treatment plants.

Artificial intelligence technologies, which gave impetus to the transition to Industry 4.0, are currently quite widely used in foreign wastewater treatment practice. Among them, neural networks have developed in recent years (Table 2).

Table 2. Brief overview of publications on the use of artificial intelligence technologies in wastewater treatment.

Authors	Article title	ANN*	SVM*	MLR*	FL*	CM*
Praewa Wongburi, Jae K. Park, 2023, Thailand [11]	Prediction of Wastewater Treatment Plant Effluent Water Quality Using Recurrent Neural Network (RNN) Models	☑				
Nitin Kumar Singh et al., 2023, India [12]	Artificial intelligence and machine learning-based monitoring and design of biological WWTS	☑	☑		☑	
M. Salomé Duarte et al., 2023, Portugal [13]	A Review of Computational Modeling in WWTP					☑
Baoying Zhu, 2023, China [14]	COD Prediction Model for Wastewater Treatment Based on Particle Swarm Algorithm					☑
Matthew Lowe, Ruwen Qin, Xinwei Mao, 2022, USA [15]	A Review on Machine Learning, Artificial Intelligence, and Smart Technology in Water Treatment and Monitoring					☑
Dipak Kumar Janaa et al., 2022, India [16]	Optimization of Effluents Using Artificial Neural Network and Support Vector Regression in Detergent Industrial WWT	☑	☑			
Soma Safeer, et al., 2022, Pakistan, UAE [17]	A review of artificial intelligence in water purification and wastewater treatment: Recent advancements					☑
Hmoud Al-Adhaileh, et al 2021, Saudi Arabia [18]	Modelling and Prediction of Water Quality by Using Artificial Intelligence	☑			☑	
Kung-Jeng Wanga et al., 2021, Taiwan [19]	A data-driven optimization model for coagulant dosage decision in industrial WWT					☑
Batsuren Sundui, et al., 2021, Taiwan, Netherlands, Mongolia [20]	Applications of machine learning algorithms for biological wastewater treatment: Updates and perspectives			☑		
Lin Zhaoa, et al., 2020, China [21]	Application of artificial intelligence to wastewater treatment: A bibliometric analysis and systematic review of technology, economy, management, and wastewater reuse	☑			☑	
Congcong Sun,Vicenç Puig, Gabriela Cembrano, 2020, Spain [22]	Real-Time Control of Urban Water Cycle under Cyber-Physical Systems Framework			☑		
Mohammad Najafzadeh, Maryam Zeinolabedini, 2019, Iran [23]	Prognostication of wastewater treatment plant performance using efficient soft computing models: An environmental evaluation		☑		☑	
Yi Mana, Yusha Hua, Jingzheng Ren, 2019, China [24]	Forecasting COD load in municipal sewage based on ARMA and VAR algorithms			☑		
Ata Allah Nadiri, et al., 2018, Iran [25]	Prediction of effluent quality parameters of a wastewater treatment plant using a supervised committee fuzzy logic model				☑	
Vahid Nourani et al., 2018, Iran, Türkiye [26]	Wastewater treatment plant performance analysis using artificial intelligence – an ensemble approach		☑	☑	☑	
Fouzi Harroua et al., 2018, Saudi Arabia, Algeria [27]	Statistical monitoring of a wastewater treatment plant: A case study		☑			

*ANN – Artificial neural networks; SVM – Support vector machine; MLR – Multilinear regression; FL – Fuzzy logic; CM – Computational modelling; DL – Deep learning

4 Discussion

The advantage of the considered computer models BioWin, STOAT, Aspen HYSYS, and GPS-X is the ability to use them to predict the behavior of a complex wastewater treatment plant system and determine options for its effective operation at the design stage. However, theoretical models are based on certain relationships or empirical correlations that are derived from a particular set of experimental data, and therefore may not be valid in other systems due to differences in operating conditions. Therefore, in real operating conditions, individual cleaning quality parameters must be additionally monitored, for example, in the GPS-X system, the content of solid substances (TSS), dissolved oxygen and total nitrogen (TN) must be monitored.

The GPS-X program has built-in libraries of different types (Activated Sludge Model - ASM1, ASM2, ASM3, etc.), which can be selected depending on the initial parameters - the fractional and chemical composition of wastewater [28-29]. Disadvantages of ASM models include low accuracy, data requirements, and high uncertainty due to many assumptions.

Among artificial intelligence technologies, artificial neural networks (ANN), Fuzzy logic (FL), Machine learning algorithms (MLAs), support vector machines (SVM) and recurrent neural networks (RNN) have found the most application [30].

In addition to predictive models, deep neural networks (DNNs) and SVM technologies play an important role in wastewater treatment plant management to detect dangerous deviations from the normal operation of wastewater treatment plants [31], which can also prevent environmental risks and simplify the operational maintenance of wastewater treatment plants.

Hybrid predictive models, including physical models (such as ASM) and empirical knowledge, also dominate the reviewed publications and reviews. However, with established digital monitoring systems and the constant increase in the amount of available data, methods based on data analysis are becoming increasingly attractive. In models of this type, the structure of the wastewater treatment plant system is not explicitly specified, but is determined by searching for connections between available data [32].

One of the most significant disadvantages of these systems is the acquisition of a large data set necessary for building mathematical models and conducting predictive analysis. Some publications refer to literally decades of data collection for a full-fledged study [14]. Large data sets are needed to train AI. Real wastewater is used to test the models, and the lack of sensors to monitor the studied parameters of wastewater, flow, and other elements of digital monitoring can become a serious problem for the use of AI.

5 Conclusion

In recent years, computer models have become widespread as effective tools for managing wastewater treatment plants. For the purpose of predicting the operation of wastewater treatment plants, various deterministic, stochastic and time series models are used, which are used to monitor wastewater parameters and take preventive measures. Countries that are actively introducing artificial intelligence technologies into the practice of managing the operation of wastewater treatment plants include China, Iran and Saudi Arabia. In the context of agricultural holdings, future research appears to focus on developing hybrid computer models for wastewater treatment that combine physical and data-driven models. This approach will help improve the quality of treatment, environmental and economic efficiency of treatment facilities.

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