Dry Weather Adaptations in Wastewater Treatment: Innovative Control Strategies for Effective Organic and Nitrogen Elimination

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Abstract. Through a meta-heuristic framework, this study examines various wastewater treatment methods in detail and proposes a novel application of genetic algorithms (GAs) in plant optimization. ASM models are adapted to include ion speciation and pairing models, and microplastics (MPs) are challenged, indicating the need for further research. An integrated model accounts for carbon, nitrogen, phosphorus, oxygen, and hydrogen, emphasizing pH's crucial role in biological treatment processes by examining microbial growth rates and organic compound removal. By applying natural selection and evolutionary processes, GAs are investigated as an optimization tool for plants, improving gene sequence structures and, by extension, treatment processes. The importance of this is particularly evident when dealing with non-standard numerical solutions and algebraic calculations. A robust and adaptable wastewater treatment strategy that accommodates variable weather conditions is provided by the study, which illustrates GAs, their stopping conditions, and the selection process for fitness functions.

Keyword-: WWTP, Control Strategies, Dry Weather, GA, PH, ASM Models.

1 Introduction

Increasing temperatures, evaporation rates, and precipitation in the wet/dry tropics due to climate change are predicted to drive up demand for potable water and aggravate problems

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with wastewater treatment. Although water sensitive urban design (WSUD) can enhance water quality, it cannot be applied directly to the tropics, either wet or dry. To determine if it would be feasible to keep operational WSUD components in the area, long-term research is required [1-3]. The influence of Port-Harcourt Refinery Company Limited's industrial wastewater on Ekerekana Creek, a major fishing source, was examined in [4-6]. Different quantities of heavy metals and other contaminants were found by analyzing parameters including pH levels and dissolved oxygen. The flora population was adversely affected by the highest quantities, which were discovered at the discharge site. In order to save the ecosystem and the health of the communities that rely on the creek, it is crucial to manage and treat wastewater in a proper manner so as to protect the ecosystem and the health of the communities that depend on the creek. Among the most effective methods for treating high-strength wastewaters, livestock wastewater, swine farm slurry, and high-COD and high-N wastewaters are treatment wetlands. But when it comes to stillage, which is more concentrated, they are less experienced [7]. Raw stillage would need to be treated with a treatment wetland in a large area in the Caribbean with low slope lands. Utilizing vertical downflow treatment wetlands and sequenced batch reactors is a good idea when coupling demanding technologies. Since 11% of the world's agricultural area is irrigated with wastewater, managing industrial wastewater is a major concern in developing nations. Because there is a shortage of water, this activity is common even though it is illegal. When wastewater and industrial pollutants are deposited on agricultural land, crop development is hampered and water pollution results. Water that has been contaminated is poured into drains and utilized to grow crops and vegetables [48. Process optimization depends on forecasts of the inflow dynamics into wastewater treatment plants. In order to quantify forecast uncertainty and effectively estimate short-term wastewater influx, a seasonal probability based time series model is developed. As exogenous regressors, rain forecasts take into consideration buffering in the sewage network and flow-dependent catchment reaction time [9]. The model's applicability in the real world is demonstrated by comparing its performance against two other models: an autoregressive model time-varying model and a long short-term memory ANN.

Two goals were analyzed using the WWTP model, Benchmark Simulation Model 1: the decrease of nitrogen and ammonia concentrations, as well as the operating cost index and effluent quality index. Employing a multi-objective genetic algorithm (MOGA), a Pareto front was produced. The optimal tuning parameters for the proportional integral controller were obtained by the NSMOCS method, which minimized cost functions. The outcome of the simulation demonstrated considerable daily pollution unit and operational cost index reductions under various weather scenarios [10]. The accuracy of the supplied data determines how well wastewater treatment plant simulations perform. A technique for producing dynamic inflow descriptions using operational measurements—such as continually documented inflow water flow rates and volume-proportional 24-hour composite samples—is described [12]. By using this technique, modeling of wastewater treatment plants may be verified and online influent concentrations estimations can be computed. These results can then be used as input data for digital twins such as predictive controllers integrated observer models [13-15].

2 Methodology

Different methods are used in wastewater treatment plants, such as prior treatments, primary-treatment, and supplementary-treatments [16]. Bar screening, degreasing, air the flotation process, initial sedimentation, biofilm/activated sludge treatment, and secondary sedimentation are some of these procedures. To enhance the quality of the effluent, tertiary treatment techniques like membrane filtration, sand filtration, and advanced oxidation are employed. There is a lack of treatment methods that are specifically made to remove microplastics (MPs), hence more study is necessary. This study considers three standard designs of wastewater treatment plants i.e; shown in Fig.1. Initially a nitrogen (N) removal plant (WWTP1) with one secondary-sedimentation tank (SEC) and five reactors in sequence is examined. Tanks 3, 4, and 5 (AER1, 2 and 3) are aerobic, whereas tanks 1 and 2 (ANOX1, 2) are anoxic. Through a mechanism called internal recycling, AER3 as well as ANOX1 are connected (QINTR) [17-20].

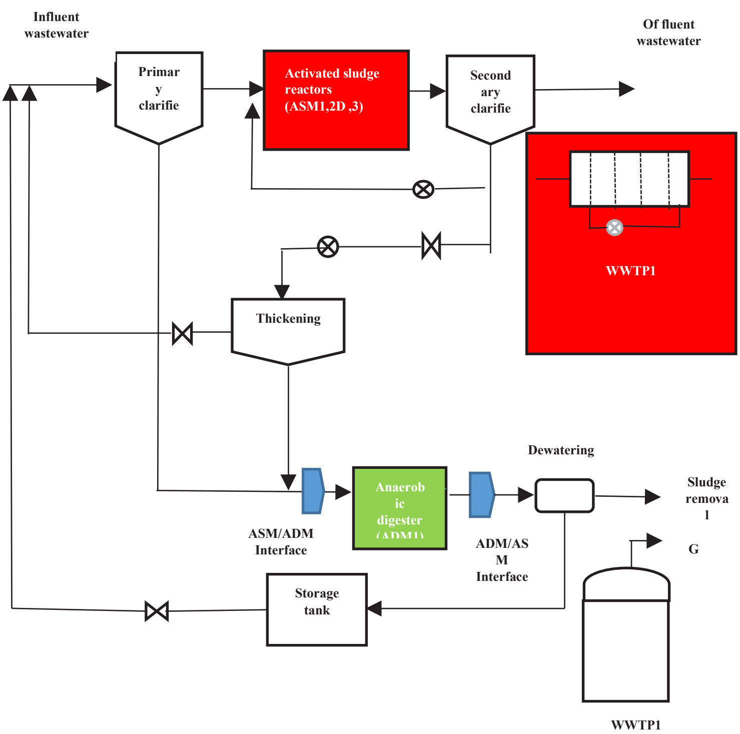

Fig. 1: Diagram showing the flow of the investigated wastewater treatment facilities

There has been an adjustment to the default implementation of the three ASM models (ASM, ADM, and ASM-II) to incorporate the ion speciation/pairing model into the default implementation [21]. The modifications include the removal of the ASM alkalinity state (SALK) and a new source-sink compound, inorganic carbon (SIC), as a means of closing the mass balances between source and sink compounds. For the calculation of the mass of each element per mass of COD in all models, it is assumed that the C, N, P, O, and H content of all state variables are known.

There is an introduction of phosphorus (P) and a carbon dioxide stripping process is included in the model. Solids separation processes, such as clarification and filtration, are used to remove phosphorus from water by using metal salts that react with the soluble phosphate to form solid precipitates [22-24]. By multiplying the oxygen volumetric mass transfer (KLa) by the square root of the ratio between the diffusivities of oxygen and CO2, we can calculate specific CO2 volumetric mass transfer (KLaCO2) [25]. Microbial growth is profoundly affected by the pH of the environment, with acidic (low pH) and basic (high pH) conditions altering enzyme structure and preventing growth. If the pH of biological treatment processes is abnormal or irregular, organic compounds are removed from the environment at a slower rate, affecting the measurements of biochemical oxygen demand (BOD) [26].

3 Plant Optimization using Genetic Algorithm

In the context of plant optimization, genetic algorithms (GAs) are designed in two phases based on metaheuristics. Initially, it gathers various potential solutions for consideration, then embarks on a quest to enhance them, governed by meticulously designed rules to generate new solutions. This is because GA function on a set-based paradigm, where at any given step k, the solution cohort Sk represents the entire solution domain, and the state S represents the current state [27].
Using specific operations on the existing solutions, a vicinity N (Sk) is delineated for each solution collective Sk. Several promising solutions are carefully selected for further study from this vicinity [28]. Based on performance metrics or estimations, this subset is thoroughly evaluated [29]. Following this evaluation, the cycle continues until a predetermined convergence criterion is met, resulting in the subsequent solution set SK+1. Fig. 2 illustrates a performance flow chart of a GA within this metaheuristic scaffold [30-34].

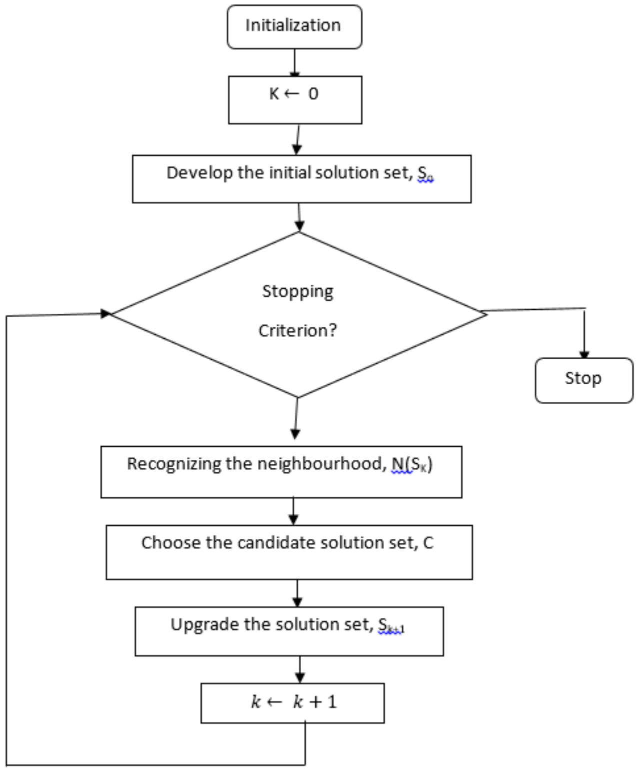

Fig. 2: Flowchart for genetic algorithm

The GA is particularly useful when a numerical solution defies definition or when an algebraic calculation yields a negative result [35]. By approximating the global optimum across a wide range of search landscapes, GA acts as a generic, probabilistic metaheuristic. GA looks at neighboring states of the current state, and decides probabilistically whether to transition to a new state or maintain the status quo, based on probabilities that allow the system to move toward more favorable states. Until either the allocated computational budget is depleted or the solution reaches a satisfactory threshold for the application, this iterative process continues [36].

By using a combination of natural selection, genetic, and evolutionary processes, this optimal search mechanism identifies gene sequences that can adapt to natural selection, facilitates random information exchange about genetic structures, and produces an adaptable generation under given conditions when genetic information is exchanged [37-39]. The goal of GA is to enhance the gene sequence structure by utilizing historical data to predict new search locales based on natural selection. In order to achieve optimal results, GA conducts parallel searches from multiple independent points.

The GA method differs from gradient-based or derivative-based optimization methods in that it takes considerable computational resources to achieve its goals. The offline implementation of this approach is nevertheless possible. Fig.2 illustrates how GA can optimize the parameters of membership functions. Initiating with a randomly selected population of 20–100 individuals, each represented by chromosomes of real or binary sequences, a cost function evaluates each chromosome's performance. The next generation is benefited by chromosomes that demonstrate lower costs. Through selection, crossover, and mutation, fitness-based selection is augmented by genetic operations, which enhance solution quality. According to specific objectives, operational cost and effluent quality indices define the fitness function.

Based on the outlined program settings, the algorithm executes until it meets termination criteria based on gene convergence or progress metrics, using MATLAB's GA tools. Iteratively determining optimal fitness values is accomplished through this meticulous process, albeit randomly, resulting in determining optimal weights for W1 and W2. GA's adaptability and efficacy in plant optimization scenarios are demonstrated by these weights, designed for varying weather conditions.

Table 1: Weighting factors and their values

Weather	W1	W2
Dry	0.28	0.72

In order to ensure correct weighting and lower the possibility of errors, the Table 1 offers a thorough examination of the weighting components, including their corresponding values.

4 Result and Discussion

Wastewater treatment facilities (WWTPs) have unpredictable, unstable, and time-sensitive characteristics that make it difficult to reduce emissions and save energy. To improve water treatment procedures and lower yearly overall energy usage, a streamlined supervisory control approach was created. The best operating parameters for raising the quality of the output water were found by optimizing internal circulation and fixed residence time using an adaptive genetic algorithm. Currently, a useful method for balancing various objectives like pH, BOD, COD, and operating stability in WWTPs is artificial intelligence-based control. Water treatment process has been informed about dry weather conditions. An efficient genetic algorithm-based optimization control of complex WWTPs is created in order to address the conflict between multiple performance indicators, and both algorithms analyze influential data, such as pH levels in each reactor. Furthermore, the effluent data is analyzed for other factors, and the two algorithms are evaluated.

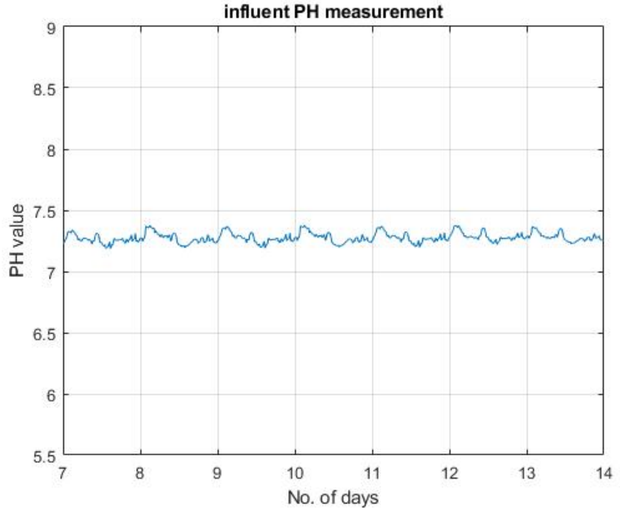

Fig. 3: PH of the influent stream in Plant during dry weather

A graph providing the pH levels of a plant's influent stream during dry weather conditions is shown in Fig. 3. Most biological and chemical processes in wastewater treatment require pH values between 6.5 and 7.5, which is considered a neutral range. During the observed period, the pH of the influential stream showed no significant changes, which could be beneficial for consistent treatment effectiveness.

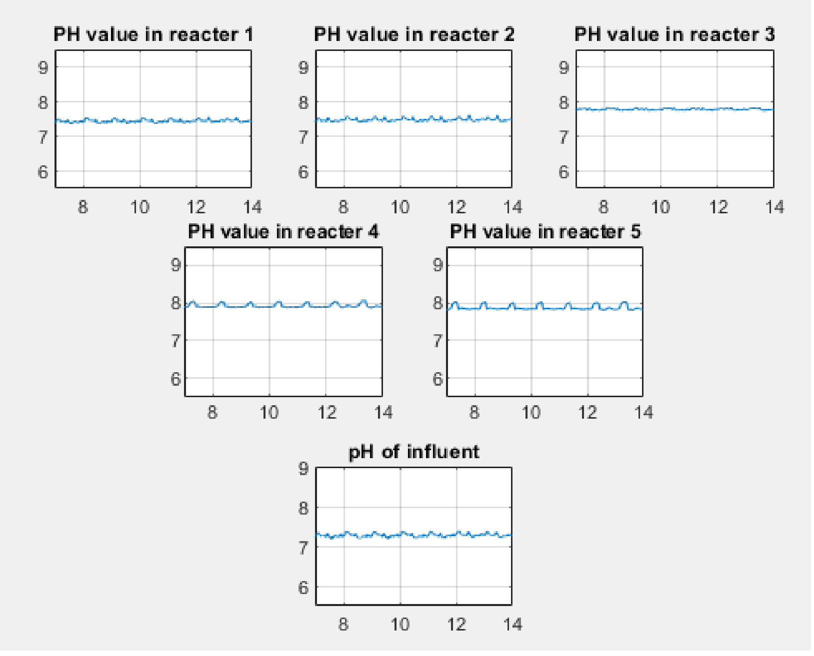

Fig. 4: At different stages of WWTP, value of pH

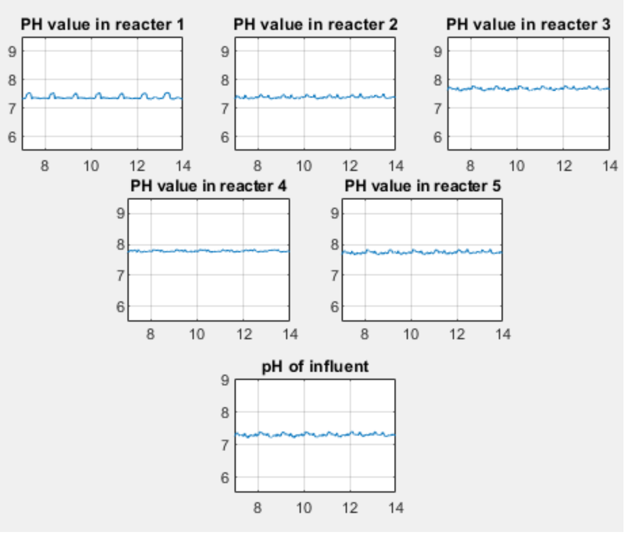

Fig. 5: An AI-based controller for PH values in WWTP at various stages

In a plant operating under dry weather conditions, PH values were determined in various stages of the WWTP using a simplified supervisory controller. A WWTP with multiple tanks is designed and the PH level at each stage is measured at each stage, as shown in Fig. 4, which corresponds to the design of the WWTP. There are several types of supervisory control systems that are used to achieve the desired outcome. As shown in Fig. 5, we design a WWTP with multiple tanks and evaluate the PH levels at each stage. PH levels are optimized in the tank using a genetic algorithm based on artificial intelligence.

5 Comparative Analysis of pH, BOD, COD, and operating stability in WWTP

For assessing treatment efficiency, it is essential to compare pH, BOD (Biochemical Oxygen Demand), and COD (Chemical Oxygen Demand) in wastewater treatment plants (WWTPs). From the study it can be observed that apart from balancing acidity and alkalinity and eliminating organic contaminants, these metrics can be employed to assess a wastewater treatment plant's effectiveness under diverse conditions. Also throughout the evaluations, effluent quality is maintained and environmental requirements are guaranteed to be met.

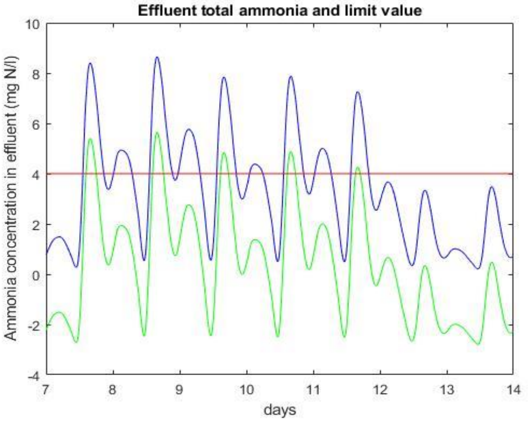

Fig. 6: Ammonia output in the effluent from the two different WWTP controllers

The analysis represents the concentration of ammonia in the effluent when using the standard supervisory control system by the blue graph in Figure 6, whereas the concentration using the proposed GA based controller is presented by the green graph.

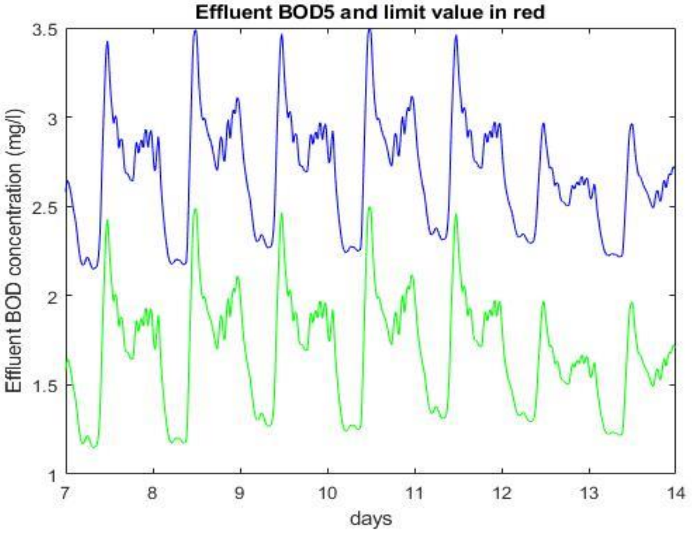

Fig. 7: Comparison of BOD in effluent generated by two WWTP controllers

It is evident from the blue graph in Fig.7 that the BOD concentration in the effluent from the standard supervisory controller has remained unchanged, and the green graph in Fig. 7 shows that the BOD concentration in the effluent from the proposed controller has decreased, thus showing that the amount of organic compounds in water has decreased.

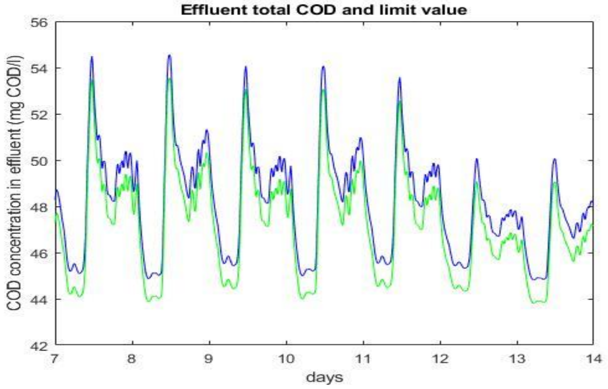

Fig. 8: Comparison of COD using two controllers in WWTP

COD in the effluent is depicted in blue in Fig. 8 with a supervisory controller, and in green with a proposed controller, which reduces the amount of organic compounds found in water.

5 Conclusion

The study explores the optimization of wastewater treatment plants (WWTPs) in an effort to demonstrate that the operations of WWTPs are dynamic and highly sensitive. In order to enhance water quality and balance critical performance indicators such as pH, BOD, COD, and operational stability, it was necessary to develop an adaptive genetic algorithm that would identify optimal operating parameters.

- Potential for managing complexities under dry weather conditions.
- Comparative analysis of pH, BOD, and COD across WWTP designs validated models' effectiveness.
- Genetic algorithms improve effluent quality and environmental standards compliance.
- Results pave way for innovation in WWTP management, optimizing performance and addressing microplastic removal challenge.

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