



Design and Prototyping of a Low-Cost, Automated Water Quality Analysis and Reporting System for Rural and Urban Water Sources

Praveen Ashok M¹, Syed Moula Hussain², T Mohamed Shahid², Mohammed Muzammil², Mohammed Mehtab²

¹Assistant Professor, Department of Civil Engineering
Ballari Institute of Technology and Management, Ballari, Karnataka, India

²U.G Students, Department of Civil Engineering
Ballari Institute of Technology and Management, Ballari, Karnataka, India

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ABSTRACT

Water quality monitoring is essential for safeguarding public health, environmental sustainability, and efficient water resource management. Conventional laboratory-based methods, although accurate, are costly, time-consuming, and unable to capture real-time variations in water quality. This study presents the design and prototyping of a low-cost, automated water quality analysis and reporting system capable of continuous monitoring in both rural and urban environments.

The system integrates multiple sensors for measuring pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), and temperature using an ESP32 microcontroller. Advanced features such as calibration tracking, quality assurance flags, temperature compensation, and real-time data transmission via IoT platforms are incorporated to enhance reliability. The system supports local visualization through an LCD display and remote monitoring using the ThingSpeak cloud platform.

Experimental validation demonstrates acceptable accuracy with pH error within ± 0.05 , turbidity error within $\pm 3\%$, and EC accuracy within $\pm 1\%$. The system effectively detects real-time variations and provides alerts for unsafe conditions. The proposed solution is cost-effective, portable, and energy-efficient, making it suitable for deployment in resource-constrained environments. This work highlights the potential of integrating embedded systems and IoT technologies for scalable and reliable water quality monitoring.

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Keywords

Water Quality Monitoring, IoT, ESP32, pH, Turbidity, TDS, EC, Calibration, Real-Time Monitoring



I. INTRODUCTION

Water quality monitoring plays a crucial role in ensuring safe drinking water, protecting ecosystems, and maintaining efficient water treatment systems. However, increasing urbanization, industrial discharge, and agricultural runoff have significantly degraded water quality in both rural and urban regions.

Traditional monitoring methods rely on periodic sampling and laboratory analysis. While these methods provide high accuracy, they suffer from limitations such as delayed results, high operational costs, and inability to capture transient variations in water quality. Events such as sudden turbidity spikes after rainfall or rapid pH fluctuations due to contamination often go undetected.

Recent advancements in sensor technology, embedded systems, and IoT have enabled the development of automated monitoring systems capable of real-time data acquisition. These systems provide continuous monitoring and enable early detection of contamination events. This study aims to design and prototype a low-cost automated water quality monitoring system that integrates sensing, processing, and reporting capabilities while maintaining accuracy, reliability, and affordability.

II. LITERATURE SURVEY

IoT-based water quality monitoring systems have gained significant attention due to their ability to provide real-time data and remote accessibility. Zulkifli et al. conducted a comprehensive review highlighting the integration of sensors, wireless communication, and cloud platforms in modern monitoring systems.

Studies by Padma et al. and Muriithi demonstrated the use of ESP32 microcontrollers with multiple sensors for continuous monitoring of parameters such as pH, turbidity, and TDS. These systems enable real-time visualization but often lack proper calibration and quality assurance mechanisms.

Camargo et al. analyzed low-cost sensors and identified limitations such as sensor drift, reduced accuracy, and sensitivity to environmental conditions. Their study emphasized the need for calibration protocols and validation against standard methods.

Advanced approaches incorporating machine learning, such as LSTM models and self-organizing maps, have been explored for predictive analysis. However, these methods increase system complexity and cost. Despite significant advancements, many existing systems lack a balance between cost, accuracy, reliability, and field deployability. This study addresses these gaps by integrating calibration tracking, QA mechanisms, and robust system design.

III. METHODOLOGY

A. System Overview

✓ The system is designed to continuously monitor key water quality parameters using sensor-based measurements integrated with a microcontroller. The architecture includes sensing, signal conditioning, data acquisition, processing, communication, and reporting modules.

B. Sensor Selection and Measurement Principles

✓ **pH Sensor:** Measures hydrogen ion concentration using a glass electrode. The output voltage follows the Nernst equation and requires calibration for slope and offset.

✓ **Turbidity Sensor:** Uses infrared light scattering (ISO 7027 principle) to measure suspended particles in water.

✓ **EC/TDS Sensor:** Measures electrical conductivity using AC excitation to avoid electrode polarization. TDS is derived from EC using a conversion factor.

✓ **Temperature Sensor:** Used for compensation and monitoring physical conditions.



C. Data Acquisition and Processing

- ✓ The ESP32 microcontroller collects sensor data at regular intervals. Signal conditioning techniques such as filtering and amplification are applied to improve accuracy. Raw sensor outputs are converted into engineering units using calibration equations.
- ✓ Temperature compensation is applied for pH and EC measurements to minimize thermal errors.

D. Calibration and Quality Assurance

- ✓ Calibration is performed using standard solutions:
- ✓ pH: Buffer solutions (4, 7, 10)
- ✓ Turbidity: Standard NTU solutions
- ✓ EC: KCl standards
- ✓ Quality assurance mechanisms include:
- ✓ Stability checks
- ✓ Range validation
- ✓ Sensor drift monitoring
- ✓ QA flags (valid, suspect, out-of-range)

E. IoT Integration and Communication

- ✓ The system uses Wi-Fi communication to transmit data to the ThingSpeak platform. Data is stored, visualized, and analysed through cloud dashboards. Local storage and buffering ensure data integrity during communication failures.

F. Working Process

- ✓ Sensors measure water parameters
- ✓ Data is processed by ESP32
- ✓ Calibration and validation applied
- ✓ Results displayed locally
- ✓ Data transmitted to cloud
- ✓ Alerts generated for unsafe conditions

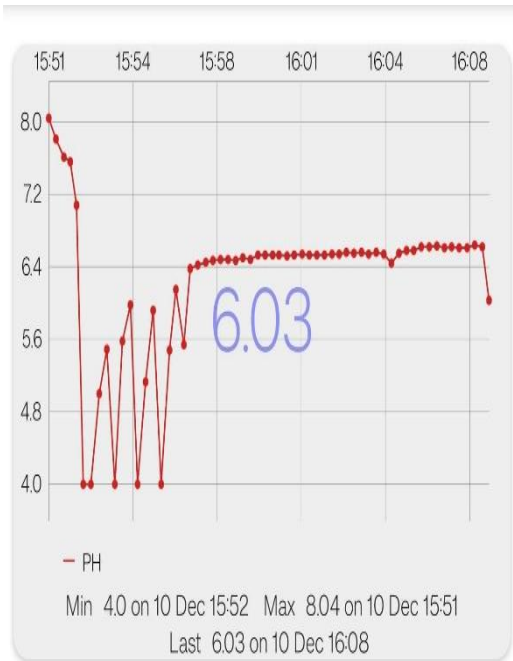
IV. RESULTS AND GRAPHICAL REPRESENTATION

The system was tested using various water samples including tap water, bore water, canal water, and commercial beverages

Sl. No	Sample Description	pH	Turbidity (NTU)	TDS (mg/L)	Temperature (°C)
1	Tap Water (Ballari)	7.1	1.8	420	25
2	Tap Water (Hospet)	7.4	2.1	450	24
3	Distilled Water	6.5	0.0	5	23
4	Canal Water	6.7	12.5	360	28
5	Filtered Water	7.3	0.9	120	22
6	Bore Water	6.9	3.8	650	26
7	Coca-Cola	2.5	0.0	1050	22
8	Sting Energy Drink	3.1	0.0	1650	25
9	Mirinda	2.9	0.6	1350	26
10	Sprite	3.3	0.0	950	25
11	Lemon Water	2.6	2.8	380	25
12	Salt Water	8.2	4.5	35000	24
13	Mud Water	7.2	18.0	480	28
14	RO Water	7.4	0.0	35	23



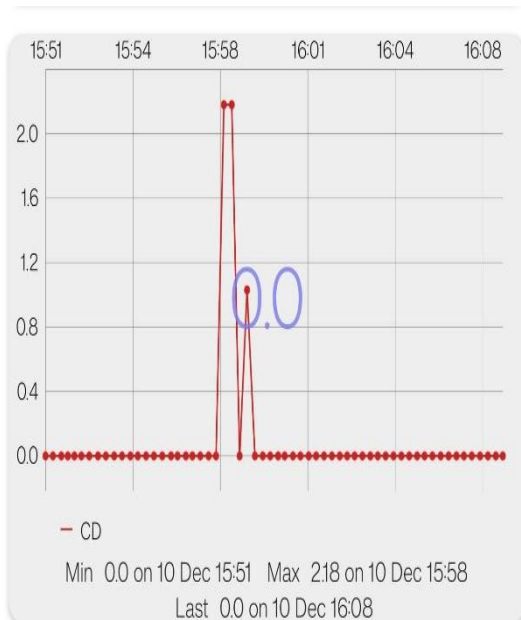
Graphical Representation of Water Quality Parameters



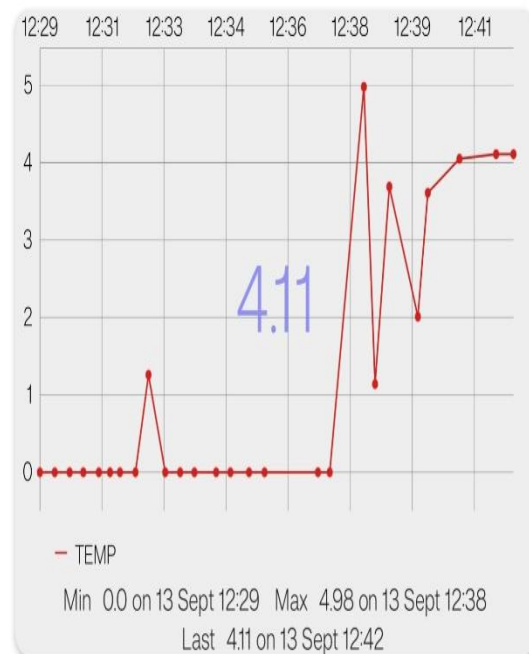
pH



Turbidity



TDS



Temperature



V. CONCLUSION

This study presents the successful design and prototyping of a low-cost automated water quality monitoring system. The system integrates sensors, embedded processing, and IoT communication to provide real-time monitoring of water quality parameters. The results demonstrate acceptable accuracy and reliability for practical applications. The system reduces dependency on laboratory testing and enables timely detection of contamination. Future work includes integration of advanced analytics, improved sensor durability, and large-scale deployment for smart water management systems.

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