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JALRAKSHAK: IOT-BASED SMART WATER QUALITY MONITORING AND MULTI-PURPOSE CLASSIFICATION SYSTEM USING MACHINE LEARNING

An IoT-Based Framework for Continuous Water Quality Monitoring and Early Decision Support

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Abstract : Access to safe drinking water is a major public-health concern, particularly in rural and semi-urban communities that depend on groundwater sources. Conventional water-quality assessment generally relies on manual sampling and laboratory testing, which provides accurate measurements but does not support continuous surveillance or immediate user feedback. JalRakshak proposes an IoT-based framework that combines pH, Total Dissolved Solids (TDS), turbidity, and fluoride sensing with an ESP32 microcontroller, wireless communication, cloud-based data management, machine-learning analysis, and a mobile user interface. The proposed system is designed to collect water-quality measurements at sources such as borewells, storage tanks, and pipelines; transmit the readings through Wi-Fi; classify water according to intended use; detect abnormal conditions; and provide alerts and treatment-oriented recommendations. The planned classification categories are Drinking, Irrigation, Cleaning, and Unsafe. In the current implementation, the pH, TDS, and turbidity sensors were interfaced with the ESP32 and tested for data acquisition. The sensors demonstrated observable responses to changes in sample conditions, and Wi-Fi communication and basic data transmission were successfully demonstrated. The project is approximately ; therefore, machine-learning classification, complete sensor calibration, the final mobile application, and real-time notification features remain future implementation tasks.

IndexTerms - IoT, Water Quality Monitoring, ESP32, pH Sensor, TDS Sensor, Turbidity Sensor, Fluoride Sensor, Machine Learning, Water Classification, Early Alert System, Cloud Computing.

I. INTRODUCTION

Access to safe and clean drinking water is essential for human health and sustainable development. Water-quality degradation is a major environmental and public-health concern, particularly where rural and semi-urban communities depend heavily on borewell and groundwater sources. The project report identifies high Total Dissolved Solids (TDS), abnormal pH, and elevated turbidity as important water-quality concerns. Such changes are not always visible to users, making periodic observation insufficient for timely intervention.

Traditional water-quality monitoring commonly involves manual sample collection followed by laboratory testing. Although laboratory analysis can provide high analytical precision, the process is time-consuming, comparatively costly, and provides only a snapshot of the source condition. It therefore does not continuously observe transient contamination events or directly translate measurements into simple user guidance.

JalRakshak addresses this gap through an IoT-oriented architecture that combines multi-parameter sensing, an ESP32 microcontroller, wireless communication, cloud-oriented data management, planned machine-learning analysis, and a mobile interface. The overall objective is to move from raw measurement toward timely, understandable water-quality information.

1.1 Problem Statement

Existing monitoring solutions may either focus primarily on data collection or provide raw numerical measurements without meaningful interpretation. Users may find pH, TDS, and turbidity values difficult to understand without appropriate analysis. The proposed system therefore aims to integrate sensing, data transmission, analysis, classification, early alerts, and user-oriented recommendations in a unified framework.

1.2 Objectives

The objectives of JalRakshak are: (1) to design and develop a continuous water-quality monitoring system using IoT technology; (2) to measure pH, TDS, and turbidity; (3) to establish microcontroller-based data acquisition and transmission; (4) to analyze water-quality data and classify water according to intended use; (5) to identify abnormal or contaminated conditions; (6) to provide early warning alerts; (7) to suggest appropriate treatment or corrective measures; (8) to display water-quality information through a user-friendly application; and (9) to maintain historical data for analysis and future improvement.

II. RELATED WORK

The literature reviewed in the project report shows a progression from manual testing toward IoT-based sensing, cloud storage, machine-learning analysis, and actionable decision support. Jan et al. [1] discuss IoT-based water-quality monitoring and the use of low-cost sensors for continuous surveillance. Grbcic et al. [2] demonstrate the use of machine learning for identifying patterns in fluctuating water-quality parameters. Kumar et al. [3] emphasize IoT sensors and cloud monitoring, while Jain et al. [4] discuss supervised machine learning for water-quality prediction.

Further studies considered in the report examine real-time IoT and ML monitoring [5], cloud-based water-quality systems [6], hybrid machine-learning and IoT approaches [7], parameter-oriented water-quality analysis [8], sustainable water monitoring [9], data-driven water classification [10], and intelligent IoT-based monitoring with recommendation support [11]. These studies collectively support the use of multi-parameter sensing, cloud processing, historical data, and intelligent classification.

The project report identifies a practical gap: systems that collect sensor data do not necessarily provide simple, actionable information to end users. JalRakshak therefore proposes a combined architecture that links sensor acquisition with classification, alerts, recommendations, and mobile presentation.

III. PROPOSED SYSTEM

JalRakshak follows a multi-tier IoT architecture. The proposed workflow begins with sensing at the water source and progresses through edge processing, wireless transmission, cloud-oriented analysis, classification, and user feedback. The intended deployment environments include borewells, storage tanks, pipelines, rural water-supply systems, residential communities, educational institutions, and community water-storage facilities.

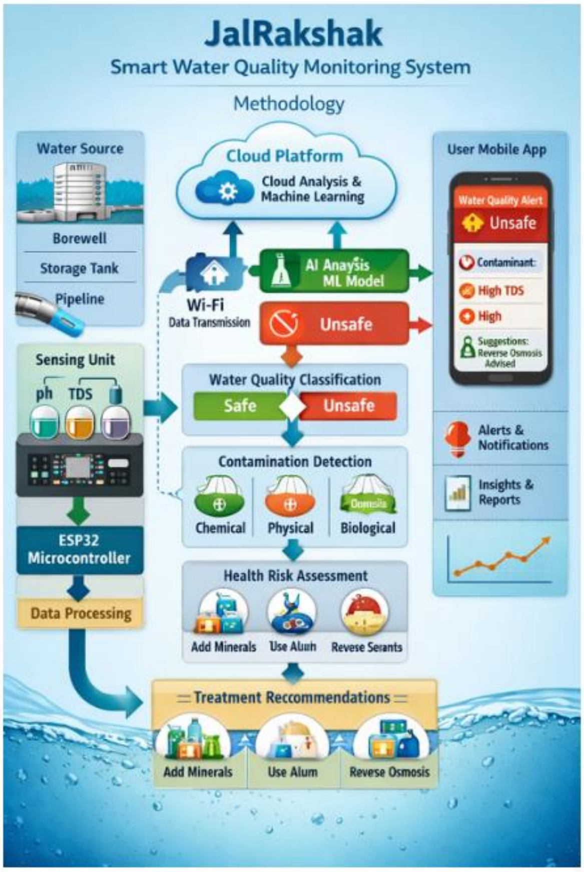

Figure 1. JalRakshak system methodology

TABLE 1. MAJOR STAGES OF THE PROPOSED JALRAKSHAK ARCHITECTURE

Stage	Components	Function
Data Acquisition	pH, TDS, turbidity and fluoride sensors	Capture water-quality parameters.
Edge Processing	ESP32	Read sensor outputs and prepare data for transmission.
Communication	ESP32 Wi-Fi	Transmit sensor readings to the data layer.
Cloud / Analytics	Firebase / ThingSpeak; Python; Scikit-Learn	Store readings and support planned ML analysis.
Decision Support	Classification and diagnostic logic	Determine water-use category and abnormal conditions.
User Interface	Flutter / Android	Display status, alerts and recommendations.

3.1 Hardware Components

The sensing node uses an ESP32 microcontroller together with pH, TDS, and turbidity sensors. The ESP32 is selected as the central processing and communication unit because it provides integrated Wi-Fi and sufficient GPIO capability for multiple analog sensors. The pH sensor measures hydrogen-ion activity to indicate acidity or alkalinity. The TDS sensor measures the concentration of dissolved solids in parts per million. The turbidity sensor uses optical measurement to indicate cloudiness associated with suspended particles.

3.2 Software and Technology Stack

Arduino IDE is used for ESP32 programming. Python is specified for building and training machine-learning models, with Scikit-Learn identified as the machine-learning framework. Firebase or ThingSpeak is specified for cloud/database functions, while Flutter/Android is planned for the user-facing application. The architecture keeps the sensing node lightweight and moves computationally heavier analytical operations to the cloud-oriented layer.

IV. METHODOLOGY

The methodology consists of six connected stages. First, the pH, TDS, turbidity, and fluoride sensors acquire raw measurements from the water source. Second, the ESP32 reads the analog outputs and performs basic processing. Third, the ESP32 transmits the sensor data through Wi-Fi. Fourth, the data is stored and prepared for analysis. Fifth, the planned machine-learning and diagnostic layer analyzes the measurements to classify water and identify abnormal conditions. Finally, the result is intended to be delivered to the user through alerts, recommendations, and a mobile interface.

4.1 Water-Quality Classification

The proposed classification model is intended to categorize water into four practical usability classes: Drinking, Irrigation, Cleaning, and Unsafe. The classification is designed to consider the combined behavior of pH, TDS, turbidity, and fluoride instead of depending on one parameter alone. The system is also designed to identify contamination as chemical, physical, or biological and use the diagnosis to support corrective guidance.

4.2 Diagnostic and Alert Logic

The project report describes example threshold conditions, including TDS greater than 500 ppm and turbidity greater than 5 NTU, as part of the proposed diagnostic logic. These values are used to support identification of abnormal conditions and recommendations in the proposed workflow. Before real-world deployment, sensor calibration and validation against appropriate water-quality standards are required.

The intended feedback loop is: sensor acquisition → data transmission → analytical processing → classification/diagnosis → alert generation → recommendation → user display. Historical records are also intended to support trend analysis and future improvement of the classification model.

V. IMPLEMENTATION AND PRELIMINARY RESULTS

JalRakshak is designed as an integrated water-quality monitoring and decision-support system. The proposed implementation combines hardware sensing, wireless communication, data management, intelligent analysis, classification, alerts, and user interaction to provide a complete workflow for water-quality assessment.

5.1 Hardware Setup

The sensing layer consists of pH, TDS, turbidity, and fluoride sensors connected to an ESP32 microcontroller. The ESP32 reads the sensor outputs and prepares the measurements for further processing. The combined sensing approach enables the system to observe changes in acidity or alkalinity, dissolved solids, and suspended particles. The fluoride sensor is intended to detect fluoride-ion concentration in water, adding an important chemical parameter to the overall water-quality assessment.

TABLE 2. PRELIMINARY SENSOR AND COMMUNICATION OBSERVATIONS

Test condition	Observed response	Inference
Different water samples / slightly acidic solution	pH values varied	pH sensor responded to sample-condition changes.
Water with added salt	TDS value changed	TDS sensor detected changes in dissolved solids.
Cloudy water / suspended particles	Turbidity increased	Turbidity sensor responded to suspended matter.
Wi-Fi communication test	Connection and data transmission successful	Communication layer was demonstrated.

5.2 Communication and Data Transmission

The ESP32 uses Wi-Fi communication to transmit the acquired sensor measurements to the cloud or data-management layer. The transmitted data can then be stored, analyzed, and used for historical trend monitoring and intelligent decision support.

5.3 Current Limitations of the Prototype

The system is designed to support sensor calibration, machine-learning analysis, historical data storage, real-time notifications, and a user-friendly mobile interface. Appropriate calibration and validation are required to ensure reliable measurements before practical deployment.

VI. DISCUSSION

The proposed architecture demonstrates how a low-cost ESP32-based sensing node can be used for continuous water-quality data acquisition. The combined response of the three sensors provides a basis for monitoring variations in the measured parameters, while wireless communication enables remote access to the collected information.

Reliable water-use decisions require calibrated sensors, representative water-quality data, and appropriate model evaluation. The proposed system therefore incorporates data preprocessing, supervised machine-learning classification, diagnostic logic, and historical analysis so that raw sensor measurements can be transformed into understandable water-use information.

VII. FUTURE WORK

The system can be extended through improved sensor calibration, larger and more representative datasets, supervised machine-learning model evaluation, robust cloud storage, mobile application integration, real-time alerts, treatment recommendations, and optimization for reliability and scalability.

VIII. CONCLUSION

JalRakshak presents an IoT and machine-learning-oriented framework for water-quality monitoring and multi-purpose water classification. The architecture integrates pH, TDS, and turbidity sensing with an ESP32-based communication node, cloud-oriented data management, intelligent analysis, and a mobile interface. The system is designed to transform sensor measurements into understandable water-use classifications and timely alerts.

The proposed end-to-end system provides a foundation for continuous monitoring, intelligent classification, early warning, and user-oriented decision support. Validation with calibrated sensors, representative datasets, and appropriate performance evaluation is essential to establish its reliability for real-world water-quality applications.

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