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Water Quality Monitoring in Agriculture: Applications, Challenges and Future Prospectus with IoT and Machine Learning

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Abstract: Water is one of the key elements involved in maintaining the quality of life. It is essential in the field of agriculture for food production and livestock farming. Water quality is continuously declining as a consequence of the growing trend of urbanization and industrialization, which can harm the environment and human health. In recent years, several researchers in the field of agriculture have shown advancements in techniques with the implementation of the Internet of Things (IoT) Artificial Intelligence (AI) machine learning (ML) and smart technologies. These advancements aim at improving water usage and enhancing the quality and quantity of different crops, with the ability to lower analysis costs, time and facilitate the achievement of management results. This paper outlines an overview of recent studies on water control and management using the IoT and ML models in the field of agriculture. Thus, new technologies for analyzing water quality metrics like pH, temperature, color, turbidity, Total Dissolved Solids (TDS), salinity, and nitrogen are described. It also describes few exposed contests used to draw related study suggestions in the future, such as the use of advanced intelligent tools and strategies for water quality assessment and management in the agriculture sector.

Keywords: Agriculture, Water Quality, Water Management, Water Monitoring, Internet of Things, Machine Learning

1. Introduction

Agriculture is an important field that contributes to meeting the expanding food demand of the world population. It is regarded as the largest contributor to employment in developing countries and a foundation of the economy in non-petroleum countries [1]. To achieve such goals, agricultural

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processes must consider ecological and environmental concerns. Despite significant investments in agricultural development in many emerging economies, the nutritional situation remains poor. One important cause of this discontent is that most of these developments have proven unsustainable. The Food and Agriculture Organization (FAO) even emphasizes implementing a smart agriculture policy to maintain, conserve, and promote natural resources while also assuring public health [2]. In general, major efforts must be made to expand agriculture sectors such as forestry, crops, and livestock to meet the food needs of the population. Water, being a fundamental natural resource for all biological systems, is an essential factor in long-term agricultural development [21].

Agriculture is also the most significant sector of water consumption, contributing to approximately 80% of overall consumption, and is a major polluting factor in the environment. Water resource development and management approaches in this framework must not just address the limitations implied by the hydrologic cycle on quantity and quality, but also those caused by significantly increasing agricultural development processes, particularly the growth of irrigated agriculture [22]. As a result, water planning and management at an affordable cost for irrigation is necessary to guarantee a sustainable agricultural environment. Water quality assessment in real time has difficulty presently due to worldwide warming up, shortage of water means, increasing population, etc. Thus, there is a requirement for healthier tactics for analyzing water quality metrics in real-time [3].

Water quality monitoring helps in the detection and quantification of toxic pollutants compared to accepted criteria for each location, serving as a critical planning technique for decision-making and the control of water pollution [4].

However, the primary existing approaches for monitoring water are often costly, need skilled experts and complex hardware, and, in many cases, do not support direct examination in the area with instant outcomes. However, with advancements in ML techniques in recent years, a growing number of scholars consider that huge amount of information may be positively acquired and investigated to meet the complicated and large-scale water quality assessment criteria [5]. Emerging artificial intelligence (AI) and ML, together with smart technology, are filling a gap in water applications that were neglected earlier by old approaches and concepts. ML, AI, and smart technologies are predicted to model and solve multifaceted and tough challenges in water applications due to their generalization, robustness, and relatively simple design, resulting in cost reductions and quality improvement [23].

Water and wastewater treatment, precision/water-based agriculture, and natural-systems monitoring are among the water applications that have experienced many ML methods. These industry researchers have been found to trust a variety of ML techniques, including the most widely used recurrent neural networks (RNNs), artificial neural networks (ANNs), and support vector machine (SVM), with the infrequent AI method involving fuzzy inference systems (FISs). Many researchers have shown success using ML, AI, and smart technology in water-based applications to optimize modeling techniques [24]. While these achievements have been acknowledged, ML and AI applications do not come without constraints that need to be addressed before general execution. This analysis provides a cross-section of primarily ML techniques, with some AI and smart technologies, that have been used to improve and model water processes in water-based systems. This survey is not aimed to be comprehensive of ML, AI, and smart-technology applications in water-based research, but rather to demonstrate the present work of many of these relevant published papers [25][26]. This work intends to be a Survey literature that combines technology and portable sensors designed to monitor water quality, keeping in view sustainable agricultural development environmental preservation, and effective water management. It provides a complete summary of the latest work done in the area of intelligent water quality monitoring systems.

1.1 Report Structure

This paper is structured in a pattern discussed as follows. In Section II, a literature review on related topics is done by reviewing and analyzing previous research. In Section III, the major water quality parameters and studies that implemented technologies to analyze those metrics are discussed. In Section IV, we discuss the challenges encountered and some suggestions for extending this project in the future. Finally, in Section V, the conclusion of this report is presented.

2. Literature Review

This section covers peer-reviewed publications regarding the IoT, AI, ML and Smart Technology in water quality monitoring and testing.

2.1 Overview of the IoT and Smart Sensing Technology

The IoT is a term that refers to a network of hardware devices that can link to the Internet (or other communications systems) and are frequently equipped with some form of logical method (like atmospheric sensing) that is supported by software, hardware, or other innovations. In water applications, the IoT frequently incorporates Internet-enabled devices configured with flow sensors, pressure sensors, and/or water-quality/characteristic detectors [6]. Typically, the objective is to exchange information with other attached devices or networks and the period of the sensor or other innovation, frequently for system optimization, comfort of use, efficiency, and transparency [7]. IoT comprises a supportive structure of data gathering that can be retained nearby or remotely without the requirement for a human to substantially take the data or manage the physical entity. As a result, it is necessary to preserve the linked device's long-term functionality and durability. However not exactly AI, the IoT can be combined with AI to produce what has been termed the "Artificial Intelligence of Things," which would merge this process of data collection to provide AI with important inputs for its learning procedure [8]. Smart sensing technology is associated with IoT, although it frequently reflects a broader range of systems that are not determined by their collectiveness and might include isolated or stand-alone systems/sensors. To be labeled as a "smart" sensing system, the sensors must perform some task elsewhere their basic sensing capabilities [9], which is typically accomplished by a legal task or mechanization. For example, a thermometer that senses the temperature of a room and communicates with a heater to attain a preset temperature, without the need for a connection to other smart appliances in the home. The capacity to wirelessly interface with other devices via Bluetooth or Wi-Fi abilities can strengthen the smart designation [28]-[29].

2.2 Overview of Machine Learning

ML is extensively applied as an advanced data analysis tool to detect patterns or predict outcomes based on large data gathered from various events. Data acquisition, selection of appropriate algorithms, model training, and model validation must all be performed before ML can be used in practice. Among these methods, the selection of an algorithm is important. The two basic categories of ML technologies are supervised and unsupervised learning [10]. The existence of labels in the datasets distinguishes these two groups. The labeled training datasets are used in supervised learning to derive predictive functions. Each training instance contains input values and predicted corresponding outputs [30]. Several methods, including linear regression, decision trees (DT), support vector machines (SVM), artificial neural networks (ANN), k-nearest neighbor (KNN), Naive Bayes, random forests (RF), etc., have been designed and used for supervised learning in data classification and regression. Unsupervised learning, in contrast, is generally used to process the data without labels, addressing different pattern recognition challenges using unlabeled training datasets. Unsupervised learning distributes training data into distinct categories based on specific criteria, particularly dimensionality reduction and grouping [11]. However, the number of classifications remains unclear, and so is the meaning of each group. As a result, unsupervised learning is commonly applied in classifying and association mining [12]. Unsupervised ML algorithms that are often utilized include principal component analysis (PCA), K-means, and others. Another type of ML algorithm is referred to as reinforcement learning, which is the capability of a machine to simplify and suitably respond to unlearned challenges.

2.3 Applications of IoT and Machine Learning in Water Treatment

Many new inventions and approaches for agriculture have been devised as advancements in IoT technology progress [36][37]. Precision agriculture refers to the gathering and analysis of different kinds of data, such as sensor data, time series, geolocation, and so on, to increase the efficiency of agricultural processes [38][39]. This study analyses the research topics addressed by the writers of the chosen publications, the related proposed approaches, and the specific methods (i.e. equipment and procedures) adopted to address the challenges [42][43]. As the trend has shifted toward IoT-based systems in most aspects of daily life, considerable research has been conducted in the field of IoT and its utility water quality assessment during the last decade [44]. The majority of the studies mentioned here are focused on water monitoring, control, and reuse. The literature review discusses the importance of recognizing the concepts and ideas implemented in the research under consideration. According to a review of the literature, water quality evaluation and modeling is a significant aspect of establishing water conservation programs. Many prior studies have been improved with ML-based models for effective classification purposes and AI-based estimations for greater effectiveness and accuracy as in Table 1:

Table 1 – Relevant study summary

Concept	Area	Studies
Multi-objective intelligent agriculture system	Raspberry Pi, ZigBee modules, and the AVR AT Mega microcontroller	[13]
IoT for assessing the quality of water	WHO standards	[14]
Water quality using IoT and multiple sensor modules	water quality by detecting pH, conductivity, temperature, and turbidity using different sensors	[15]
Approaches involving deep learning methods	water management techniques	[16]
Intelligent Water Quality	IoT, DL and Cloud	[17]
Quality of water in real-time	Raspberry Pi, Things speak.	[18]
Low-cost, real-time water quality assessment for distant rivers, ponds, and other natural water resources	web-based software tool	[19]
Surface water quality	Conductivity, temperature, and turbidity	[20]
Drinking water prediction	Fuzzy Neural Network	[27]
Underground water in Iran	Probabilistic Support Vector Machines (PSVMs) model in combination with a GIS	[31]

To assess water quality components.	Artificial Neural Networks (ANN)	[32]

3. Water Quality Monitoring Parameters

Though various factors are considered to monitor water quality, only a few are thought to be important factors in the analysis, which can vary depending on the region or intent of the use of water. For example, Alam et al. [33] and Rahmanian et al. [34] provide a report on water quality monitoring experiments in which monitoring parameters were determined based on the requirements of each location. Technologies and approaches, for instance, the use of automated samplers and autonomous sensors, are capable of easing and upgrading present water monitoring technologies, lowering expense, incorporating them with IoT, and increasing data collecting speed. The parameters to consider while monitoring the water quality and the technologies related to them are discussed as follows.

3.1 Temperature

Temperature sensors, like pH sensors, are found in the majority of multi-parametric sensing devices. This is due to the great significance of temperature regarding water quality, as many methods of other specifications are considered temperature-dependent (e.g., bioactivity, pH, conductivity, and dissolved oxygen), and, on the contrary, to its convenience of monitoring, as resistivity and temperature, or electromotive force, have a strong linear relation [35].

3.2 pH

Since pH is a critical factor for ensuring adequate water quality, it is frequently measured and is present in almost all multiparameter equipment. To determine the pH of a water sample, many techniques such as visual inspection, potentiometric, and photometric methods can be used [41]. The visual method, which uses particular materials (litmus paper) and color shift as a pH indicator, is less accurate and only gives approximations of the pH values.

3.3 Turbidity and Total Dissolved Solids (TDS)

The turbidity of water is a factor used to determine the proportion of intervention that an incident light meets when passing through it, mainly due to the involvement of dissolved particles such as inorganic and organic compounds that can result in the water appearing cloudy. As a result, turbidity is a primary attribute for assessing water quality, determining if the water is suitable for consumption and, thus preventing waterborne infections [45]. The term "dissolved solids" denotes any minerals, saline compounds, or metals dissolved in water. TDS are organic compounds (mostly calcium, potassium, magnesium, bicarbonate, sodium, chlorides, and sulfates) and trace quantities of organic compounds that are diluted in water.

3.4 Salinity

The proportion of dissolved salts in water is termed as salinity. Parts per thousand (ppt) or percentage (%) are common units of measurement.

3.5 Color

Even before technological advancement and the advent of remote monitoring tools, watercolor, which is the light reflected in tiny particles of organic or mineral sources, has been utilized as an indicator of water quality analysis for a long time. Nevertheless, as technology flourished in civilization, more research was focused on figuring out the color of water.

3.6 Nitrogen

Nitrogen can be discovered in many sources in our surroundings, like decayed plants, wildlife, human excrement, manure, and pesticides. Numerous methods, including chromatography, electrochemistry, and spectroscopy methods, can be used for monitoring nitrogen [41].

4. Challenges and Future Directions

The majority of recent agricultural and environmental quality concerns have mainly concentrated on the effect of water quality control. Several challenges concerned with water produced by humans and industrial processes, like solid pollutants, have the possibility of harming the environment and agriculture [21]. This eventually leads to complex feedback such as sustainable energy paralysis and environmental pollution. Furthermore, water resource utilization in several areas can be certainly affected, sometimes owing to increased alkalinity or salt content, which can adversely affect crop yield and production. Agriculture should wisely and sustainably manage its water resources [26]. The installation of core wastewater management plants is one illustration of a risk-reduction and pollution-prevention effort. We believe that considerable efforts should be made to maintain automated technological systems that offer sufficient water management services, with the capability of improving farmer performance while protecting the environment. A major challenge is developing smart water management pilots that ensure aspects are adaptable to various settings and applicable in multiple areas and environments. In short, the selected regions should be adaptable to various pilots, weather conditions, soils, and plants. Approachability is also a point of concern. It supports access to mediums for a diverse range of consumers, regardless of scientific training, particularly in industrialized countries. This can be accomplished by making difficult concepts as comprehensible as possible [28].

The WATERMED 4.0 initiative of the PRIMA Foundation7 is a recent project aimed at refining the quality and protection of Mediterranean cultivation in partially arid areas. To optimize the quantity and water quality for all consumers, especially planters, it reveals new approaches and strategies for intelligent water control systems in agriculture. Energy-efficient water managing units, reliable irrigation projects for agriculture in sparsely populated rural areas of the Mediterranean, water, and manure use reduction in agro systems, water reutilizing based on arithmetical technological innovations, and socioeconomic experiments to expand water management governance are some of the possible barriers [30].

5. Conclusion

Maintaining water quality is a vital water management device for reducing pollution and reducing environmental and human health effects. Agriculture is an application-specific field in which IoT and advent of the new tools and strategies can provide innovative solutions to traditional problems. We displayed a review of recent work on the serious water management concern in agriculture, supported by state-of-the-art technologies like IoT-based systems. Despite the availability of various useful intelligent water quality analyzing frameworks, the field of study remains complicated. This paper provides an overview of the efforts of recent researchers to make water quality evaluation methods reliable, highly efficient, and low-powered. Such technologies emerge as a turning point for combating the weaknesses of old-fashioned approaches and improving water manipulation. After reviewing present literature, we discussed a few related open challenges as a result of which new research guidelines have been proposed. The anticipated future efforts will focus on the development of advanced smart tools and concepts for sustainable water maintenance and management in the field of agriculture.

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