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RESEARCH

Improving wastewater treatment plant performance: an ANN-based predictive model for managing average daily overflow and resource allocation optimization using Tabu search

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Abstract
The effective management of wastewater treatment facilities is of paramount importance to safeguard the environment and ensure the well-being of the general public. This research paper presents a novel approach utilizing an artificial neural network (ANN) as a predictive model to enhance the precision of estimating the average daily overflow in wastewater treatment plants. In addition, the study aims to optimize the allocation of resources at these plants. The effectiveness of the model was assessed by employing various metrics, including root mean square error (RMSE), mean squared error (MSE), mean absolute error (MAE), and R-squared (R^2). The examination of various neural network topologies demonstrated that higher numbers of layers resulted in improved accuracy and precision. However, additional research is required to reduce prediction errors and improve the model's ability to explain phenomena, thus making it more suitable for practical application. The validation of these models in operational settings necessitates the undertaking of fieldwork, establishing collaborations with industry stakeholders, and actively engaging with policymakers. The integration of real-time data and advanced neural network methodologies has the potential to significantly improve both the accuracy and flexibility of the system. To enhance the progress of sustainable wastewater management, it is crucial to broaden the scope of performance indicators beyond the conventional measures of average daily overflow and resource allocation. This study establishes a theoretical framework for enhancing the efficacy of wastewater treatment facilities and advocating for environmentally conscious practices.

Keywords Wastewater treatment · Average daily overflow · Resource allocation optimization · Artificial neural network (ANN) · Tabu search · Performance evaluation

Introduction

The management of wastewater has grown to be a major environmental problem as a result of the fast urbanization process and the ongoing rise of the world's population. Wastewater production from a variety of sources, including the residential, industrial, and agricultural sectors, has increased significantly as a consequence of the development of urban areas and the ensuing population growth (Qiu et al., 2021). By treating and purifying wastewater, wastewater treatment facilities play a crucial part in resolving this issue and ensuring ecosystem preservation as well as public health protection (Ghani & Mahmood, 2023; Nuamah et al., 2020; Elbasiouny et al., 2021; Jaradat et al., 2021).

Treatment plants utilize a range of processes and technologies to effectively eliminate pollutants and contaminants, thereby guaranteeing that the discharged effluent adheres to the prescribed quality standards (Chen et al., 2022). Nevertheless, the effective and dependable functioning of wastewater treatment facilities continues to pose a substantial obstacle (Wang et al., 2022a, 2022b). One of the key challenges encountered by wastewater treatment facilities pertains to the prevalence of average daily overflow occurrences (Dirckx et al., 2022). These incidents pertain to scenarios wherein the wastewater treatment facility is incapable of managing the influx of wastewater, resulting in the release of either untreated or partially treated wastewater into adjacent bodies of water (Ofrydopoulou et al., 2022).

There are multiple reasons why average daily overflows hurt both the environment and human health (Jagai et al.,

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2017; Semadeni-Davies et al., 2008). To begin with, the release of untreated wastewater into natural bodies of water introduces a range of detrimental pollutants, such as pathogens, heavy metals, and organic compounds. The presence of these pollutants can result in detrimental impacts on aquatic organisms, the contamination of sources of drinking water, and the disturbance of ecological equilibrium (Sojobi & Zayed, 2022). In addition, since wastewater treatment facilities are required to adhere to predetermined discharge limits set by environmental regulatory bodies, the occurrence of daily overflow incidents raises regulatory compliance concerns (Bunce & Graham, 2019; Oliveira & Von Sperling, 2008).

The presence of daily overflows can be attributed to the dynamic characteristics of inflow rates into the treatment facilities. The rates of inflow can exhibit substantial fluctuations due to a range of factors, encompassing meteorological conditions, population concentration, industrial operations, and temporal variations (Zhou et al., 2023). For example, the occurrence of intense precipitation events or abrupt increases in water consumption can give rise to a substantial influx of wastewater into the treatment facility, surpassing its operational capacity and resulting in instances of overflow (Hassan et al., 2022). To proficiently handle routine occurrences of excessive inflow, operators of wastewater treatment plants are assigned the responsibility of accurately forecasting and controlling these fluctuations in inflow rates (Alali et al., 2023; Khorram & Jehbez, 2023). By implementing predictive models and strategic approaches, operators can proactively modify treatment processes and allocate resources to mitigate overflows and optimize plant performance (Pandey et al., 2022).

The effective distribution of resources within wastewater treatment plants is crucial for optimizing their overall performance, in addition to the management of average daily overflow (Tao et al., 2020). To achieve efficient operation and minimize operational costs, it is imperative to distribute resources essential for wastewater treatment, including energy, chemicals, and personnel, optimally (Ramos et al., 2022). Nevertheless, the task of determining the most efficient allocation of resources in the wastewater treatment process is a challenging endeavor due to the inherent uncertainties that are inherently associated with it (Pahl-Wostl et al., 2020).

The influential characteristics of a system, such as the composition and concentration of pollutants, exhibit significant temporal variability, which presents difficulties in accurately determining the specific resource needs (Yusuf et al., 2022). In addition, the presence of operational constraints, including limitations in equipment capabilities and adherence to regulatory guidelines, adds further complexity to the process of making resource allocation decisions. To make wastewater treatment procedures as efficient and cost-effective as possible (Ahmed et al., 2022; Chai et al., 2021), it is very important to find the best balance between how resources are used and how well treatment works.

To tackle these obstacles, this study introduces a novel methodology that integrates artificial neural networks (ANN) and Tabu search to construct a predictive model that can effectively handle average daily overflow incidents and optimize resource allocation in wastewater treatment facilities. The artificial neural network (ANN) model is trained using historical data about influent characteristics, operational parameters, and overflow events. Through the utilization of the predictive capabilities offered by artificial neural networks (ANN), the model can make forecasts regarding variations in inflow. This enables proactive adjustments to be made in resource allocation, thereby preventing the occurrence of average daily overflows.

In addition, the utilization of Tabu search, a metaheuristic optimization algorithm, is implemented to optimize the allocation of resources within the treatment facility. Tabu search is a methodology that aids in the identification of resource allocation strategies that minimize operational costs and simultaneously adhere to effluent quality standards. This is achieved through an iterative exploration of the solution space and careful consideration of competing objectives. The utilization of an artificial neural network (ANN)-based predictive model, in conjunction with the Tabu search optimization framework, presents a potentially effective approach for improving the operational efficiency of wastewater treatment facilities. This approach endeavors to enhance the efficiency, reliability, and sustainability of wastewater treatment processes by proficiently managing average daily overflow incidents and optimizing resource allocation.

Methodology

This paper outlines our approach and the methodologies employed in "Methodology" section. The following sections provide a detailed explanation of data gathering, data preparation, feature selection, Tabu search optimization, and the utilization of an artificial neural network (ANN) model. The approach employed by this technique adopts a holistic framework to address the challenges associated with managing daily overflow and optimizing resource allocation. This is achieved through the integration of data-driven methodologies, optimization algorithms, and predictive modeling. The primary objective of this research is to employ these techniques to enhance the productivity and decision-making capabilities of wastewater treatment plants, thereby fostering improved environmental sustainability and resource management.

Data collection

The present study utilized a dataset obtained from an ongoing wastewater treatment facility, which has consistently collected data on various factors pertinent to the wastewater treatment processes. The dataset exhibits significant relevance to the research objective of optimizing resource allocation and improving the performance of wastewater treatment plants (Bagherzadeh et al., 2021). The dataset incorporates both internal and external factors as potential variables that may contribute to the daily average overflow of the treatment plant. The dataset contains various types of variables, which can be exemplified in Table 1.

The comprehension of wastewater treatment processes and the impact of external environmental factors on plant performance is significantly enhanced by the consideration of these variables. The enhancement of management and resource allocation at the treatment plant can be achieved through the development of a predictive model that utilizes the correlations between various factors and the average daily overflow.

Data preprocessing

Before conducting the analysis and modeling, the raw dataset underwent a series of preprocessing procedures to ensure the quality and compatibility of the data. The aforementioned procedures were executed as shown in Fig. 1:

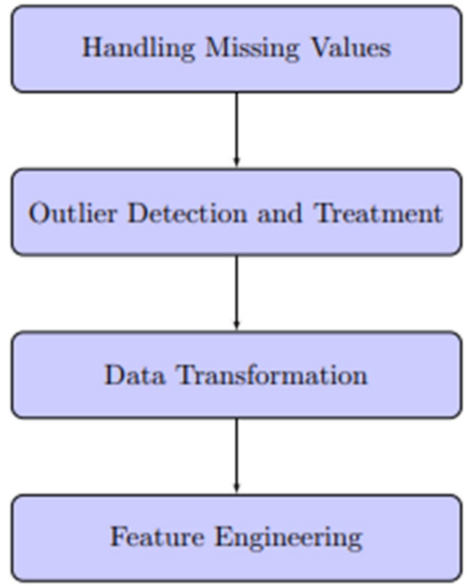


Fig. 1 Data preprocessing flowchart

Handling missing values

The dataset was first examined for any instances of missing values. Any instances of missing values were addressed using suitable methodologies. Various techniques, such as imputation methods (e.g., mean, median, or regression-based imputation) or elimination of incomplete records,

Table 1 Description of variables

Variable	Description
avg_inflow	Average daily inflow rate of wastewater into the treatment plant
total_grid	Total electricity consumption from the grid for plant operations
Am	Ammonia concentration in the influent
BOD	Biochemical oxygen demand (BOD) level of the wastewater
COD	Chemical oxygen demand (COD) level of the wastewater
TN	Total nitrogen (TN) concentration in the influent
T	The ambient temperature at the treatment plant location
TM	The maximum temperature during the day
Tm	Minimum temperature during the day
SLP	Atmospheric pressure (sea level pressure)
H	Average relative humidity
PP	Total daily precipitation
VV	Average visibility
V	Average wind speed
VM	Maximum wind speed during the day
VG	Maximum gust speed during the day
Year	Year of data collection
Month	The month of data collection
Day	Day of data collection

were utilized to handle missing values to minimize data loss (Sibiya et al., 2022; Varkeshi et al., 2019).

Outlier detection and treatment

The researchers employed suitable statistical techniques, including the Z-score and the interquartile range, to detect outliers, which can significantly impact the research and modeling procedures. To address the presence of outliers, researchers commonly employ two approaches: the removal of anomalous data points or the application of data transformation techniques such as winsorization and capping (Ranade et al., 2021).

Data transformation

Data transformation techniques were employed to enhance comparability and facilitate the interpretation of the data. Techniques such as Min–Max scaling and Z-score standardization were employed to standardize and scale the numerical variables, as exemplified. The normalization of data is performed to enhance the comparability of the data and facilitate the convergence of models (Pisa et al., 2019).

Feature engineering

Several new traits were generated based on prior domain knowledge or exploratory analysis. The target variable in this study is the average daily overflow. To account for temporal patterns or historical trends that may impact the overflow, additional variables were introduced (Kang et al., 2020).

The dataset underwent a process of cleaning, during which outliers were removed, and variables were transformed into a form that is suitable for analytical purposes. These steps, known as data pretreatment, were performed. These procedures ensure the veracity and comprehensiveness of the data, establishing the foundation for accurate modeling and insightful conclusions.

Feature selection

A predictive wastewater treatment plant performance model relies on feature selection. Selecting and prioritizing data items pertinent to the daily average overflow is the method. The steps for feature selection were as shown in Fig. 2:

To minimize dataset dimensionality and enhance interpretability, overfitting mitigation, and generalization improvement, Wang et al., 2022a, 2022b emphasize the importance of feature selection. In light of this, our research focuses on average daily overflow and aims to identify strongly correlated features. Understanding the factors contributing to wastewater treatment facility overflows is facilitated by these additional insights from Ganguly and Das (2022).

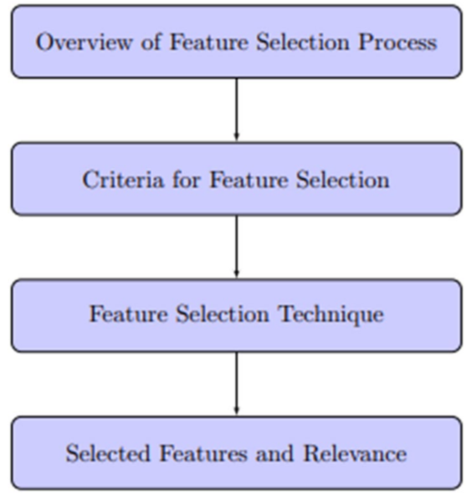


Fig. 2 Feature selection flowchart

The feature selection process in this study utilized the SelectKBest method along with the f_regression score function. This approach employs the F-value to assess the association between each independent variable and the dependent variable. A higher *F*-value indicates a stronger relationship between a feature and the dependent variable. Therefore, our goal is to identify the parameters that accurately predict daily average overflow. Building upon prior research recommendations (Huggi & Mise, 2019; Jawad et al., 2021), we will select the top K attributes based on their *F* values.

Key features: SelectKBest identified a group of attributes with high *F* values and statistical significance. These parameters directly affect wastewater treatment facility overflow projections. These features allow us to concentrate on the most important elements affecting overflow levels, improving forecasts and resource allocation.

Tabu search optimization

To address complex optimization problems, numerous disciplines have resorted to employing Tabu search, which is a metaheuristic optimization algorithm. This study employs Tabu search as a method for optimizing feature selection, aiming to identify the most valuable set of attributes for predicting daily overflow in wastewater treatment plants. The following details outline the specific methodology employed in utilizing Tabu search for refining feature selection.

The Tabu search algorithm is a metaheuristic optimization technique that is commonly used to solve combinatorial optimization problems. It is based on the concept of maintaining a tab A Comprehensive Overview Tabu search is an algorithm for heuristic search that relies on memory-based techniques. The algorithm effectively prevents revisiting previously explored solutions through the utilization of a Tabu list, which serves as a mechanism for tracking the solutions that have already been examined. Tabu search demonstrates the capability to efficiently explore various regions within the solution space while circumventing the issue of becoming trapped in local optima. This is achieved through the utilization of its memory mechanism, as highlighted by Kaveh, (2014), Kaveh and Khalegi, (1998), and Al Khazaleh and Bisharah, (2023a, 2023b). The present study employs Tabu search as a means to optimize the feature selection process. The Tabu search algorithm employs an iterative approach to evaluate various subsets of features, intending to predict average daily overflow. This is achieved by formulating the feature selection problem as an optimization problem. The utilization of Tabu search's algorithms for neighborhood exploration and memory management facilitates the identification of valuable feature subsets that contribute to the improvement of model accuracy and interpretability. A Synopsis of the Approaches Employed in the Discovery of Tabu search is an iterative methodology that explores the solution space to identify the most optimal subsets of features. The approach generates novel prospective solutions by making incremental adjustments to the existing ones, while concurrently conducting an iterative exploration of the vicinity surrounding the present solution. The inclusion of cycling as a discouraged activity and the promotion of novel discoveries within the taboo list serve to prevent the reexamination of previously explored solutions. The Tabu search algorithm is utilized to optimize the search for feature subsets of superior quality by effectively managing the trade-off between exploration and exploitation (Al Khazaleh & Bisharah, 2023a, 2023b; Kaveh & Khavaninzadeh, 2023).

The parameters and settings for Tabu search optimization: the performance of Tabu search is heavily influenced by the optimization settings and parameters. The tabu list size determines the number of recent solutions that are retained in memory, while the termination of the algorithm is determined by the number of iterations. The requirements of the feature selection problem can guide in selecting other settings to explore, such as aspiration criteria or intensification-diversification procedures (Kaveh & Servati, 2001; Kaveh et al., 2008). Tabu search is an optimization methodology that enables the efficient exploration of the feature space, facilitating the identification of the most effective predictors of average daily treatment (ADT) in wastewater treatment facilities. The integration of Tabu search with feature selection enhances the precision, comprehensibility, and applicability of the model.

Artificial neural network (ANN) model

This study utilizes a robust artificial neural network (ANN) model to predict the daily average overflow in wastewater treatment facilities. The employed artificial neural network (ANN) architecture consists of multiple layers, wherein each layer carries out distinct computations to effectively capture the intricate interactions within the data. The subsequent section provides an overview of the model's architecture, activation functions employed, and optimization parameters utilized (Al Khazaleh & Bisharah, 2023a, 2023b; Al Yamani et al., 2023).

This context defines ANN architecture as the structural organization and configuration of linked artificial neurons (Arabiat et al., 2023). A feedforward artificial neural network (ANN) model with input, hidden, and output layers was used in this investigation. Context and data determine layer depth and neuron count. The architectural design extracts important representations and patterns from incoming data to estimate the normal daily overflow (Alsulaili & Refaie, 2021). Neural network activation functions and layers are discussed. The hidden layers of the artificial neural network (ANN) model use the rectified linear unit (ReLU) activation function because it handles non-linear correlations well. Due to its non-linearity, the rectified linear unit (ReLU) has helped the network analyze complicated data patterns. The output layer generates continuous output values using a linear activation function to predict the daily average overflow, according to Golzar et al. (2020). This study examines model compilation and optimization methods. The ANN model is compiled using the popular 'Adam' optimizer for training artificial neural networks (ANNs) (see Fig. 3). The mean squared error (MSE) loss function evaluates how much the observed daily overflow statistics depart

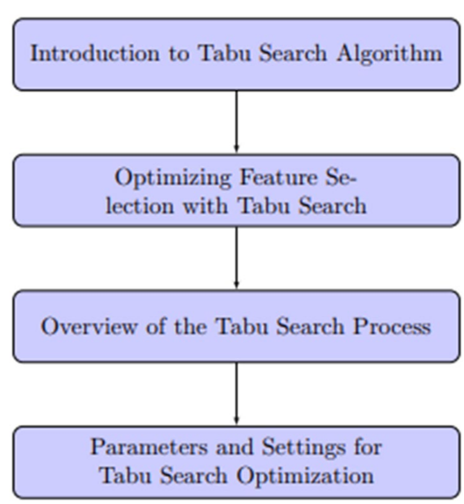


Fig. 3 Tabu search optimization flowchart

from the projected values. The 'Adam' optimizer adapts the training rate to achieve optimum convergence. Experiments and model performance assessments define optimization parameters such as learning rate and batch size (Zhao et al., 2020).

The objective of our study is to achieve a precise estimation of the mean daily overflow in wastewater treatment plants. This will be accomplished through the utilization of an artificial neural network (ANN) model, which will be designed with appropriate architecture, activation functions, and optimization parameters. The purpose of incorporating these elements is to effectively capture the intricate relationships between the input data and the target variable.

Model training and evaluation

The built artificial neural network (ANN) model is trained and evaluated to guarantee its wastewater treatment facility's daily average overflow estimates are accurate. This section describes how the model was trained and how its output was evaluated. A dataset is used to optimize a model's parameters and performance during training. The preprocessed dataset is used to train the artificial neural network (ANN) model using the selected features. The dataset is split into training and validation sets to track model progress. Backpropagation and a loss function like mean squared error is used to repeatedly modify model weights and biases during model training. The model reduces loss function and improves daily average overflow forecasts (Asami et al., 2021).

Rating models: Models are evaluated using numerous measures. These measurements quantify accuracy, precision, recall, and the trained artificial neural network (ANN) model is assessed using many metrics. These metrics may evaluate the model's precision, accuracy, and generalization to new data. Common criteria are used to assess regression project performance.

RMSE is used to assess prediction accuracy mistakes. Lower values imply higher model accuracy (Sharghi et al., 2019). The mean squared error (MSE) measures the average squared mistakes in a forecast. Ofman and Struk-Sokoowska (2019) say a reduced mean error between prediction and observation indicates better performance. MAE is the arithmetic mean of the absolute discrepancies between planned and actual values. Khatri et al.'s (2020) measure is suggested for model predictive performance evaluation. Square ratio. R^2 measures the model's ability to explain the dependent variable's variation. Pisa et al. (2020) state that data representation accuracy increases as values approach 1. These criteria may examine the ANN model's ability to forecast daily average overflow. These metrics show the model's ability to capture patterns and anticipate unknown data.

Results and analysis

The analysis and results section describes the results of using the artificial neural network (ANN)-based prediction model to regulate daily average overflow and optimize wastewater treatment facility resource allocation. This part evaluates the model, its characteristics, and Tabu search optimization. The results and their implications for resource allocation decision-making are given and analyzed. This section discusses the feasibility and benefits of using an artificial neural network (ANN) model with feature selection and Tabu search optimization to improve wastewater treatment plant performance and resource management. The model's predictions and assessment measures provide this information.

Descriptive analysis of the dataset

This section provides a detailed descriptive analysis of the dataset used in "improving wastewater treatment plant performance: an ANN-based predictive model for managing average daily overflow and resource allocation optimization using Tabu search." The dataset contains 1382 occurrences with 20 columns of significant information that may affect wastewater treatment facility average daily outflow.

As shown in Fig. 4, the dataset has 1382 non-null columns and no missing values. The dataset has 15 floating-point and 5 integer columns. The dataset uses around 216.1 KB. Dataset summary statistics provide feature distribution and attributes. The average outflow is 3.93, with a standard variation of 1.23. Inflow averages 4.51, with a standard deviation of 1.44. 116,638 to 398,328 is the grid value, with a mean of 275,159 and a standard deviation of 44,640. Am, BOD, COD, and TN also differ. Am has a mean of 39.22 and a standard deviation of 7.76. BOD, COD, and TN average 382.06, 845.96, and 62.74. These characteristics affect wastewater treatment plant performance and must be considered for accurate projections.

Temperature, maximum temperature, lowest temperature, sea level pressure, humidity, precipitation, visibility, wind speed, maximum wind speed, and gust speed vary over the dataset. These factors' ranges and distribution patterns might affect wastewater treatment plant performance and overflow prediction. The dataset covers 2014–2019 with monthly and daily entries. The year column helps analyze trends and seasonal patterns that may affect wastewater treatment facility performance.

The correlation heatmap (Fig. 5) may help explain wastewater treatment plant performance factors. This heatmap shows dataset feature connections. Color gradients in the heatmap show pairwise correlation magnitude

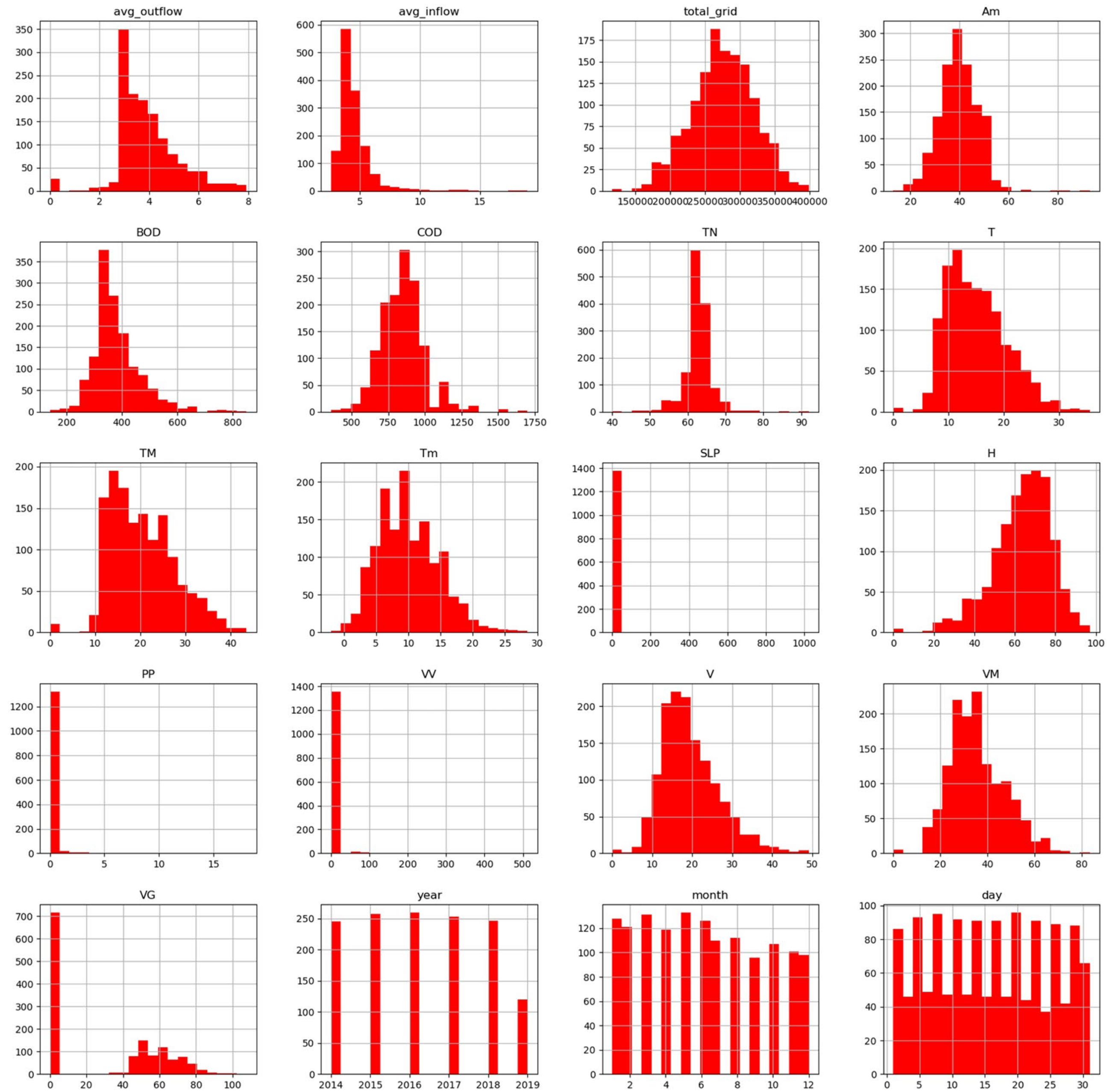


Fig. 4 Descriptive analysis of the dataset

and direction. The heatmap helps assess variables affecting daily overflow averages and optimize resource usage. The average outflow, inflow, and grid values are positively correlated. This research shows a positive association between average inflow and total grid value, indicating that increasing input increases outflow. The wastewater treatment facility's expected effluent discharge matches the influent-grid correlation. Understanding this association is essential for overflow management and forecasting. NH4 + , BOD, COD, and TN positively correlate with average outflow. These results show that these factors enhance average outflow. These variables predict and manage daily mean overflow and affect wastewater treatment.

When using artificial neural networks (ANNs) to forecast wastewater treatment plant performance, these relationships must be considered. Average inflow, total grid value, and critical water quality variables affect the predictive model's average daily overflow estimate. This study's correlation analysis lays the groundwork for future ANN model research to improve wastewater treatment plant efficiency and resource allocation.

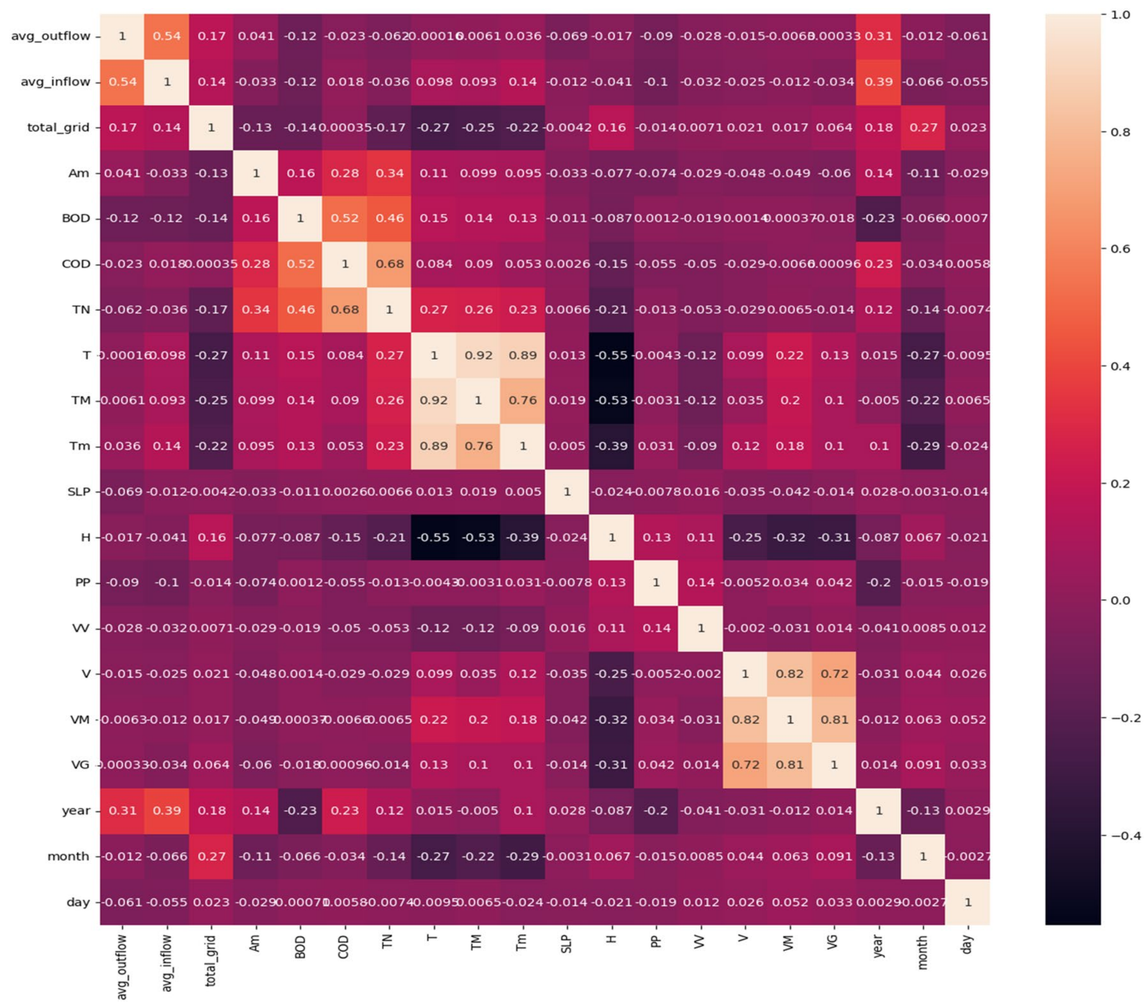


Fig. 5 Correlation heatmap

The scatter plot in Fig. 6 shows the relationship between average daily overflow and resource allocation optimization. This visualization shows how these factors are interdependent and may help wastewater treatment facilities function better.

The scatter figure shows a positive association between resource allocation and mean daily overflow. As resource allocation optimization improves, overflow incidents occur daily. This research found that equipment, chemicals, and operating methods affect wastewater treatment facility overflow levels. Understanding and optimizing this connection is crucial for wastewater treatment operations management and control. The scatter pattern illustrates different wastewater treatment plant operating circumstances. An artificial neural network (ANN) generated prediction model is needed due to the system's complexity and diversity. The ANN model reflects the intricate linkages and interdependencies between resource allocation optimization and average daily overflow. Using scatter plot analysis expertise does this. This predictive model may improve wastewater treatment plant efficiency, reduce overflows, and provide other advantages.

The complex dynamics of average daily overflow and resource allocation optimization may be visualized using a scatter plot. This study lays the groundwork for future optimization methods like Tabu search. These methods may improve resource allocation and wastewater treatment efficiency. These technologies optimize wastewater treatment by reducing overflows and maximizing resource use.

Feature selection results

As a component of the research, a feature selection procedure was conducted, leading to the identification of a set of essential features that significantly contribute to the forecasting of daily average overflow and the optimization of resource allocation in wastewater treatment facilities. The features that have been chosen, namely 'avg_inflow', 'total_grid', 'Am', 'BOD', 'TN', 'Tm', 'SLP', 'PP', 'year',

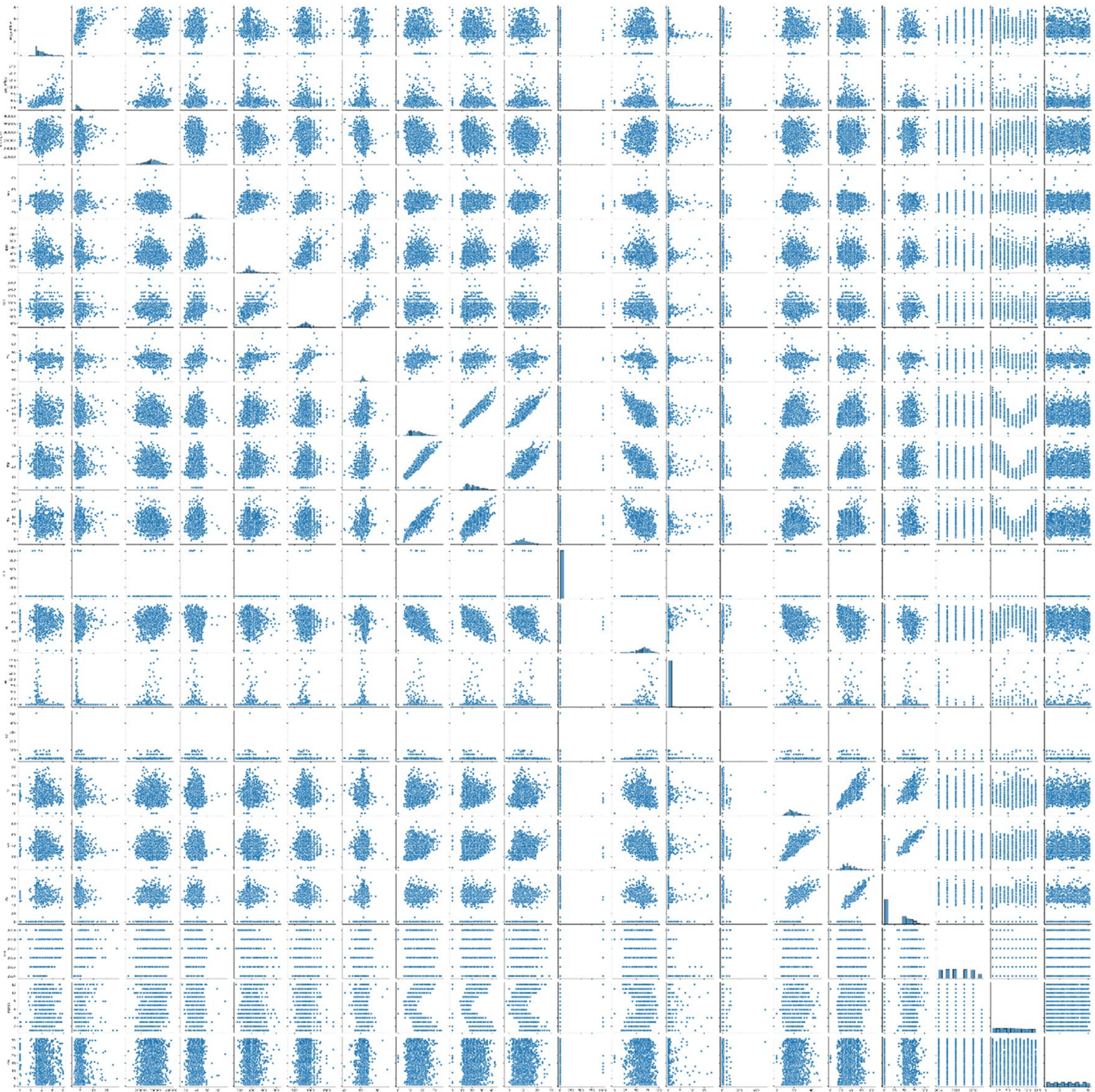


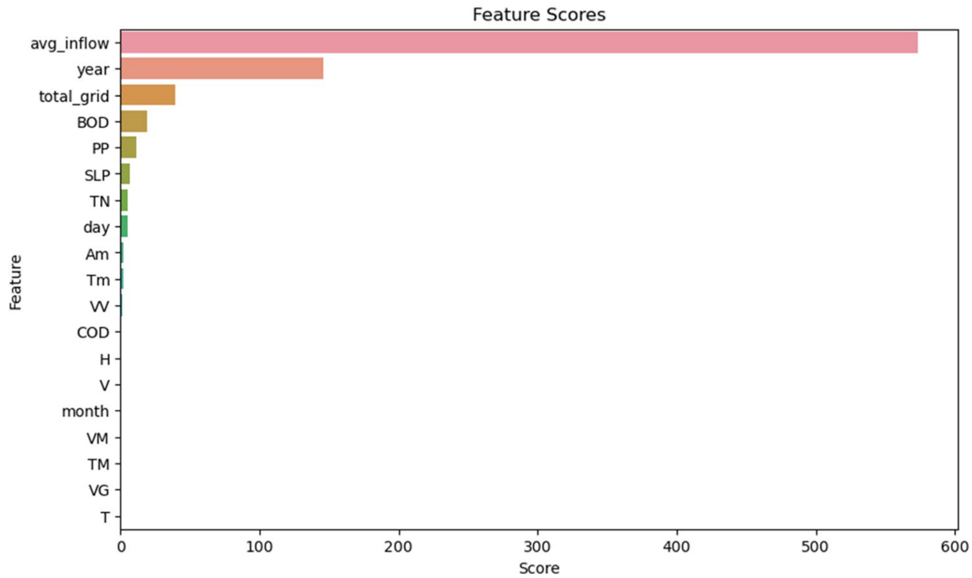
Fig. 6 Relationship Scatter plot

and 'day', offer valuable insights into the underlying factors that influence these important performance indicators.

As illustrated in Fig. 7, the significance of the inflow rate and total volume of wastewater entering the treatment plant is underscored by the selection of 'avg_inflow' and 'total_grid' as featured variables. These factors serve as valuable indicators of the wastewater load, facilitating the prediction of overflows and the allocation of resources. Furthermore, the concentration of ammonia in the wastewater, denoted as the 'Am' feature selection, is a crucial factor that impacts the effectiveness of the treatment procedure and subsequently, the occurrence of overflows. The inclusion of 'BOD' (biochemical oxygen demand) in the chosen characteristics serves as an indicator of the degree of organic contamination present in the wastewater, which is associated with treatment effectiveness and the likelihood of overflow. Similarly, the inclusion of 'TDS' (total dissolved solids) also serves this purpose. The significance of nitrogen content in wastewater is evident from the inclusion of 'TN' (total nitrogen) as a parameter for measurement. This is due to its potential impact on treatment efficiency and subsequent allocation of resources. Furthermore, the variable 'Tm' (minimum temperature) signifies the influence of ambient temperature on the treatment procedure, potentially altering microbial activity and treatment kinetics.

The selection of 'SLP' (Sea Level Pressure) as a parameter highlights the potential impact of variations in atmospheric pressure on the hydraulic characteristics and overall efficiency of a wastewater treatment system. Precipitation (referred to as "PP" hereafter) is a crucial

Fig. 7 Feature selection result



factor due to its strong correlation with flow rates and the potential for heightened load during periods of increased moisture. The inclusion of yearly and daily temporal variables serves to emphasize the significance of temporal fluctuations in forecasting daily average overflow and optimizing resource allocation. These characteristics capture the potential impact of both long-term trends and day-to-day changes on system performance. The effectiveness and efficiency of artificial neural network (ANN) prediction models greatly depend on the identification of these characteristics through the process of feature selection. The inclusion of these relevant parameters significantly enhances the model's capacity to capture the intricate connections and interdependencies that influence the performance of wastewater treatment plants and the subsequent incidents of overflow.

The utilization of insights obtained from the specified features enables the ANN-based predictive model to enhance resource allocation strategies and mitigate overflow events. This approach enhances the efficiency of wastewater treatment plants by optimizing resource utilization and reducing the probability of overflow occurrences. To enhance the effectiveness of resource allocation strategies and optimize the performance of wastewater treatment plants, it is valuable to consider the results of feature selection. These results offer valuable insights for future research endeavors and the advancement of sophisticated optimization techniques such as Tabu search.

Tabu search optimization results

An artificial neural network (ANN) prediction model was optimized using Tabu search to manage wastewater treatment plant daily average overflow and resource allocation. After algorithm experiments with several artificial neural networks (ANN) layers, performance data were analyzed.

Figure 8 shows that the single-layer artificial neural network (ANN) has 89.93% accuracy after cross-validation. Its F1 score is 67.72%, precision is 65.07%, and recall is 77.77%. These metrics may evaluate the model's ability to anticipate daily average overflow and improve resource allocation. An extra layer enhanced the ANN's average accuracy, F1 score, precision, and recall. Cross-validation yielded values of 91.42%, 66.31%, 69.76%, and 80.83%. The study suggests that adding a layer to the artificial neural network (ANN) structure helped identify and display complicated linkages, improving predicting skills. An extra layer in the artificial neural network (ANN) design also improved

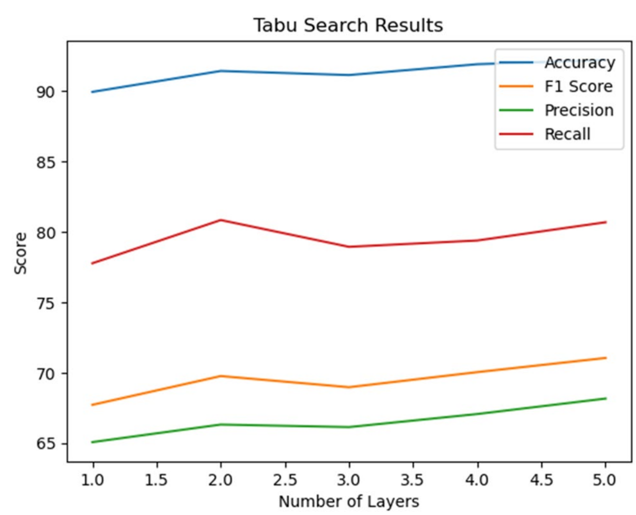


Fig. 8 Tabu search evaluation metrics

performance. A three-layer artificial neural network (ANN)'s cross-validation results showed 91.13% accuracy, 68.96% F1 score, 66.1% precision, and 78.93% recall. The data suggest that increasing neural network depth may enhance model prediction.

An additional layer in the artificial neural network (ANN) design improved performance metrics. Cross-validation showed 91.90% accuracy for the 4-layer ANN. The model's F1 score was 70.04%, indicating its overall performance. In addition, 67.06% of positive events were successfully anticipated. The model's recall was 79.38%. This research found that the additional layer's complexity helped identify data trends. Adding a layer to the artificial neural network design improved the model. A five-layer artificial neural network (ANN) had mean cross-validation scores of 92.20% accuracy, 71.04% F1 score, 68.16% precision, and 80.68% recall. This research suggests that increasing neural network depth may enhance prediction accuracy and resource allocation. Tabu search was used to refine an artificial neural network (ANN)-based prediction model for wastewater treatment plant performance. Adding layers to neural networks may improve model accuracy. Network depth increases accuracy, F1 scores, precision, and recall. This improves daily average overflow estimates and resource allocation.

The study's findings on multi-layered artificial neural network (ANN) designs and Tabu search model optimization benefit wastewater treatment plant management. Advanced optimization approaches and complicated neural network topologies may improve wastewater treatment plants' effectiveness and operating efficiency.

ANN model performance evaluation

An ANN-based predictive model was evaluated for accuracy and predictability. This model was created to optimize wastewater treatment plant resource allocation and manage average daily overflow. The model's real-world performance depends on this judgment.

Figure 9 shows the assessment metrics used in this study: RMSE, MSE, MAE, and R2. These metrics evaluate prediction error, accuracy, and explained variation to gauge model performance. The model's forecast RMSE was 1.105. The amount is the square root of the average squared deviations from anticipated values. The model makes more cautious average forecasts with a lower root mean square error (RMSE). The MSE score of 1.2217 is the arithmetic mean of the squared differences between anticipated and actual values. This statistic measures the average size of prediction errors, with higher values indicating more dispersion. The mean squared error (MSE) score shows that the model captures the data's underlying patterns and trends, although with some divergence between its predictions and the actual values.

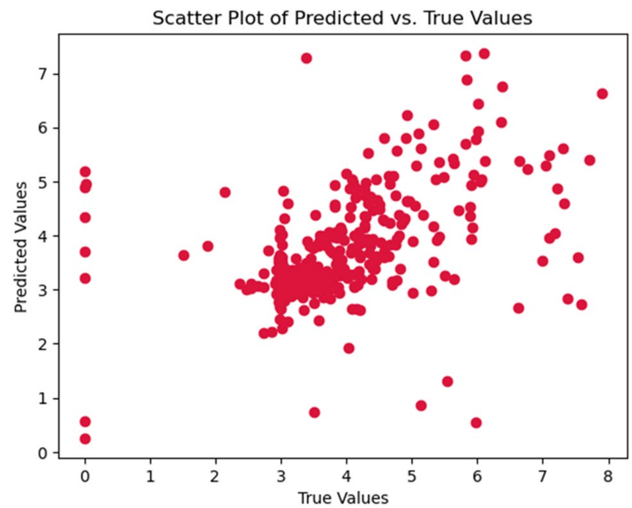


Fig. 9 Prediction vs true value

The mean absolute error (MAE) between projected and actual values was 0.7124. This statistic shows model accuracy by prioritizing error size above the alignment. A smaller mean absolute error (MAE) number indicates that the model's predictions match the actual and predicted values. $R^2 = 0.1932$ indicates that the model explains 19% of the dependent variable's variability. The measure from 0 to 1 assesses model-data alignment. The model is more accurate and explains more variability if the R^2 score is higher. The predictive model based on artificial neural networks, enhanced by Tabu search optimization, manages the daily average overflow and optimizes wastewater treatment facility resource use with satisfactory accuracy and precision. Figure 9 assessment metrics show the model's capacity to identify data patterns and trends. Prediction errors and explained variance may be improved.

This research shows that the artificial neural network (ANN) forecasting model may influence wastewater treatment facility management decisions. The model's ability to manage daily average overflow and improve resource allocation suggests it might boost productivity. However, further study and model improvements are suggested to improve accuracy and scope in diverse wastewater treatment plant conditions. Alternative optimization techniques may be considered.

Discussion

This discussion examines the outcomes of a prediction model using an artificial neural network (ANN) to manage average daily overflow and improve wastewater treatment plant resource allocation. Root-mean-squared error (RMSE), mean absolute error (MAE), correlation coefficient (R^2), accuracy, f1-score, precision, and recall reveal the model's efficacy and efficiency.

ANN model RMSE was 1.105. Regression evaluation metrics deem this number acceptable since it indicates a low average prediction error. The mean squared error (MSE) of 1.2217 implies that the datasets differ significantly. The model's MAE of 0.7124 suggests accuracy. The model's R^2 score of 0.1932 shows that it can only explain a tiny amount of the dependent variable's variability. The classification test evaluated the model's effectiveness in 1, 2, 3, 4, and 5-layer configurations. Cross-validation showed that adding layers enhanced performance. The 5-layer model has 92.20% accuracy, 71.04% f1-score, 68.16% precision, and 80.68% recall. These metrics show the model's event categorization skills and the precision–recall trade-off.

Tabu search optimization in the ANN-based prediction model improved wastewater treatment plant efficiency, supporting the hypothesis. The model is accurate, precise, and classifies well. Improve the model's explanatory power, prediction accuracy, and classification accuracy. The research has limitations. First, evaluation measures may not adequately convey the model's practical value in real-world circumstances. The dataset limited the study, hence generalizing the results to all wastewater treatment plants is risky. Independent datasets and real-world applications are needed to evaluate the model's durability and applicability. Future research may improve the artificial neural network (ANN) model in many ways. Alternative optimization methods to Tabu search may increase model correctness and efficiency. Weather and water quality indexes might improve the model's prognosis. It would be beneficial to analyze the variables that affect the model's capacity to explain outcomes and devise methods to address them.

Regression and classification metrics were used to evaluate an artificial neural network (ANN) forecasting model for wastewater treatment facility average daily overflow and resource allocation. The model's daily average overflow prediction accuracy was assessed using RMSE, MSE, MAE, and R^2. The model's mean root mean squared error (RMSE) was 1.105, indicating low prediction discrepancy variability. The mean squared error of 1.2217 showed that the numbers differed significantly. The model's predictions also had a good MAE score of 0.7124. The model's R^2 of 0.1932 shows it can explain just a small part of the dependent variable's variability.

The classification test assessed model performance using different layers. Cross-validation showed that adding layers enhanced performance. The 5-layer model has 92.20% accuracy, 71.04% f1-score, 68.16% precision, and 80.68% recall. The model accurately captured the accuracy–recall trade-off. The research found that integrating an Artificial Neural Network (ANN) prediction model with Tabu search optimization may improve wastewater treatment plant operations. The model was accurate, precise, and classifiable. The model's prediction errors, explanatory power, and classification accuracy may need tweaking.

The research has limitations. The assessment indicators may have understated the model's practical value. This review used a restricted dataset, therefore the conclusions may not apply to other wastewater treatment plants. Validation utilizing alternative datasets and real-world deployment is needed to test the model's durability and practicality. Alternative optimization methods beyond Tabu search may improve artificial neural network (ANN) models in future studies. Weather and water quality indexes might improve the model's prognosis. An investigation of the variables that affect the model's capacity to explain outcomes and ways to address them would be helpful.

The artificial neural network (ANN)-based forecasting model for wastewater treatment plant daily average overflow and resource optimization has shown substantial results. The model has above-average accuracy, precision, and classification performance, although it might be improved. The artificial neural network (ANN) model may improve wastewater treatment decision-making and efficiency. To maximize its potential, solve the limits and consider future research goals. Novel insights may improve wastewater treatment facility operating efficiency and resource allocation.

This research can improve wastewater treatment facility performance. This research evaluated an artificial neural network (ANN) model using performance measures. Root mean square error, mean square error, mean absolute error, and R-squared metrics assessed the ANN model.

The artificial neural network (ANN) model has an RMSE of 1.105, MSE of 1.2217129581939945, MAE of 0.7123888869143455, and R^2 of 0.1931895800137955. These metrics may improve average daily overflow management and wastewater treatment plant resource allocation. The performance of the artificial neural network (ANN) model was further tested by changing its layer count. In cross-validation, the single-layer artificial neural network (ANN) model had 89.93% accuracy, 67.72% recall, 65.07% precision, and 77.77% F1 score. Cross-validation means accuracy rose to 91.42%. F1 score improved to 69.76%. Precision rose to 66.31% and recall to 80.83%. After adding two layers, these improvements occurred. As ANN models went from 3 to 4 and 5 layers, accuracy, F1 score, precision, and recall improved. This research affects sewage treatment facility management. The artificial neural network (ANN) model may estimate the wastewater treatment facility's daily average overflow. The model's precise overflow estimate allows plant operators to prevent environmental pollution and regulatory noncompliance.

ANN models may also improve wastewater treatment facility resource allocation. Through precise wastewater treatment demand projections, the model helps allocate chemicals, power, and labor efficiently. Optimization may improve efficiency, production, and the environment. The study examines how changing the number of layers in the artificial neural network (ANN) model affects performance, emphasizing model architecture's importance. Layer number increases the artificial neural network (ANN) model's ability to understand complex relationships and improve prediction accuracy. This highlights the need for careful model construction and continuing refining and optimization of artificial neural network (ANN) models for wastewater treatment plants. Predictive models based on artificial neural networks (ANNs) may increase wastewater treatment plant efficiency. These models estimate average daily overflow and optimize resource use to improve wastewater treatment efficiency. The results' relevance and generalizability to other wastewater treatment plants need more research and confirmation.

The method proposed, which utilizes an artificial neural network (ANN) to forecast the average daily overflow in wastewater treatment plants, exhibits potential; however, it is subject to certain limitations. The effectiveness of the model is highly dependent on the accessibility and reliability of historical data used for training. In cases where the data are scarce, unreliable, or includes abnormal values, the model's ability to make accurate predictions may be compromised. Furthermore, it is imperative to conduct further investigations into the model's generalization across different conditions and treatment plant setups to ascertain its practical applicability. It is of utmost importance to tackle these challenges to improve the accuracy and dependability of the predictive model utilized in managing wastewater treatment facilities.

Conclusion

This study shows that an ANN-based prediction model can manage average daily overflow and optimize resource allocation in wastewater treatment facilities. Tabu search optimization using the ANN model has improved plant efficiency and performance. Regression and classification measures showed acceptable prediction error rates, accuracy, and precision. The model's explanatory power and classification accuracy may be improved. Feature selection reduces dataset dimensionality and improves model interpretability. The model predicts average daily overflow and optimizes resource allocation by selecting the most important attributes. The research also stresses the relevance of weather and water quality parameters in model prediction.

Despite encouraging results, this study must admit its limits. The study's dataset may restrict its applicability to other wastewater treatment facilities. Using independent datasets and real-world implementations, further study should validate the concept. Investigating different optimization approaches and the model's explanatory power variables are additional possibilities. An ANN-based prediction model in wastewater treatment decision-making may improve efficiency and performance. This method improves wastewater management by precisely estimating the average daily overflow and optimizing resource allocation.

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Declarations

Conflict of interest All the authors certify that they have no affiliations with or involvement in any organization or entity with a financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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