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A Systematic Survey on the Research of AI-predictive Models for Wastewater Treatment Processes

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ABSTRACT: *Context:* To increase the efficiency of wastewater treatment, modeling and optimization of pollutant removal processes are the best solutions. The relationship between input and output parameters in wastewater treatment processes (WWTP) is a complicated one, and it is difficult for designing models using statistics. Artificial Intelligence (AI) models are generally more flexible when compared with statistical models while modeling complex datasets with nonlinearity and missing data.

Objective: Studies on WWTP of AI-based are increasing day by day. Therefore, it is crucial to systematically review the AI techniques available which are implemented for WWTP. Such kind of review helps for classifying the techniques that are invented and helps to identify challenges as well as gaps for future studies. Lastly, can sort out the best AI technique to design predictive models for WWTP.

Method: With the help of the most relevant digital libraries, the total number of papers collected is 1222 which are based on AI modeling on WWTP. Then the filtration of the papers is mainly based on the inclusion and exclusion criteria. Also, to identify new relevant papers, snowballing is the other technique applied.

Results: Finally selected 76 primary papers to reach the result were published between 2004 and 2020.

Conclusion: ANN with MLP approach on BP algorithm become a supervised neural network called BPNN is the most used AI modeling for WWTP and around 40% of the experimental research done with BPNN. Then there are some limitations on AI modeling of WWTP using photoreforming which is the current study of WWTP represents a promising path for generating renewable and sustainable energy resources like chemicals and fuels.

Keywords: Systematic literature review, backpropagation neural network, support vector machine

1. INTRODUCTION

The awkward maintenance of the wastewater treatment plant can cause serious ecological and public health issues and it can be a chance for various waterborne diseases affecting human life and water nature [1-3]. Problems like groundwater contamination and Volatile Organic Compound (VOC) control must be forwarded to satisfy environmental laws and maintain a quality user image [4-6]. Extremely, during the operation of a wastewater treatment plant, for efficient monitoring of process performance, various control actions have to be executed [7]. Models are mandatory since the effects of adjusting the operating variables can be researched more briefly on a computer system than by doing experimentation. Thus, many optional designs and practical approaches can be calculated without the demand for real bench tests of each plot [8, 9]. By replicating the execution estimate models using proper prominent variables, one can promptly respond to any adjustments in the processes and devise operational strategies to shift the plant to new operating conditions. These new conditions improve the stability, and the quality of the effluent and can

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attain fewer running costs [10-12]. Then it leads to modeling as well as optimization and became a very important procedure in pollutant removal processes in wastewater treatment to increase their efficiency without increasing the cost [13-16].

It is tough to be designed using statistical models due to the complexity of the parameters used in Wastewater Treatment Processes (WWTP) [17]. Accordingly, Artificial intelligence (AI) models are generally flexible while modeling complex datasets, especially with possible nonlinearities or missing data [18, 19]. AI can be used as an important tool in the experimental design that can generate suitable variables for the modeling as well as optimization of pollutants removal efficiency [20, 21]. AI has achieved a boundless establish in various areas [22] such as big data [23], pattern recognition [24], image understanding [25], robotics [26], intelligent search engines [27], automatic programming [28], autonomous driving [29, 30] and human-computer games [31]. AI technology manages the design of cyber security systems [32, 33] and programs that are adequate to imitate human features such as problem-solving, learning, perception, reasoning, and experiences from surroundings [34, 35].

There are a lot of AI techniques available now and the problem is to find out which one is the best for making predictive models in WWTP. Therefore, the main aim of this review work is to sort out the AI technique suitable to design predictive models for WWTP. For this, we have systematically identified and reviewed 76 papers targeting WWTP modeling with AI-based and analyzed the data retrieved from those papers to find the answer to three research questions. The research questions addressed by this study are:

- Research Question 1 (RQ1): How much of studies done on AI modeling for WWTP from 2004 until 2020?
- Research Question 2 (RQ2): Which AI techniques are more used for the implementation of WWTP modeling?
- Research Question 3 (RQ3): What are the limitations of the current research?

According to RQ1, we considered the articles which are published in 2004. From that time onwards, the publications were more on the topic of the implementation of AI in WWTP. Then we look through AI techniques that are more used for the implementation of WWTP modeling concerning RQ2 and finally go through the limitations of the current research based on RQ3.

The remaining content of the paper is organized as follows: Section 2 describes Systematic Literature Review (SLR) methods. The results of the research questions are discussed in Section 3. Finally, Section 4 concludes the study with future scope.

2. METHOD USED FOR SYSTEMATIC REVIEW

Our systematic research method consists of mainly four sections – Strategy of searching, admittance and elimination criteria, selection process flow, and data extraction.

2.1 STRATEGY OF SEARCHING

The strategy of searching has been divided as Population, Intervention, Outcome, and Context (in short PIOC) are the criteria to define search terms. Therefore, in this Systematic Literature Review (SLR),

- The population should be an application area such as general WWTP or specific WWTP (e.g., Petroleum Wastewater Treatment) otherwise Wastewater industry or Water industry or else Wastewater treatment plant.
- The intervention is methodology, tools, and techniques that address AI modeling or Machine Learning (ML) modeling.
- The outcome is the prediction of data for improving the performance of WWTP.
- The context is the AI or ML-based neural network, regression, and ensemble learning techniques.

Mainly three digital libraries have been used for searching papers namely – Google Scholar, ScienceDirect, and Microsoft Academic. Search terms are used to run a trial search and authenticate the applicability of the subsequent papers. Then the search string has been revised to form the final search terms as well as the combination of synonyms and related terms was the final search terms.

2.2 ADMITTANCE AND ELIMINATION CRITERIA

Mainly, three admittance criteria have been set to restrict the application domain, context, and outcome type. Then, some papers have eliminated that were not peer-reviewed like keynotes, books, and dissertations, and the papers that were not written in English. Also, we searched the papers only from previously mentioned digital libraries based on admittance and elimination criteria.

2.3 SELECTION PROCESS FLOW

The papers from January 2004 to December 2020 have been covered and filtering the papers have done by using admittance and elimination criteria by the following steps.

Stage 1: A total of 1222 papers have retrieved by running the search string on 4 digital libraries and got 916 papers after removing the irrelevant papers.

Stage 2: Eliminated studies have been done by checking titles and keywords. Some papers were kept for rechecking if they were not eliminated simply by reading titles and keywords. At the end of this stage, 298 papers were selected.

Stage 3: In this stage, 151 quality papers were identified with high relevance to the research goal of our SLR by filtering the papers by reading abstracts.

Stage 4: The reasons for exclusion for each eliminated paper has recorded and this selection decision has been made by reading the introduction and conclusion. The irrelevant papers, or whose full texts were not available were eliminated. Moreover, the quality of primary studies was critically examined, and 29 papers excluded those which having lacked sufficient information.

Stage 5: From the fifth stage, the snowballing process has been implemented which is in two directions: backward and forwards. In a backward direction, scan the references of a selected paper and find any other relevant papers published before the selected paper. Similarly, in the case of forward direction, checking the other relevant paper was published after the selected paper and cited it. This SLR, mainly used forward snowballing to include additional papers and found 47 new relevant papers from snowballing. Concluded with 76 papers as initial studies for detailed examination as well as sorting all the chosen studies in Table 1.

Table 1. – Selected studies sorted based on the publication year

References	Type of articles	Year	Publication venue
[36]	Research	2020	Journal of Cleaner Production
[37]	Research	2020	Chemical Engineering Journal
[38]	Research	2020	Process Safety and Environmental Protection
[39]	Book chapter	2020	Bioremediation for Environmental Sustainability
[40]	Book chapter	2020	Computer Aided Chemical Engineering
[41]	Research	2020	Environmental Technology & Innovation
[42]	Review	2020	Journal of Hydrology
[43]	Research	2020	Water Research
[44]	Review	2020	Process Safety and Environmental Protection
[45]	Research	2020	Science of The Total Environment
[46]	Research	2020	Process Safety and Environmental Protection
[47]	Research	2020	Journal of Contaminant Hydrology
[48]	Review	2020	Separation and Purification Technology
[49]	Research	2020	Computers & Electrical Engineering
[50]	Review	2020	Journal of Cleaner Production
[51]	Research	2020	Chemosphere
[52]	Research	2020	Biochemical Engineering Journal
[53]	Research	2020	Groundwater for Sustainable Development
[54]	Research	2020	Journal of Environmental Chemical Engineering
[55]	Research	2020	Chemosphere
[56]	Research	2020	Journal of Cleaner Production
[57]	Research	2020	Science of The Total Environment
[58]	Research	2020	Journal of Environmental Management
[59]	Research	2020	Water Research
[60]	Research	2020	Process Safety and Environmental Protection

[61]	Research	2020	Environmental Research
[20]	Review	2019	Process Safety and Environmental Protection
[62]	Review	2019	Journal of Cleaner Production
[63]	Research	2019	Journal of Water Process Engineering
[64]	Book chapter	2019	Stochastic Global Optimization Methods and Applications to Chemical, Biochemical, Pharmaceutical and Environmental Processes
[65]	Review	2019	Desalination
[66]	Book chapter	2019	Artificial Neural Networks for Engineering Applications
[67]	Review	2019	Process Safety and Environmental Protection
[68]	Research	2019	Journal of Water Process Engineering
[69]	Review	2019	Journal of Cleaner Production
[70]	Research	2019	Journal of Environmental Management
[71]	Research	2019	Chemosphere
[72]	Research	2019	Measurement
[73]	Research	2019	Journal of Hydrology
[74]	Research	2019	Resources, Conservation and Recycling
[75]	Research	2019	Journal of Water Process Engineering
[76]	Research	2019	Journal of Molecular Liquids
[22]	Review	2018	Chemosphere
[77]	Book chapter	2018	Computer Aided Chemical Engineering
[78]	Research	2018	Minerals Engineering
[79]	Research	2018	Journal of Cleaner Production
[80]	Research	2018	Journal of Process Control
[81]	Research	2018	Science of The Total Environment
[82]	Research	2018	Chemical Engineering Journal
[83]	Conference	2017	Procedia Computer Science
[84]	Research	2017	Expert Systems with Applications
[85]	Research	2016	Journal of Environmental Chemical Engineering
[86]	Research	2016	Expert Systems with Applications
[87]	Research	2016	Engineering Applications of Artificial Intelligence
[88]	Conference	2013	IFAC Proceedings Volumes
[89]	Research	2013	Environmental Modelling & Software
[90]	Research	2012	Expert Systems with Applications
[91]	Research	2012	Environmental Modelling & Software
[92]	Conference	2011	Procedia Engineering
[93]	Research	2011	Applied Soft Computing
[94]	Editorial	2010	Environmental Modelling & Software
[95]	Research	2010	Environmental Modelling & Software
[96]	Research	2010	Journal of Hazardous Materials
[97]	Research	2010	Journal of Environmental Sciences
[98]	Research	2010	Environmental Modelling & Software
[99]	Research	2009	Environmental Modelling & Software
[100]	Research	2009	Expert Systems with Applications
[101]	Research	2009	Expert Systems with Applications
[102]	Research	2008	Journal of Hazardous Materials
[103]	Research	2008	Computers & Chemical Engineering
[104]	Research	2008	Expert Systems with Applications

[105]	Conference	2006	IFAC Proceedings Volumes
[106]	Review	2006	Marine Pollution Bulletin
[107]	Review	2006	Journal of Environmental Management
[108]	Review	2004	Environmental Modelling & Software
[109]	Research	2004	Environmental Modelling & Software

2.4 DATA EXTRACTION

We extracted two kinds of information for statistical analysis like publication year and research type for answering RQ1 from the selected papers. Then, key features such as research goal, major contribution, and limitation for answering RQ2 and RQ3 have been identified by collecting information.

3. RESULTS, DISCUSSIONS, AND FINDINGS

3.1 RQ1. How much of studies done on AI modeling for WWTP from 2004 until 2020?

Fig. 1 shows the distribution of primarily retrieved papers based on publication year as well as the types of work by using four digital libraries. There have been so many papers published from 2004 until 2020. In that, research articles were the most published around 55.3%, and review articles around 14.8%. Also, book chapters, editorials, short communication, and others were published in 12.7%, 1.2%, 1.2%, and 14.7% respectively.

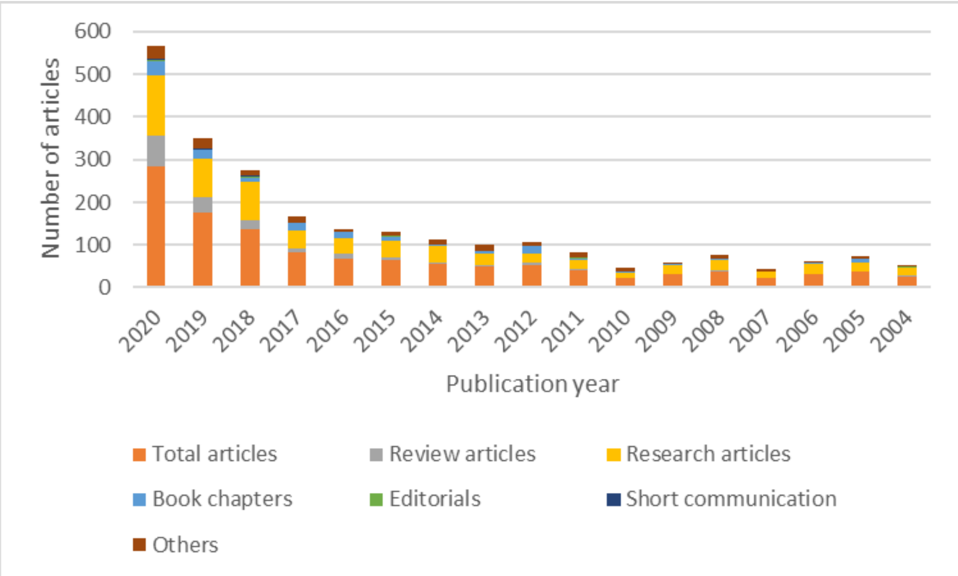

FIGURE 1. – Initial collection of selected papers from digital libraries

As already mentioned that after the 5 stages of the selection process flow, we have selected 76 relevant papers have been classified according to the type of articles and it is shown in Fig. 2. Same as before, this time also we have classified the papers as Review articles, Research articles, Book chapters, Editorials, Short communication, and others. These were published in 17.1%, 69.7%, 6.5%, 1.3%, 0%, and 5.3% respectively. This represents those researchers showing more consideration the experimental research works than any other type of work. Therefore, the application level of WWTP with AI modeling has a very wide scope at present and in the future too.

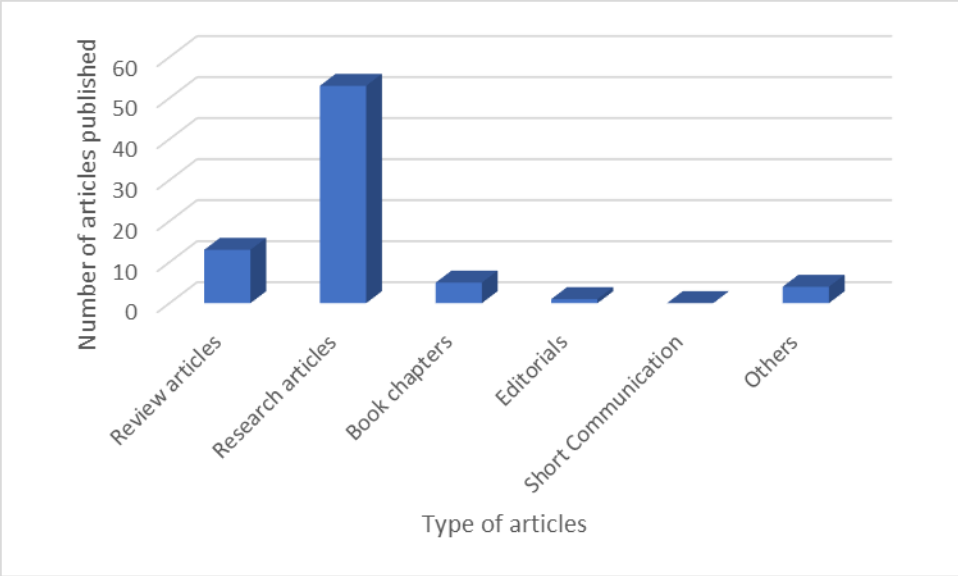

FIGURE 2. – Final classification of relevant papers from 2004 to 2020

3.2 RQ2. Which AI techniques are more used for the implementation of WWTP modeling?

As per the articles reviewed, Artificial Neural Network (ANN) with multilayer perceptron (MLP) leads to Backpropagation Neural Network (BPNN), a supervised neural network is a technique mostly used in AI modeling of WWTP. Around 40% of the work goes with BPNN from the initial stage and still, this technique is used by an ensemble with other methods. These models can learn complex model functions as well as accord with a great deal of information and this is the greatest advantage of BPNN over other techniques especially going through non-linear processes without having to estimate the form of the relationship between training datasets of input and output variables.

Then, Support Vector Machine (SVM) is the next technique used in AI modeling of WWTP after BPNN by an ensemble with other AI techniques as per the literature study of this work. The main advantage of SVM is that it can use for both classifications as well as regression, especially in the case of non-linear data. Anyhow the data collected for WWTP should be real-time data and the real-time data may be nonlinear. In such cases, the performance of BPNN may affect rarely and it can be overcome by the implementation of SVM. While in the case of efficiency and robustness, BPNN shows better performance than any other AI technique.

3.3 RQ3. What are the limitations of current research?

AI offers reliable solutions to solve practical problems which are common in many engineering disciplines including wastewater treatment. Some technologies existing for wastewater treatment are Advanced oxidation processes, Coagulation and flocculation, Membrane filtration, Adsorption process, biological process, and Integrated method. Photoreforming [110] is the latest study in WWTP, and it is in its initial stage. Therefore, AI modeling of WWTP using photoreforming parameters is the ultimate new research going on and this is the limitation of the current study [111]. Photoreforming can be considered a promising approach to producing renewable as well as sustainable chemicals and fuels [112]. The increasing number of research focuses on selectively obtaining precious chemicals as well as high-quality fuels with the help of photoreforming. A potential worldwide crisis with the quick development of the industry worldwide has arisen due to the issues of continuously intensifying environmental pollution and health disorders. Uncertainly, it is required to develop a standard and efficient technique to face these current situations.

4. CONCLUSIONS AND FUTURE WORK

The main aim of the systematic review was to sort out the best AI technique to design predictive models for WWTP. To achieve this, the results of an SLR of existing ideas as well as practices on PIOC methods have been presented for ML-based prediction techniques for AI modeling of WWTP. A total of 76 papers that were published between 2004 and 2020 were selected based on pre-defined inclusion and exclusion criteria. A systematic review analysis and synthesis of the data extracted from the finalized papers as well as comprehensive reviews of industry practices related to our Research Questions were performed. The results of the study have mentioned below:

- As per Fig 1, the greatest number of publications have reported in the year 2020 from the initial collection and 55.3% of the publications were research articles. Later by the different stages of search strategies, 69.7% of the publications were the research articles from the final 76 papers shown in Fig 2. Through this analysis, we understood that researchers are giving more attention to experimental research works than any other type of work, and the application level of AI modeling of WWTP has a great scope.

- ANN with MLP approach with BP algorithm become a supervised neural network called BPNN is the most used predictive technique for AI modeling of WWTP. Around 40% of the experimental research was done with BPNN and now this technique is implemented by an ensemble with other AI techniques.

- Photoreforming is the current study in WWTP having some limitations on AI modeling of WWTP using photoreforming parameters. It represents a dedicated footstep for generating renewable and sustainable chemicals and fuels.

This systematic survey is just the beginning of our studies for analyzing which predictive technique is the best one suitable for AI modeling of WWTP and concluded with ANNs. Next time, the focus is to improve the interpretability of ANNs by preparing an analysis for explaining why an ANN model is more robust than other models.

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Conflict of Interest

Authors declares no conflict of interest

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