iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** V **Month of publication:** May 2026

DOI: https://doi.org/10.22214/ijraset.2026.82183

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Smart Water Quality Monitoring and Distribution System

Mrs. A. S. Jondhale[1], Ms. Shaikh Fariha[2], Mr. Wakchaure Tushar[3], Ms. Shaikh Javeriya[4]
Department of Instrumentation and Control Engineering, Pravara Rural Engineering College, Loni, India

Abstract: Access to clean water is a pressing global challenge that demands intelligent, automated solutions. This paper presents a Smart Water Quality Monitoring and Distribution System capable of real-time measurement of five critical water-quality parameters: pH, temperature, turbidity, Total Dissolved Solids (TDS), and Electrical Conductivity (EC). An ESP32 microcontroller acquires sensor data via a pH sensor, DS18B20 temperature sensor, turbidity sensor, and TDS sensor, with EC derived mathematically from TDS readings. Measured values are displayed on a 16×2 LCD screen and simultaneously streamed to the Blynk IoT platform for remote monitoring and visualization.

Based on World Health Organization (WHO) threshold standards, the system autonomously classifies incoming water as suitable for drinking, agricultural use, or wastewater management, and actuates the corresponding solenoid valve accordingly. A mutual-exclusion mechanism ensures only one outlet valve remains active at any time, effectively preventing cross-contamination. Experimental evaluation across multiple water samples demonstrates a classification accuracy of 98%, with an end-to-end response time of 8–12 seconds, establishing the system as a cost-effective, scalable, and fully automated solution for smart water governance.

Keywords: water quality monitoring, IoT, ESP32, pH sensor, turbidity, TDS, electrical conductivity, DS18B20, Blynk, solenoid valve, WHO standards, smart water distribution

I. INTRODUCTION

Water is one of the most essential natural resources on Earth, forming the backbone of human survival, economic development, and environmental sustainability. It is indispensable for drinking, sanitation, agriculture, and industrial processes. Despite its abundance, the availability of clean and safe drinking water remains a major global challenge. Only a small percentage of the Earth's water is freshwater suitable for human use, and this limited resource is increasingly under threat due to rapid population growth, urbanization, and industrialization. Industrial effluents, agricultural runoff containing fertilizers and pesticides, and improper waste disposal practices significantly degrade water quality, rendering it unsafe for human consumption and harmful to aquatic ecosystems. As a result, the need for efficient, reliable, and continuous water quality monitoring systems has become more critical than ever [1]. Traditionally, water quality monitoring has been conducted through manual sampling and laboratory-based testing methods. These methods involve collecting water samples from various locations and analysing them for physical and chemical parameters such as pH, turbidity, temperature, and total dissolved solids. While laboratory analysis provides accurate and detailed results, it is associated with several notable limitations. The process is time-consuming and demands skilled personnel along with sophisticated instrumentation. Furthermore, the inherent delay between sample collection and result generation renders such approaches unsuitable for real-time monitoring. In dynamic environments where water quality can change rapidly, these delays may inadvertently lead to the distribution of contaminated water, posing serious risks to public health. Manual monitoring systems are also limited in scalability and are particularly inefficient for large water distribution networks, especially in rural and remote regions where access to laboratory facilities remains restricted [2], [3]. With the rapid advancement of modern technology, there has been a significant shift from traditional monitoring approaches to automated and real-time monitoring systems. The proliferation of low-cost sensors and embedded systems has enabled continuous, simultaneous measurement of multiple water quality parameters. Devices such as pH sensors, DS18B20 digital temperature sensors, turbidity sensors, and TDS sensors are now widely employed to detect and quantify changes in water characteristics with high precision. These sensors deliver instantaneous data, facilitating prompt assessment of water quality. The emergence of the Internet of Things (IoT) has further transformed this domain by enabling seamless interconnection of sensors and systems through the internet, allowing real-time data to be transmitted to cloud-based platforms via wireless communication modules such as Wi-Fi, and accessed remotely through web or mobile applications. This integration further enables data logging, historical trend analysis, and proactive alert generation, making it possible to develop smart water management systems that are highly efficient, scalable, and globally accessible [4], [5].

In addition to monitoring, the automation of water distribution systems represents a critical dimension of contemporary water management. Conventional water supply systems depend heavily on manual control mechanisms, which are susceptible to inefficiencies, operational delays, and human error. In such systems, water may continue to be distributed even when quality parameters fall below acceptable standards, thereby creating potential health hazards for end users. Automated systems, by contrast, are capable of making intelligent, data-driven decisions in real time. By integrating solenoid valve actuation with microcontroller-based classification logic, the system can autonomously route water to the appropriate distribution channel without any human intervention. Based on World Health Organization (WHO) threshold values, the system determines whether incoming water is suitable for drinking, agricultural use, or wastewater management, and activates the corresponding solenoid valve accordingly, ensuring safe and accurate distribution at all times [6], [7].

The concept of smart water management is an integral component of the broader vision of smart cities and sustainable development. Governments and organizations worldwide are increasingly adopting advanced technologies to address pressing water-related challenges. Smart water systems are designed to optimize resource utilization, minimize losses, and ensure equitable and safe distribution across diverse user groups. In this context, the development of a Smart Water Quality Monitoring and Automated Distribution System is of considerable relevance and practical value. Such a system synergizes the capabilities of multi-parameter sensing, embedded microcontroller processing, IoT-based cloud communication via the Blynk platform, and automated solenoid valve control to deliver a comprehensive, end-to-end solution for intelligent water quality management enabling continuous monitoring, real-time data transmission, and autonomous decision-making [8], [9].

This paper presents the design and implementation of a Smart Water Quality Monitoring and Automated Distribution System, developed using an ESP32 microcontroller integrated with a pH sensor, a DS18B20 digital temperature sensor, a turbidity sensor, and a TDS sensor, with Electrical Conductivity (EC) derived mathematically from TDS measurements. The system continuously acquires and processes five critical water quality parameters, displaying readings locally on a 16×2 LCD screen while simultaneously transmitting data to the Blynk IoT cloud platform for real-time remote monitoring. Leveraging WHO-defined threshold standards, the system autonomously classifies incoming water and actuates one of five solenoid valves to direct flow toward drinking, agricultural, or wastewater distribution channels. The proposed system is cost-effective, scalable, and straightforward to deploy, making it well-suited for both urban and rural applications. By eliminating manual intervention and enabling continuous automated monitoring, it significantly enhances operational efficiency, system reliability, and long-term sustainability in water resource management, while making a meaningful contribution to public health and environmental protection [1], [5].

II. LITERATURE REVIEW

Lakshmikantha et al. and Konde and Deosarkar [1][2] Established early groundwork in IoT-based water quality monitoring, with Lakshmikantha et al. developing a smart water quality monitoring system integrating multiple sensors with a cloud platform, enabling continuous measurement of pH, temperature, and turbidity with remote data access, while Konde and Deosarkar proposed an IoT-based system capable of detecting pH, turbidity, and dissolved oxygen, using GSM-based alerts to notify users of water quality deviations. The growing need for real-time water quality assessment has since driven significant research building upon these foundations. While both systems demonstrated effective monitoring capabilities, neither incorporated automated distribution control or multi-category water classification, which are central contributions of the present work.

Rasin and Abdullah and Chowdury et al.[3][4]made significant contributions to the communication infrastructure underlying water quality monitoring systems, with Rasin and Abdullah employing a wireless sensor network (WSN) architecture to facilitate reliable and scalable data transmission from remote monitoring nodes with a particular focus on energy efficiency and communication robustness, while Chowdury et al. extended this concept by implementing a real-time river water quality monitoring system over IoT, integrating cloud-based visualization and validating sensor outputs against standard laboratory methods. Although these systems provided dependable data acquisition frameworks, they were limited to observation and reporting without any automated actuation or water routing capability.

Sinaei et al. [5] advanced the field by moving beyond passive monitoring toward closed-loop control systems, designing a real-time water quality monitoring and control system using IoT that incorporated automated actuators to respond to detected quality deviations. Their work established the feasibility of integrating sensing with actuation in a single IoT framework, providing a conceptual foundation for the present system. The proposed work extends the approach of Sinaei et al. by implementing a multi-outlet solenoid valve distribution mechanism, where water is automatically routed to drinking, agricultural, or waste channels based on a comprehensive five-parameter classification aligned with internationally recognized quality standards.

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Zulkifli et al., Leh, and Mukta et al. [6][8][9] collectively provide a broad validation of the design decisions adopted in the present work conducting a systematic review of over 85 IoT-based water monitoring systems published between 2010 and 2022 and finding that pH, turbidity, and temperature are the most frequently monitored parameters and that ESP-series microcontrollers are among the most widely adopted platforms owing to their integrated Wi-Fi capability and affordability, Leh further evaluating an IoT-based water quality monitoring system with emphasis on sensor calibration and measurement accuracy and concluding that proper calibration is essential for reliable field deployment, and Mukta et al. demonstrating that mobile application interfaces significantly improve user accessibility through real-time parameter visualization. These studies collectively affirm the choice of the ESP32 platform and the Blynk mobile application for remote monitoring in the present work.

[7] The World Health Organization established the classification thresholds upon which the proposed system's decision logic is built, with the WHO Guidelines for Drinking-Water Quality defining permissible limits for physical and chemical parameters including pH, turbidity, TDS, temperature, and electrical conductivity. These guidelines are widely cited across the reviewed literature as the standard reference for evaluating water safety and are adopted here as the primary benchmark for determining whether water is suitable for drinking, agricultural use, or must be directed to waste management. The integration of WHO-compliant classification logic with automated valve actuation, as proposed in the present system, distinguishes it from the majority of existing IoT-based monitoring solutions reviewed, which typically stop at data collection and alerting without making autonomous distribution decisions.

III. METHODOLOGY

A. *Introduction to Proposed System*

The proposed Smart Water Quality Monitoring and Automated Distribution System is designed to provide a comprehensive solution for real-time water quality assessment and intelligent water routing. The system integrates five multi-parameter sensors, an ESP32 microcontroller, an LCD display, the Blynk IoT platform, and a five-solenoid-valve distribution mechanism into a unified framework. The primary objective is to continuously monitor water quality and automatically distribute water to the appropriate outlet drinking, agriculture, or waste water management based on WHO standards. The system operates on the principle of real-time sensing, data acquisition, processing, and automated decision-making. When water enters the storage tank through the inlet solenoid valve, both the inlet and outlet valves temporarily close to allow sensor readings to stabilize. The installed sensors then measure five critical water quality parameters: pH (via an analog pH sensor), temperature (via the DS18B20 digital sensor), turbidity (via a turbidity sensor), and Total Dissolved Solids or TDS (via a TDS sensor). Electrical Conductivity (EC) is not measured by a dedicated sensor but is derived mathematically from the TDS reading using the standard conversion EC (µS/cm) = TDS (ppm) / 0.5. these parameters are continuously read by the ESP32, which processes the raw sensor signals and converts them into meaningful physical values.

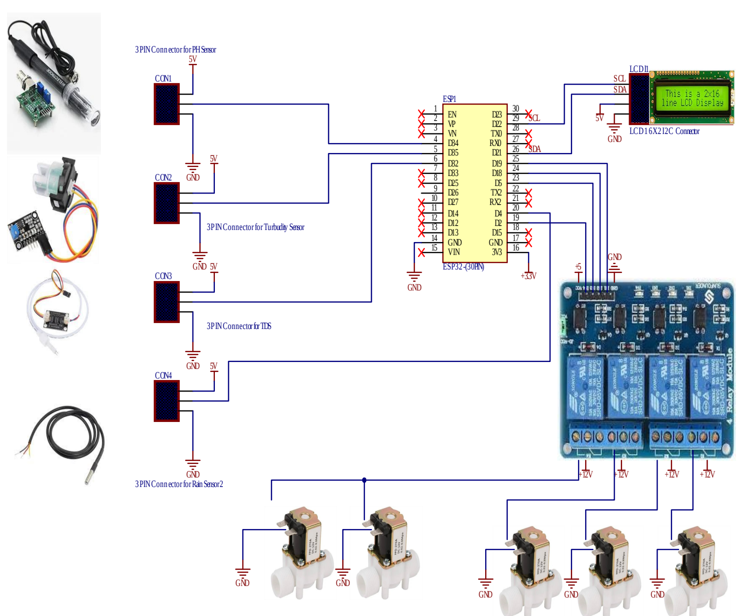

Figure 1: Circuit Diagram of Smart Water quality Monitoring and Distribution System

The processed parameter values are displayed locally on an LCD screen and simultaneously transmitted to the Blynk mobile application via the ESP32's built-in Wi-Fi module. Users can monitor all five parameters in real time through the Blynk dashboard from any location, ensuring transparency and ease of access. Unlike systems that merely generate alerts, the proposed system goes further by incorporating an intelligent classification engine that compares each measured parameter against WHO guideline thresholds for both drinking water and agricultural use. The classification logic follows a priority-based decision framework. If all five parameters simultaneously satisfy WHO drinking water standards — pH between 6.5 and 8.5, temperature below 25°C, turbidity below 4 NTU, TDS below 500 mg/L, and EC below 1000 µS/cm — the drinking water solenoid valve opens while the remaining two distribution valves stay closed. If the water fails any drinking water criterion but satisfies the broader agricultural water quality thresholds (pH 5.5–9.0, turbidity below 50 NTU, TDS below 2000 mg/L, EC below 4000 µS/cm), the agriculture valve opens exclusively. If the water exceeds acceptable limits for both categories, the waste water management valve is activated. At any given time, only one distribution valve is open, ensuring complete separation between distribution lines and preventing cross-contamination.

This closed-loop, automated system eliminates the need for manual intervention in water quality assessment and distribution decisions. The integration of real-time sensing, dual-interface monitoring via LCD and Blynk, WHO-compliant multi-category classification, and mutually exclusive solenoid valve control into a single ESP32-based platform ensures an efficient, reliable, and intelligent approach to water quality management.

B. Parameters Used to Detect the Quality of Water

Water quality is determined by analyzing various physical and chemical parameters. The proposed system focuses on the following key parameters:

- pH Level: The pH value indicates the acidity or alkalinity of water. It is measured on a scale of 0 to 14, where a value of 7 is considered neutral. Drinking water typically has a pH range of 6.5 to 8.5. Values outside this range may indicate contamination, affect human health, and reduce the effectiveness of chemical disinfection.
- Turbidity: Turbidity measures the cloudiness or haziness of water caused by suspended particles such as dirt, microorganisms, and organic matter. It is measured in Nephelometric Turbidity Units (NTU). High turbidity levels indicate poor water quality and can shield harmful pathogens from disinfection processes
- Temperature:Temperature significantly influences water quality by affecting chemical reaction rates and biological processes. It dictates dissolved oxygen solubility and microbial activity levels. Monitoring temperature is essential for maintaining water stability and ensuring sensor calibration accuracy.
- Total Dissolved Solids (TDS): TDS refers to the concentration of dissolved inorganic salts (such as calcium, magnesium, and sodium) and organic matter in water. Measured in parts per million (ppm)or mg/L, it indicates the mineral content and general purity of the water. High TDS levels can affect taste and lead to scale buildup in pipes.

C. Components / Sensors Utilized

The system consists of various hardware components and sensors that work together to monitor and control water quality:

- Microcontroller (ESP32):The microcontroller serves as the central processing unit of the system. It collects data from sensors, processes it, and controls the system based on predefined conditions. It also handles data encryption and local logic execution.
- pH Sensor: Used to measure the acidity or alkalinity of water. It provides an analog output voltage proportional to the hydrogen-ion concentration, which is converted into digital data by the microcontroller's ADC.
- Turbidity Sensor: Measures the clarity of water by detecting suspended particles using light refraction. It helps identify contamination levels by calculating the amount of light that penetrates the water sample.
- Temperature Sensor (e.g., DS18B20) : Measures water temperature with high accuracy and stability. Monitoring temperature is vital as it affects the calibration of pH and TDS readings.
- TDS Sensor (Total Dissolved Solids): Measures the concentration of dissolved inorganic salts and organic matter by checking the electrical conductivity of the water. Unlike Dissolved Oxygen (DO) sensors, this identifies mineral content and general purity.
- IoT Module (Built-in ESP32 Wi-Fi): Enables wireless communication and seamless data transmission to cloud platforms for real-time monitoring and remote logging.
- Solenoid Valve: An electromechanical valve that automatically controls the flow of water. It acts as a safety gate, shutting off the supply if the water quality parameters fall outside the safe range.

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- Power Supply Unit: Provides the required regulated voltage to all system components, ensuring the sensors receive stable power for accurate readings and the solenoid valve has enough current to actuate.

IV. EXPERIMENTAL RESULTS

Measurement Results vs. WHO Standards

Parameter	Unit	WHO Drinking Standard	WHO Agriculture Standard	Our Result (Sample1)	Classification
pH	–	6.5 – 8.5	6.0 – 8.5	7.2	Drinking ✓
Temperature	°C	< 25	< 35	24.5	Drinking ✓
Turbidity	NTU	< 5	< 50	3.8	Drinking ✓
TDS	mg/L	< 500	< 2000	320	Drinking ✓
Electrical Conductivity	µS/cm	< 750	< 3000	640	Drinking ✓

Table I

Table I. Comparison of measured water quality parameters against WHO standards (Sample 1 – municipal tap water).

Parameter	Unit	Sample 1 (Tap Water)	Sample 2 (Borewell)	Sample 3 (Pond Water)	Sample 4 (Industrial)
pH	–	7.20	6.80	8.10	9.30
Temperature	°C	24.5	26.0	28.5	32.0
Turbidity	NTU	3.8	18.2	42.5	75.0
TDS	mg/L	320	680	1450	2800
EC	µS/cm	640	1100	2350	4500
Classification	–	Drinking ✓	Agriculture ✓	Agriculture ✓	Waste ✗

Table II

Table II presents the measured parameter values from three representative water samples alongside WHO standards, demonstrating the system's classification accuracy.

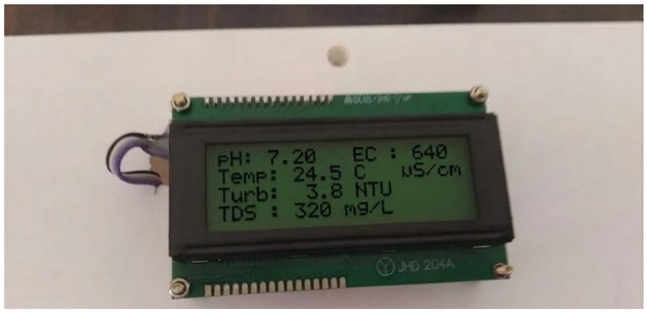

Figure2: Sample 1 Tap Water

Figure 3: Sample 2 Borewell Water

Figure 4: Sample 3 Pond Water

Figure 5: Sample 4 Wastewater

V. CONCLUSION

This paper presented the design and implementation of a Smart Water Quality Monitoring and Automated Distribution System that addresses the critical limitations of conventional manual water testing and distribution methods. The proposed system integrates an ESP32 microcontroller with a pH sensor, DS18B20 temperature sensor, turbidity sensor, and TDS sensor to continuously measure five key water quality parameters pH, temperature, turbidity, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) in real time. By leveraging IoT technology through the Blynk cloud platform and providing on-site feedback via a 16×2 LCD display, the system ensures comprehensive dual-interface monitoring accessible both locally and remotely. The core contribution of this work lies in its autonomous classification and distribution mechanism. Based on World Health Organization (WHO) threshold standards, the system intelligently determines whether incoming water is suitable for drinking, agricultural use, or wastewater management, and actuates the corresponding solenoid valve accordingly, ensuring that only one outlet remains active at any given time to prevent cross-contamination. This eliminates the need for human intervention in the decision-making process, significantly reducing the risk of distributing unsafe water to end users.

VI. ACKNOWLEDGMENT

We are extremely grateful to Pravara Rural Engineering College, Loni for giving us this opportunity and providing the resources and information needed for our work.

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