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Smart Wastewater Management: The Role of AI Technologies

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Abstract: The integration of Artificial Intelligence (AI) technologies into wastewater management systems is revolutionizing the way we treat and monitor water resources. Smart wastewater management utilizes machine learning, data analytics, and real-time sensors to optimize treatment processes, reduce operational costs, and enhance environmental sustainability. AI-based models can predict contaminant levels, detect system malfunctions, and recommend adaptive control strategies. Current trends show increasing implementation of AI in decentralized and automated treatment facilities. This paper explores the key applications of AI in wastewater treatment, highlights recent technological advancements, and discusses the potential future impacts of AI on achieving more efficient and resilient water management systems.

Keywords: Internet of Things; artificial intelligence; machine learning; artificial neural network; soft sensors for water-treatment plants.

1. Introduction The most important component of human existence and industrial operations is water, which is currently seriously threatened by dangerous contaminants brought on by both human activity and natural processes. Water accessibility in safe and healthy ways is a big issue across the world. Therefore, it is vital to categorize and keep track of the water quality; however, the fundamental problem is that, with current technology, adequate parametric quality metrics are not accessible [1]. Due to the increase in human population, the activities of aquatic systems (aquaculture, aquaponics, and hydroponics) have increased. As a result, the nutrient load, mainly nitrogen and phosphorus, drained to the water bodies has been increased, causing damage in several water habitats [2,3]. Therefore, the treatment of effluent aquaculture wastewater should be improved and developed in a sustainable way using modern technologies [4,5].

Water- and wastewater-treatment facilities, as well as numerous industrial and biological systems that depend on different resources, must have access to sustainable and clean water. Treatment facilities must deal with complicated regulatory procedures to fulfill the rising standards of quality, in addition to catering to customer wants and enhancing infrastructure for quality of life [6]. Approximately 300–400 million tons of contaminants are reported to be released into global water every year, leading to water pollution, which is a great burden on water quality management. This is only complicated by the fact that nations continue to have severely contaminated rivers, which damage aquatic and terrestrial life in addition to human life. These problems are gradually worsening as nations continue to industrialize and modernize. Researchers from all over the world have looked for ways to improve water-related applications. For several years, there has been enough focus on developing and modeling optimal, economical, and intelligent models to help resolve this problem.

2. Smart Technology. Computer systems that can learn from data without being explicitly programmed are referred to as ML, a subfield of AI that focuses on the development of algorithms and statistical models (Figure 1).

Developing predictive models with the ability to make precise predictions or decisions based on data-driven learning is the fundamental aim of ML. Finding patterns or generating predictions from large amounts of data generated by different scenarios is a common use case for ML, a powerful data analysis technique. Before ML is applied in a practical setting, it is necessary to complete data collection, appropriate algorithm selection, model training, and model validation [19]. The main differentiating factor between these two types is the presence of labels in the datasets. The term "Internet of Things" refers to a network of physical objects that can connect to the internet or other communication networks. These objects are often equipped with software, hardware, or other technologies that enable them to facilitate analytical processes, such as environmental sensing. Figure 1.

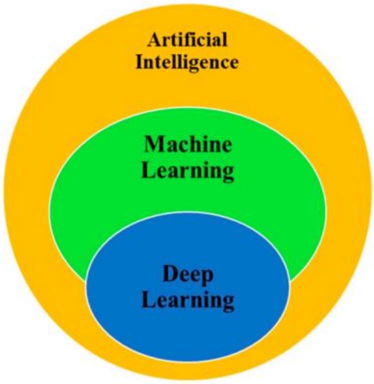

Figure 1. Artificial intelligence methods

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3. AI Models. According to the literature, Figure 2 depicts the important AI models used in WWT. These models can be divided into three categories: ML, ANN, and SA.

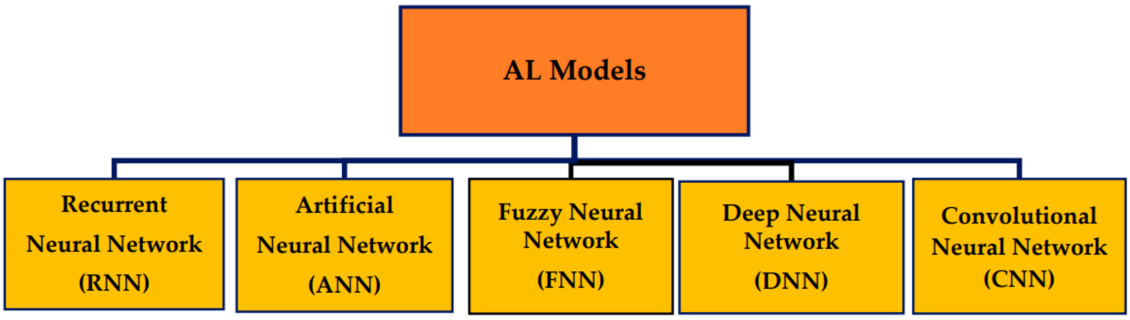

Figure 2. Models of AI.

An RNN, a type of NN, operates by iterating in the direction of sequence evolution and taking sequence data as input. RNN has memory, parameter sharing, and Turing completeness, making it advantageous for learning nonlinear features in time-series problems. The LSTM is the most commonly used RNN to address the problem of gradient disappearance. RNN has achieved notable success in various applications, such as water, WWT, water quality management, and water-based agriculture.

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