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Aqua Sense: Smart IoT System for Water Usage and Quality Monitoring

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Abstract

Water scarcity and water quality degradation are becoming significant global issues due to rapid urbanization and improper water management practices. This paper proposes a smart IoT-based system named Aqua Sense, which can be used for real-time monitoring of water consumption and water quality in water tanks, cities, and commercial areas. In the proposed system, water flow, water level, pH, TDS, and turbidity sensors are connected to an ESP32 microcontroller for real-time monitoring of water parameters. A threshold-based approach and an alert counter are used for efficient water parameter monitoring. Moreover, motor control is also included in the proposed system for efficient water management, which can prevent water overflow and motor dry running. All the operations of the proposed system are stored in a cloud database, which can be accessed remotely using a mobile or web-based application. The experimental results of the proposed system show efficient water parameter monitoring, water savings, and increased awareness of water consumption. The proposed system can be used as a cost-effective, efficient, and reliable solution for water management systems.

Keywords: IoT-based Water Monitoring, Smart Water Management, ESP32 Microcontroller, Water Quality Analysis, Real-Time Data Visualization.

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1. Introduction

Water is considered one of the most important natural resources essential for the survival of the world's population, but the efficient management of this resource has become a critical problem in modern society. The rapid increase in urbanization, the growing world population, and the aging of the current water management infrastructure have resulted in significant problems of water waste, unnoticed leakage, and deterioration of the quality of managed water in residential and commercial environments. The conventional method of managing this problem involves the direct inspection of water, which is considered time-consuming, inaccurate, and unable to produce real-time results. Therefore, issues such as tank overflow, motor dry-run, poor quality of managed water, and excessive consumption of the resource are unnoticed.

However, the invention of the Internet of Things (IoT) has introduced significant opportunities for the intelligent and efficient management of the world's resources, and Aqua Sense: Smart IoT System for Water Usage and Quality Monitoring is proposed as the most efficient solution to the problems of both the quality and quantity of managed water in residential environments. Aqua Sense uses a system of constant monitoring of important water parameters, which include flow rate, water level, pH, TDS, and turbidity, with the help of multiple sensors. The collected information is then processed by an ESP32 microcontroller and sent to a cloud-based platform via Wi-Fi connectivity, which can be accessed by the user through a mobile application or a website. The proposed system also includes intelligent features that help avoid overflow, wastage, and ensure safe water quality, making it a suitable option for a smart home in the future.

2. Literature Review

The incorporation of Internet of Things (IoT) technology in the management of water resources has attracted considerable attention due to its ability to facilitate real-time monitoring, efficient utilization, and improved management of water quality. Existing literature has indicated that IoT-based systems have been employed for continuous data collection and monitoring purposes, where sensors and communication modules have been employed for continuous tracking of parameters such as water level, flow rate, and quality, thereby facilitating smart water management systems [1]. Smart water metering systems have also been developed for accurate measurement of water consumption patterns for efficient utilization, thereby facilitating water conservation [2]. IoT-based systems have also been employed for efficient management of water usage at the domestic level, where users have been able to monitor their usage patterns and control the flow rate for efficient utilization [3]. Comprehensive review studies have indicated that IoT-based systems for efficient management of water resources have employed sensor networks and cloud platforms for effective management, thereby facilitating efficient management in both urban and rural areas [4].

In addition, there are several research papers on consumption monitoring, but there are also several research papers on water level monitoring systems, especially for tanks and reservoirs, where IoT sensors are employed for the automation of water supply systems, avoiding situations of overflow or shortage [5, 6]. Water quality monitoring is another significant area of IoT-based applications, especially for ensuring safe and potable water supply, for which systems are designed to monitor pH, turbidity, temperature, and dissolved oxygen levels in real time [7, 8]. Even more sophisticated systems are employed for this purpose, especially for ensuring early detection of contamination or pollution of water supplies, for which several sensors are used along with wireless communication technologies [9, 10]. Previous foundational works also show the possibility of real-time IoT-based water quality monitoring, establishing the foundation for today's smart water systems. Moreover, with the utilization of WSNs in IoT systems, the monitoring of both water consumption and quality has been made possible with increased efficiency and real-time monitoring of various locations simultaneously. Thus, based on the literature reviewed, there is an evident move towards intelligent and automated systems for managing and monitoring water. However, there are still concerns regarding accuracy, reliability, efficiency, and scalability.

2.1 Limitations and Constraints

The lack of comprehensive system integration is one of the significant constraints identified in previous works. Most of the works reviewed concentrated on individual parameters such as water level and water flow without integrating various monitoring aspects of a system. This constraint is identified in works where there is a primary concentration on system architecture and single-parameter monitoring without comprehensive implementation [1], [2]. Another significant constraint identified in previous works is the lack of implementation of water quality monitoring. Most of the systems reviewed measure only quantity-related parameters of water. This includes systems that implement alerts immediately after a single abnormal reading without any form of validation and confirmation [3], [5].

The lack of automated motor control is another constraint identified in most of the reviewed works. This constraint is observed in works where there is a primary concentration on monitoring without control. This makes most of the systems prone to cases of water overflow and dry running [2], [4], [5]. Scalability and the limitations of long-term data management are also noted in various studies. Some systems may not have an efficient cloud-based data logging system, historical analysis tools, and the ability to evaluate trends. This limits the use of the system for long-term water management planning. In addition, the complexity of the system, the difficulties involved in calibrating sensors, and the need of constant internet connectivity are also observed as limitations for the system [1], [3].

2.2 Problem Statement

Water scarcity is becoming a major problem due to factors like urbanization, population increase, and water misuse. In some residential, industrial, and farming sectors, water consumption is not being monitored in real-time. This is causing issues like overconsumption, leakages, inaccurate billing, and delayed remedial actions. Conventional water meters do not offer real-time data or alerts, as they require manual reading. Therefore, a smart solution is needed that can help monitor water quantity, detect abnormal consumption, and send real-time data and alerts to users for efficient water utilization.

3. Proposed System

A. **Sensor-Based Data Collection:** This system utilizes a number of sensors, such as water flow, water level, pH, TDS, and turbidity sensors, which help in monitoring the necessary water parameters. The flow sensor is used for monitoring water consumption through the water inlet, whereas the water level and quality sensors are placed inside the water tank. These sensors help in collecting the necessary data for proper water management.

B. **Data Processing and Decision Making:** The central processing unit is an ESP32 microcontroller, which receives sensor data, calibrates it, and compares it with threshold values. The alert counter mechanism is employed to ensure abnormal conditions are detected before sending any alert. This helps prevent false alarms.

C. **Automatic Control Mechanism:** A control unit using a relay is connected to the ESP32, which can control the water pump motor automatically. The motor will be switched ON when the water level is low, and the motor will be switched OFF when the tank reaches its maximum capacity or the water quality becomes unsafe for use.

D. **Cloud Integration and User Interface:** The ESP32 sends the processed information to a cloud platform through Wi-Fi. Users can view information regarding water usage, quality, alerts, and the motor through a mobile application or a web interface. The information is stored in the cloud platform and can be analyzed later.

E. **Alert and Notification System:** The system also provides local and remote alerts using a buzzer and cloud-based notifications systems. The system sends out alerts when abnormal conditions are sustained. This ensures meaningful and reliable notification for the user.

3.1 Requirement and Functions

3.1.1 ESP32 Microcontroller

Figure 1. ESP32 Microcontroller

ESP32 is the brain of the system. It collects information from all the sensors, processes the information, connects to the Wi-Fi network, and drives the motor through the relay. The ESP32 enables real-time monitoring and automation. The Wi-Fi module is used to transmit the information to the cloud platform. The mobile app is used for real-time information display and system status.

3.1.2 Water Level Sensor

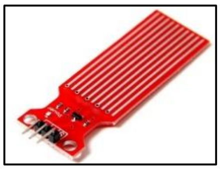

Figure 2. Water Level Sensor

The Water level sensor detects the quantity of water present in the tank. It prevents overflow and ensures that the motor switches off when the tank is full. It detects the water level in the tank, prevents overflow, and enables automatic motor control.

3.1.3 Flow Sensor

Figure 3. Flow Sensor

The flow sensor is used to detect the volume of water entering the tank. It is helpful for tracking water usage and identifying abnormal flow states. It measures water usage, tracks usage, and helps analyze usage.

3.1.4 Water Quality Sensors (pH, TDS, Turbidity)

Figure 4. Water Quality Sensors

These sensors monitor the quality of the water inside the tank. They help in detecting impurities in the water so that it is safe for use. Monitor water quality parameters, ensure safe water, and detect contamination early.

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3.1.5 Relay Module

Figure 5. Relay Module

The relay module is for controlling the water pump motor. It switches the motor ON or OFF automatically based on the system's decision. It switches the motor ON/OFF, enables automatic pump control, and prevents manual effort.

3.2 System Architecture

The proposed system architecture Figure 6, as discussed above, indicates a layer-based design concept for ensuring modularity, scalability, and data processing efficiency. As shown in Figure 6, the system architecture is based on four main layers: the Sensor Layer, Communication Layer, Process Layer, and Application Layer. This layer-based abstraction helps in seamlessly integrating hardware, data processing, and applications.

The Sensor Layer, at the lowest level, is responsible for acquiring environmental data in real time. This layer consists of several sensors for acquiring different parameters of the water system, such as water level sensors, flow sensors, pH sensors, total dissolved solids (TDS) sensors, turbidity sensors, and others Each of these sensors is responsible for acquiring different physical or chemical properties of the water system. The overall combination of all these heterogeneous inputs helps in acquiring a complete picture of the system, which serves as the primary source of data for processing.

The Communication Layer serves as an interface between sensors and computing units. The output of the sensors is fed to microcontrollers, which act as the main aggregators of data. This layer ensures the proper transmission of signals and synchronization of various modules of sensors. The integration of various sensors into a single communication system facilitates continuous monitoring and handling of sensor data.

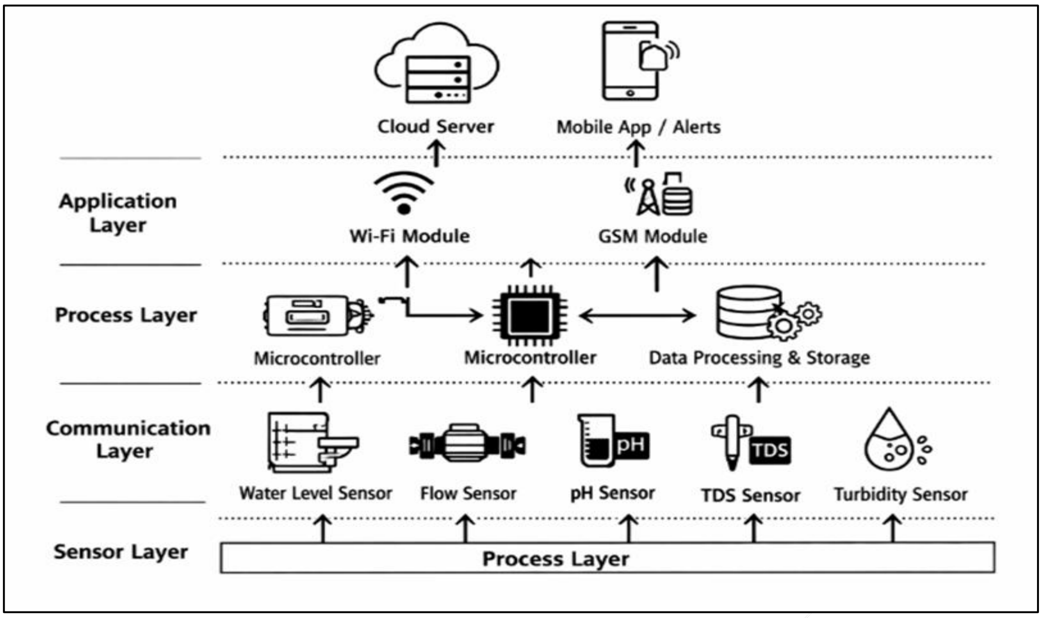

Figure 6. Architecture Layers

The Process Layer involves the processing of data, control logic execution, and storage. The microcontrollers of this layer receive input from sensors and process the signals. They then send the processed signals to a centralized unit for data processing and storage. This unit is responsible for managing structured data sets and processing them for intermediate analytics before transmitting them to higher layers. The two-way communication between microcontrollers and storage modules facilitates efficient handling of data.

The Application Layer is responsible for external communication and user interaction. The processed data is sent through Wi-Fi and GSM communication modules for transmission to cloud servers and mobile applications. The Wi-Fi module is responsible for synchronizing data in real-time using cloud infrastructure. At the same time, the GSM module is responsible for alert-based communication, allowing users to receive notifications and updates through mobile applications. The system architecture is capable of providing an end-to-end data flow from physical sensors to intelligent decision-making. The use of IoT-based communication modules and processing layers ensures scalability, reliability, and real-time response. This system architecture is suitable for smart monitoring systems, allowing for data-driven management and remote supervision of environmental or industrial systems

3.3 Methodology

As illustrated in Figure 6, the Aqua Sense system starts with the acquisition of data from the various sensors installed in the water tank and the pipeline. The level sensors detect the amount of water stored in the overhead tank, whereas the flow sensor detects the rate of consumption of water, including abnormal flow that may result in leakage during the supply process. At the same time, the quality of the water is monitored by the pH, TDS, and turbidity sensors, which detect the quality of the water in real time to determine its suitability for consumption by the household. The data collected by the sensors are then processed by the microcontroller unit, which acts as the CPU of the entire system. The microcontroller compares the data collected by the sensors with the threshold limits stored in the memory of the microcontroller to make decisions automatically, such as turning the pump ON if the level of water in the tank is low and turning the pump OFF if the level of water in the tank reaches maximum capacity.

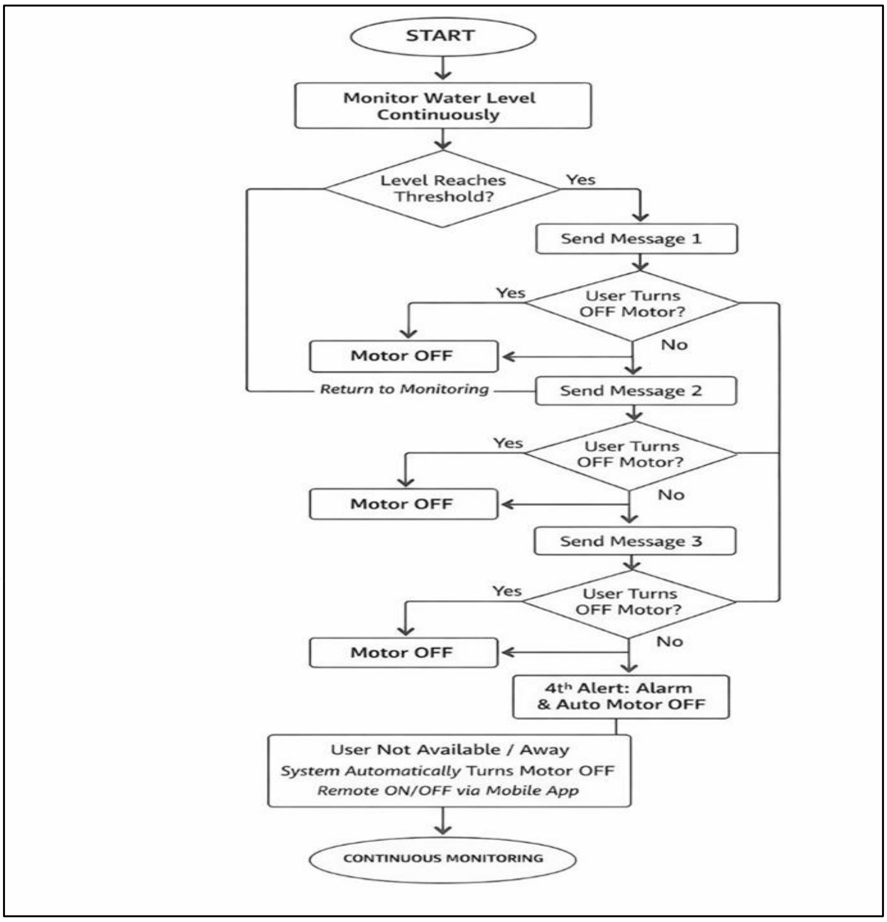

Figure 7. Workflow Diagram

To avoid false alarms, the proposed system uses the response-based alert method, where the alert will be sent only when the abnormal conditions are maintained for a certain number of readings. As soon as the abnormal conditions are identified, the alert message will be sent to the user through the mobile application, SMS, or notification service, which will notify the user of the issues, i.e., overflow, leakage, poor quality of water, and flow rate. The proposed workflow will help in intelligent water management, efficient control, and alert systems, which will significantly save water.

The system offers real-time monitoring of water level, flow rate, and water quality, ensuring prompt detection of abnormalities. Automated Water Management offers automatic motor control for on/off to avoid overflows and motor dry-running. Water Quality Assurance monitoring of pH, TDS, and turbidity helps in the early detection of water contamination, improving water safety for domestic use. Reduced Water Wastage through early detection of water leakage and flow control helps minimize water wastage and promotes water conservation. Cloud-Based Accessibility makes the system accessible anywhere, anytime, through a mobile/web dashboard, enabling users to monitor water usage remotely. Accurate Alerts with Reduced False Alarms feature sends reliable alerts by notifying users only when abnormal conditions are detected. Logging and Analysis allow the system to store data for water usage analysis, system evaluation, and decision-making. Scalable and Flexible Design means the system design is flexible and easy to scale for multiple tanks and systems. Cost-Effective Solution reduces costs by preventing water wastage and equipment damage, providing a cost-effective solution for water management. Environmentally Sustainable practices are supported through efficient water monitoring and conservation.

The Figure 7 depicts a continuous IoT-based water monitoring control system where sensing, processing, communication, and control are combined in a closed-loop fashion. The process is continuous in nature, allowing real-time monitoring, analysis, and control.

The first step of the process begins at the water source and sensing stage. In this phase, several sensors are placed within the water tank and pipeline. The water level sensor constantly records the amount of water present in the tank, ensuring that the maximum and minimum levels can be monitored. In parallel to this, the flow sensor records the flow of water through the pipeline, allowing the user to understand the usage of the pipeline and detect any possible leaks.

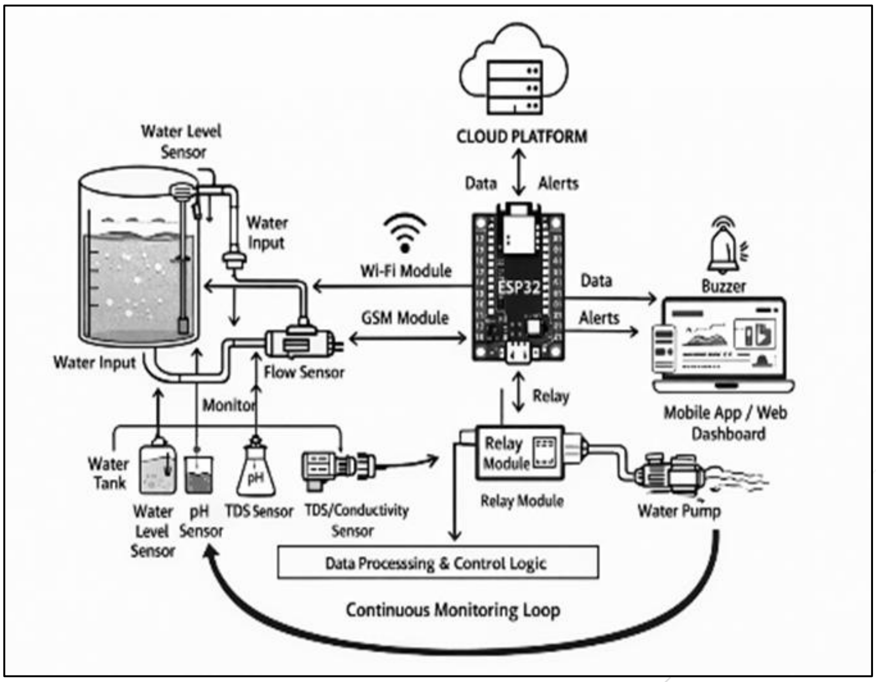

Figure 8. Proposed Framework

Additionally, several sensors are placed to record the quality of the water, including pH sensors, TDS sensors, and conductivity sensors. These sensors work together to ensure that the quality of the water is accurately recorded. The sensors represent the water quality as a series of data points. The recorded sensor data is then fed into a central processing unit, which is an ESP32 microcontroller. This microcontroller serves as the main controlling unit of the entire system. In this phase, the microcontroller performs several operations on the recorded sensor data. The recorded sensor data and prepares it for further use.

For the purpose of communication, the system employs a combination of Wi-Fi and GSM modules. The Wi-Fi module will ensure continuous communication with a cloud platform, where the received data will be stored, analyzed, and visualized. The inclusion of a cloud platform in the system will enable remote monitoring, allowing the user to track the system's conditions in real-time, including history and analysis, through a mobile application. Based on the thresholds set and defined in the ESP32, the system will be able to send alarms in case of unusual conditions, such as low water levels, low water quality, and flow rate, through a mobile application and buzzer for awareness.

In the system, an automated control mechanism exists in addition to monitoring. This is where the relay module receives control signals from the ESP32. The relay module serves as the interface between high-power and low-power devices. In this system, the water pump's control is managed by the relay module, ensuring effective management of the water system by eliminating the possibilities of water overflow and dry running of the water pump. The system operates in a loop where the collection, processing, and transmission of necessary actions are performed while the sensors are being monitored. The system's architecture includes the Internet of Things, the cloud, and the user as integral components for the effective management of water and also possible to automatic cleaning which helps to save time a 286 optional feature of internal maintenance of tank.

4. Result and Discussion

The proposed system was implemented and tested under real-time operating conditions. It was successfully tested for its efficiency in monitoring water quantity and quality. The system was able to collect sensor readings from the water level sensor, water flow sensor, pH sensor, TDS sensor, and water turbidity sensor, transmitting them to the cloud platform almost in real-time. The system successfully detected the low and highwater levels, which can automatically switch the motor ON/OFF. The water flow sensor was able to detect abnormal water usage that may indicate a leak. Water quality was normal; however, abnormal readings were detected when limits were exceeded.

The system implemented a alert counter mechanism that can prevent false alarms by sending alerts only after repeated abnormal readings. It was also able to visualize the sensor readings from the connected sensors through the cloud platform. The experimental observations demonstrated the efficiency of the proposed system. Figure 8 shows the hardware output of the proposed model.

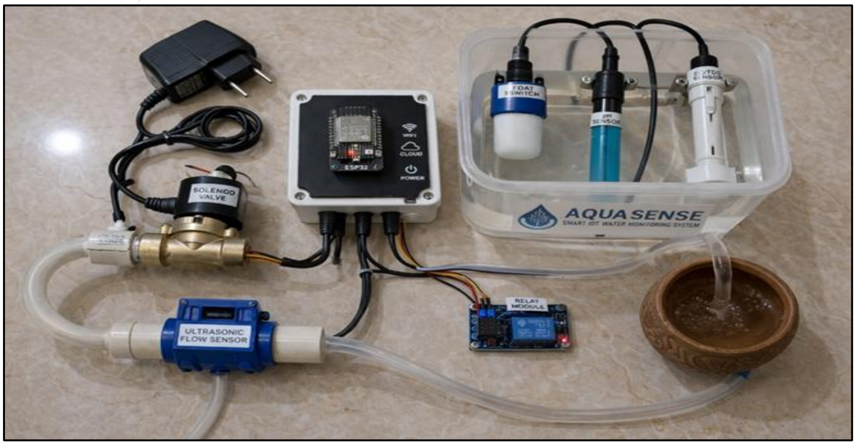

Figure 9. Prototype Model of the Proposed Work

Figure 10. Real-time Smart Water Monitoring Dashboard

As shown in Figure 9, there is a web-based platform for real-time monitoring of water quality and quantity using four analytical panels. The top-left panel indicates changes in water level over time, suggesting dynamic usage for automated pump control. The top-right panel indicates flow rate, which reveals usage patterns that are important for detecting anomalies. The bottom-left panel shows constant pH levels between 6 and 8, indicating good water quality. The bottom-right panel displays Total Dissolved Solids (TDS), reflecting changes in water composition.

Figure 10 enables real-time visualizations through four main plots for water level, flow rate, pH value, and TDS concentration, respectively. The water level graph has shown substantial fluctuations, which could mean that the water is being used and even drained completely. The flow rate graph has shown varying flow, which could indicate that water is being transferred, thus relating to the water level graph. The pH value has remained constant, which could suggest that the water is of good quality. However, the TDS graph has shown variation, which could mean that the water composition is changing. Overall, the dashboard has visualized the sensor data, thus assisting users in understanding the system and ensuring water quality compliance.

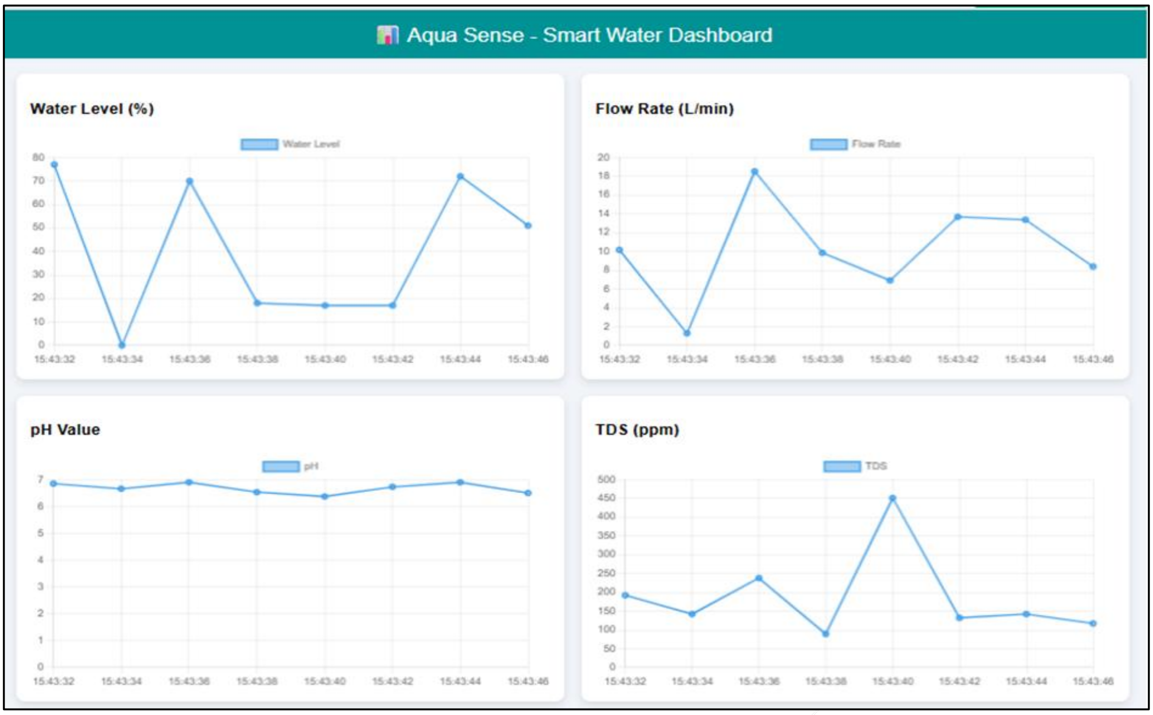

Figure 11. Dashboard Illustrating Temporal Variations

5. Conclusion

This paper proposes a new IoT-based smart water monitoring and control system, named Aqua Sense, which can be used for efficient water usage management and water quality analysis. This system uses different sensors along with an ESP32 microcontroller for real-time monitoring and decision-making, which can be accessed through a cloud-based interface. This system can efficiently monitor water parameters and also cancel false alarms with the help of an alert counter system. Moreover, the automated control system can increase efficiency by avoiding overflow and dry-running conditions. This system can be used for a wide range of applications, making it a cost-effective solution for efficient water management practices.

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