


Chapter 12

Wastewater Treatment and Recycling With AI

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ABSTRACT

The intensifying global water crisis demands innovative approaches to wastewater treatment and recycling as core strategies for sustainable water management. The chapter discusses how artificial intelligence transforms the process of modernizing wastewater systems offering improvement in the operational effectiveness of the system, optimal utilization of resources, and adaptive process control. It starts with a survey of the traditional treatment steps and its limitations and proceeds to show a detailed report of the Artificial Intelligence (AI) application in the field related to monitoring, prediction of quality, detecting anomalies, and analysis of microbial populations. The chapter also demonstrates how AI is applicable to more innovative approaches to water reuse at the industrial, municipal, and decentralized scale-equipping systems with the intelligence to perform smarter control, minimize energy and chemicals consumed, as well as maximize effluent reliability.

INTRODUCTION

Water scarcity is rapidly emerging as one of the most pressing global challenges of the 21st century. As population growth, urbanization, industrial development, and climate change intensify, the demand for freshwater is rapidly outstripping supply across many regions of the world. The United Nations has estimated that by 2025, almost two-thirds of the world population will be living under the circumstances of water stress. Against this background, sustainable management of water resources

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has emerged as an imperative in terms of strategy to governments, industries and communities. The recycling process of wastewater can be regarded as one of the central pillars of sustainable water management because through these efforts, contaminated water is transformed and can be used again as a productive resource thus relieving the burden of the freshwater system, as well as helping in the conservation of the environment (Mishra & Sundaram, 2024).

Conventional wastewater treatment systems, though aesthetically necessary, are being limited by a number of very important constraints making them rather inefficient in this fast-evolving world. These systems tend to be systems with stiff operational procedures, use a lot of energy and chemicals, lack the capacity to be flexible against the changing levels of contamination and expensive infrastructure. Moreover, traditional treatment methods often require human surveillance and support to monitor, maintain and make decisions and this has the tendency to insert inefficiencies, delays and errors. Consequently, the integrity and effective execution of the entire system of conventional wastewater treatment plants may be damaged especially when under stressful or complex conditions (Liu et al. 2024).

In recent years, the advent of artificial intelligence has opened new avenues for addressing these longstanding challenges in wastewater management. Artificial Intelligence (AI) describes a set of machine learning (ML) algorithms that allow machines to learn and develop through experience and by finding patterns in data and decide on future actions that bring about performance enhancement without explicit programming. The field of wastewater treatment and recycling is one that has also shown profound potential in its ability to be transformed by the introduction of AI, giving rise to the ability to operate in real time optimization of processes, predictive analytics, automated detection of anomalies in the process and intelligent control systems. Such abilities are of special significance in ever-changing and complicated situations in which swift choice-making and devising are important (Alprol et al. 2024).

AI-driven approaches in wastewater management are not confined to a single application but span the entire treatment continuum—from the monitoring of influent characteristics to the optimization of effluent quality and the strategic reuse of treated water. With continuous integration of the AI model with the sensor network, control systems, and big analytics, current wastewater facilities can also realize a higher degree of efficiency and automation than before. As an example, machine learning can be applied to predict biological oxygen demand (BOD) of influent streams, deep learning (DL) can be used to model dynamics of microbial population, and reinforcement learning may be used to optimize aeration settings or even chemical dosing to achieve regulatory mandates at minimum resource usage (Altowayti et al. 2022).

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