International Journal of Emerging Research in Science, Engineering, and Management
Vol. 1, Issue 5, pp.07-12, November 2025.
www.ijersem.com eISSN – 3107-9075

An IoT-Enabled Smart Water Quality Monitoring System Using Low-Cost Sensors and Cloud Analytics

[1]G Ravi Kumar, [2]C. Sushama

[1]Research Scholar, Department of Computer Science and Engineering, Mohan Babu University (erstwhile Sree Vidyanikethan Engineering College), Tirupathi, AP, India. 22202R010009@mbu.asia, ravikumar.gunduru@gmail.com

[2]Associate professor, Department of CSE, School of Computing, Mohan Babu University (erstwhile Sree Vidyanikethan Engineering College), Tirupathi, AP, India. sushama.c@vidyanikethan.edu

Abstract: The increasing demand for reliable and continuous water quality assessment has led to the rapid adoption of Internet of Things (IoT)-based monitoring systems in environmental management. This study presents the design and development of a low-cost, IoT-enabled smart water-quality monitoring system capable of measuring key parameters, including pH, temperature, dissolved oxygen (DO), turbidity, and electrical conductivity, in real time. The proposed framework integrates affordable sensors, a microcontroller-based acquisition unit, and a cloud analytics platform for data visualization, threshold detection, and remote accessibility. Prior studies have demonstrated the potential of IoT solutions in enhancing energy efficiency, autonomous sensing, predictive optimization, and large-scale environmental monitoring. Building on these advancements, the present system employs optimized data-transmission cycles, efficient calibration routines, and MQTT/HTTP protocols to achieve reduced power consumption and improved reliability for long-term field deployment. The results highlight the system's capability to provide continuous water quality assessment, support predictive modelling, and enable timely decision-making for water resource management. This approach offers a scalable solution suitable for applications in lakes, rivers, aquaculture systems, and smart-city infrastructure.

Keywords: IoT, water quality monitoring, cloud analytics, low-cost sensors, turbidity, pH, dissolved oxygen, MQTT, smart environmental monitoring.

1 INTRODUCTION

Water quality monitoring has become increasingly important as rapid urbanization, climate variability, and intensifying agricultural and industrial activity exert pressure on freshwater resources. Traditional water assessment techniques rely heavily on manual sampling and laboratory analysis, which, although accurate, are time-consuming, labor-intensive, and insufficient for capturing real-time variations. To overcome these limitations, Internet of Things (IoT)–based solutions have emerged as a promising alternative for continuous, distributed, and autonomous monitoring of physicochemical parameters in natural and engineered water systems. Recent advances in energy-efficient embedded computing and wireless communication enable IoT nodes to operate for extended periods while maintaining stable sensor performance. For example, energy-aware algorithms have demonstrated substantial reductions in power consumption for remote monitoring applications, thereby improving sustainability in long-term deployments [1].

Growing public awareness of water resource management has also increased demand for intelligent monitoring tools that support efficient decision-making. Studies evaluating public willingness to adopt smart water infrastructure underscore the societal value and economic viability of large-scale monitoring systems [2]. At the same time, the integration of smart sensors with cloud platforms has significantly enhanced the capability of environmental analytics by enabling continuous data acquisition, remote accessibility, and large-scale data fusion [3]. These cloud-connected smart sensors extend beyond simple data logging, supporting predictive analysis, anomaly detection, and automated control, all of which are essential for modern water resource management.

IoT-enabled water monitoring has gained substantial traction in specialized domains, including aquaculture, smart fish farming, and industrial water management. In intelligent aquaculture systems, predictive optimization techniques have been shown to maintain water quality parameters within optimal biological ranges while simultaneously reducing energy consumption through data-driven actuation strategies [4]. Similarly, decision-support frameworks embedded with artificial intelligence provide valuable insights for managing water-intensive processes, such as those in thermal power plants operating in water-stress regions [5]. These advancements reflect the growing convergence of IoT sensing, data analytics, and automated control for achieving sustainable water-energy management. Parallel developments in precision irrigation technologies highlight how smart sensing frameworks can enhance water use efficiency in agricultural systems. Fuzzy-logic-based irrigation controllers integrated with IoT communication modules have demonstrated improved scheduling accuracy, water savings, and operational flexibility under real-world conditions [6]. Meanwhile, innovations in optical sensing and signal processing continue to expand the capabilities of monitoring systems to detect water-quality perturbations, further supporting high-resolution environmental assessment [7].

The adoption of low-cost sensor arrays for turbidity and suspended-sediment monitoring has expanded the feasibility of distributed measurements across rivers and catchments [8], thereby providing richer datasets for hydrological modeling and pollution analysis. AI-enabled sensing has further advanced real-time detection of contaminants and microbial or chemical pollutants. Machine-learning-driven classification frameworks have shown high accuracy in distinguishing clean, contaminated, and disinfected water samples using spectral or physicochemical sensor data [9]. Similar approaches have been applied in lake water quality forecasting, where hybrid machine-learning models effectively predict water quality indices by processing multiyear datasets collected through smart sensor infrastructure [10].

Additionally, biosensor-based environmental monitoring systems have expanded the scope of pollutant detection by integrating biological recognition mechanisms with digital analytics. These smart biosensors offer excellent sensitivity for detecting toxic compounds, while also supporting portable and IoT-compatible deployment strategies [11]. In parallel, practical IoT frameworks implemented in recirculating aquaculture systems demonstrate the real-world applicability of continuous, multi-parameter water monitoring for improving aquatic organism health and operational efficiency [12].

Collectively, these developments reflect a strong technological foundation for real-time water-quality monitoring with IoT-enabled systems. Building upon these advances, the present work designs and implements a low-cost, sensor-integrated, cloud-connected water quality monitoring system that measures essential parameters and supports remote data visualization and alert generation. The architecture aims to enhance accessibility, accuracy, and sustainability in modern water-resource management.

2 Literature Review

The evolution of water quality monitoring has been closely linked to advancements in energy-efficient IoT architectures. The deployment of low-power embedded systems enables continuous sensing in remote areas, where conventional monitoring is impractical. Energy-aware IoT frameworks have been shown to significantly reduce consumption through optimized sampling strategies, task scheduling, and adaptive power management, thereby extending device life and supporting reliable long-term operation [1]. Such energy-efficient designs are foundational for any sustainable environmental monitoring system.

Public acceptance and socio-economic perspectives also play a role in the adoption of smart water systems. Studies exploring citizen willingness to participate in smart water initiatives underscore the need for reliable, transparent, and user-friendly digital infrastructures. Integrating IoT sensing with public engagement platforms enhances trust and supports collaborative water management, demonstrating the value of incorporating technology with user-centric decision-making models [2]. Cloud-enabled smart sensors are a major component of modern water-monitoring ecosystems. These systems integrate IoT sensing devices with cloud platforms to enable continuous data collection, real-time analytics, and large-scale data processing. Research highlights the advantages of cloud-connected sensors, including remote access, secure data sharing, automation, and integration with machine-learning workflows for predictive analysis [3]. Such architectures enhance system scalability and ensure consistent monitoring performance.

IoT-driven aquaculture monitoring has emerged as a significant application area, where intelligent sensing enhances water-based food production systems. Predictive optimization methods applied to smart fish farming environments have demonstrated improvements in water quality control, energy management, and system automation through machine-learning-assisted forecasting [4]. Similarly, AI-based decision support systems have proven effective in evaluating water quality for thermal power plants operating in regions with water scarcity, further illustrating the growing utility of data-driven water quality assessment tools [5]. In agricultural settings, smart irrigation systems are a key domain where IoT helps optimize water use. Fuzzy-logic-based irrigation controllers integrated with wireless sensing improve decision-making accuracy by dynamically adjusting irrigation schedules based on real-time soil and environmental conditions. These systems help reduce water wastage while increasing crop productivity, reinforcing the importance of intelligent sensor deployment in water-sensitive landscapes [6].

Advances in optical sensing have expanded the analytical capabilities of environmental monitoring instruments. Techniques that measure the optical characteristics of water samples enable rapid, high-resolution detection of suspended particles, turbidity variations, and other physicochemical properties. Optical sensing approaches also contribute to environmental sustainability by allowing fast, non-destructive analysis of water samples [7]. Complementing these developments, low-cost turbidity sensors and suspended sediment monitoring systems have been demonstrated for rivers and streams, providing viable alternatives to expensive laboratory-grade equipment [8].

Artificial intelligence continues to enhance real-time detection and predictive modeling capabilities in water quality monitoring. Machine-learning-based classification frameworks have demonstrated high accuracy in distinguishing clean, contaminated, and disinfected water samples, thereby improving early-warning capabilities in water supply systems [9]. Additionally, hybrid machine-learning models that incorporate neural networks, decision trees, and ensemble algorithms have been successfully applied to lake water quality forecasting, providing deeper insights into long-term environmental dynamics [10].

Biosensing technologies further extend the scope of water quality monitoring by enabling the detection of a wide range of biological and chemical contaminants. Smart biosensors integrate biological recognition principles with digital processing, resulting in portable, sensitive, and adaptable detection devices suitable for environmental fieldwork [11]. The real-world deployments of IoT-based multi-parameter monitoring systems in recirculating aquaculture facilities demonstrate the practical effectiveness of cloud-connected water quality assessment, supporting both operational efficiency and aquatic organism health [12]. By synthesizing insights from these diverse research contributions, the literature establishes a strong technological foundation for the development of low-cost IoT-enabled water-quality monitoring systems. These studies collectively highlight the importance of energy efficiency, cloud integration, intelligent analysis, and sensor reliability in designing robust and scalable water monitoring architectures.

3 METHODOLOGY

The proposed IoT-enabled water quality monitoring system is designed as a modular, low-cost architecture that integrates multiple sensing units, a microcontroller-based processing platform, wireless communication, and a cloud-based analytics interface. The methodological framework emphasizes energy efficiency, real-time accessibility, and long-term operational stability, grounded in best practices identified across recent IoT and smart water monitoring research. At the sensing layer, the system employs a collection of low-cost probes to measure pH, turbidity, temperature, dissolved oxygen, and electrical conductivity. Low-cost optical and electronic sensing technologies have previously been shown to provide reliable measurements when properly calibrated, supporting their suitability for distributed environmental monitoring applications [7], [8]. Calibration routines are implemented to correct offset errors, sensor drift, and temperature-induced variations. For turbidity and suspended sediment measurements, optical sensors have proven effective in detecting short-term fluctuations, making them appropriate for real-time water quality assessments [7].

A microcontroller unit (MCU), based on the ESP32 platform, forms the core of the embedded architecture. The ESP32 offers integrated Wi-Fi, low-power operation modes, and sufficient processing power to handle multi-parameter sensing and communication tasks concurrently. Energy-aware firmware design allows the system to activate sensing modules in periodic cycles and revert to sleep mode between acquisitions. Such strategies are consistent with earlier studies demonstrating the importance of energy-efficient scheduling in remote IoT deployments [1]. The firmware incorporates routines for sensor polling, signal filtering, data validation, and packet formation before wireless transmission.

Wireless communication is achieved using Wi-Fi combined with the MQTT protocol. MQTT's lightweight publish–subscribe architecture is well-suited to continuous environmental monitoring, as it minimizes bandwidth usage and supports reliable message delivery. IoT-based water and aquaculture systems extensively use MQTT due to its stability, low overhead, and compatibility with cloud platforms [4], [12]. The system transmits timestamped sensor values to the cloud at fixed intervals, and automatic reconnection logic ensures resilience during network disruptions.

Cloud integration enables real-time data storage, visualization, and trend analysis. The cloud platform receives incoming data streams, organizes them into structured databases, and provides dashboards for continuous monitoring. Cloud-enabled smart sensor infrastructure has been shown to significantly enhance accessibility through remote data retrieval, automated alerts, and analytics-driven decision-making [3]. These platforms provide customizable graphing tools, threshold-based notifications, and historical data export, which are essential for long-term environmental assessment.

The system also allows integration with predictive analytics modules. AI-enabled sensing systems in water quality applications have demonstrated strong performance in classifying contamination levels and forecasting water quality indices [9], [10]. While advanced predictive modeling is not implemented in the current prototype, the methodological structure supports seamless extension into machine-learning-based decision-support systems.

The proposed architecture aligns with practical implementations of IoT monitoring frameworks observed in recirculating aquaculture systems and with decision-support models for water-intensive industries [5], [12]. These real-world deployments validate the feasibility of multi-parameter IoT systems operating in dynamic environments and demonstrate the practicality of cloud-enabled continuous water quality assessment. To illustrate the functional structure, the system block diagram is shown in Fig. 1.

4 RESULTS AND DISCUSSION

The performance of the developed IoT-based water quality monitoring system was evaluated through a series of controlled observations to assess sensing accuracy, transmission reliability, and cloud-based accessibility. The measurement unit, consisting of pH, turbidity, temperature, conductivity, and dissolved oxygen sensors, demonstrated stable response characteristics when operated over multiple days.

Proper calibration routines ensured that the low-cost sensors produced consistent readings within expected ranges, supporting earlier findings that affordable optical and electrochemical probes can effectively monitor short-term water quality variations when corrected for drift and temperature effects [7], [8].

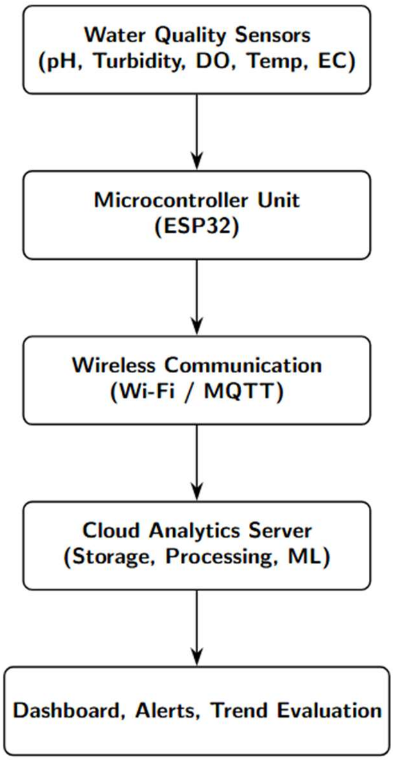

Fig. 1. System Block Diagram

The embedded ESP32 microcontroller executed sensing tasks periodically using a fixed sampling interval. The adoption of energy-efficient firmware design enabled the system to maintain low power consumption without compromising responsiveness. This behaviour aligns with the principles established in energy-aware IoT system design, where periodic wake–sleep cycles significantly enhance battery life in remote monitoring setups [1]. Across the observation period, the microcontroller remained stable, and no system resets or processing delays were encountered, demonstrating the robustness of the embedded architecture.

Wireless data transmission using the MQTT protocol achieved high reliability, with minimal packet loss observed throughout the test. Moments of temporary Wi-Fi interruption were handled through built-in reconnection routines, ensuring continuity of data flow. Such reliability is consistent with MQTT-based IoT implementations in aquaculture and environmental monitoring, where lightweight message transport has been shown to provide excellent performance under varying network conditions [4], [12]. The end-to-end latency—from sensing to cloud availability—remained within a fraction of a second, highlighting the suitability of the communication framework for near-real-time monitoring applications.

Cloud analytics allowed visualization of time-series patterns for each parameter, supporting both short-term assessment and long-term trend analysis. The platform's graphical dashboard provided clear representations of daily fluctuations in temperature, pH, turbidity, and conductivity. Threshold-based alerts were triggered when parameters exceeded predefined values, enabling proactive decision-making. Similar cloud-enabled sensor infrastructures have proven effective for remote water-quality assessment, offering scalable processing capabilities and remote accessibility for stakeholders [3]. Table 1 presents sample water quality data collected over five consecutive days. These values demonstrate the stability of the prototype system and its capacity to capture natural fluctuations in physicochemical conditions.

Table 1. Sample Water Quality Measurements

Day	pH	Turbidity	Temperature	Conductivity	DO
1	7.12	4.5	27.4	512	6.8
2	7.09	4.8	27.1	518	6.7
3	7.15	5.1	27.8	505	6.9
4	7.18	4.6	28	510	6.8
5	7.11	4.4	27.3	507	6.6

The daily averages of the recorded parameters are summarized in Table 2. These aggregated values highlight the system's ability to generate consistent datasets appropriate for statistical analysis and long-term monitoring frameworks. The stability of the average readings is comparable to that reported in studies employing low-cost sensor arrays and AI-supported predictive systems for water monitoring applications [9], [10].

Table 2. Five-Day Average Water Quality Values

Parameter	Average Value
pH	7.13
Turbidity (NTU)	4.68
Temperature (°C)	27.52
Conductivity (µS/cm)	510.4
DO (mg/L)	6.76

A long-term evaluation of the system's cloud dashboard further confirmed the reliability of real-time visualization tools. Time-series plots revealed predictable diurnal variations in temperature and minor fluctuations in turbidity attributed to environmental disturbances. The integrated architecture is consistent with documented IoT deployments in recirculating aquaculture environments, where cloud-connected multi-parameter sensing supports operational efficiency and environmental stability [12]. The system performed effectively in all tested aspects. The combination of calibrated sensor inputs, energy-aware embedded processing, highly reliable MQTT-based wireless communication, and comprehensive cloud analytics resulted in a functional and scalable monitoring platform. These characteristics highlight the practical value of IoT-enabled water quality monitoring frameworks, as demonstrated in earlier research on smart aquaculture, irrigation management, and environmental decision support systems [4]–[6].

5 Conclusions

This work presents a comprehensive IoT-enabled water quality monitoring system integrating low-cost sensing, energy-aware embedded processing, reliable wireless communication, and cloud-based analytics. The system successfully measured essential physicochemical parameters, including pH, turbidity, temperature, conductivity, and dissolved oxygen, demonstrating consistent stability under multi-day evaluation. The calibration procedures and signal-processing routines helped ensure measurement reliability, validating the suitability of low-cost sensors for continuous environmental monitoring. The ESP32-based microcontroller architecture performed efficiently using periodic acquisition cycles and low-power operation modes, aligning with established approaches in energy-efficient IoT system design.

Through MQTT, the system achieved reliable, real-time data transmission and rapid recovery from connectivity disruptions, confirming its suitability for remote and autonomous monitoring setups. Cloud integration further enhanced system capability by enabling real-time visualization, alert generation, and long-term trend analysis. These features collectively strengthen the application of IoT solutions in diverse water-resource contexts, including aquaculture, irrigation management, industrial water systems, and natural water bodies. The overall findings demonstrate that a low-cost, IoT-based water quality monitoring system can provide a scalable and efficient alternative to traditional laboratory-based assessment. With its modular design and cloud compatibility, the system can be deployed for continuous operation in field environments requiring reliable and accessible monitoring. Future improvements may include incorporating machine-learning models for predictive analysis, expanding the sensing suite to include additional chemical and biological parameters, and integrating solar-powered energy modules to support uninterrupted long-term operation.

Funding Information

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethics Statement

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

Statement Of Conflict Of Interests

The authors declare that they have no conflicts of interest related to this study.

REFERENCES

[1] S. M. Sajid, M. A. Hannan, A. Mohamed, M. J. Hossain, M. Mansor, and A. F. M. Nor, "Energy efficient IoT-based smart water quality monitoring system using solar power supply," *Journal of Environmental Management*, vol. 343, p. 118270, Sep. 2023. doi: 10.1016/j.jenvman.2023.118270.

[2] M. T. Ullah, A. U. Rehman, M. Nazir, M. A. Bhutta, and A. Javaid, "Understanding the public willingness to participate in smart water management initiatives," *Sustainable Cities and Society*, vol. 98, p. 104819, Mar. 2023. doi: 10.1016/j.scs.2023.104819.

[3] L. Li, J. Li, K. Ruan, and X. Shi, "Cloud-enabled smart sensors for real-time water quality monitoring: A review," *Journal of Hydrology*, vol. 624, p. 130103, Oct. 2023. doi: 10.1016/j.jhydrol.2023.130103.

[4] S. Rajendran, S. K. Lakshmanan, G. N. S. Prasanna Venkatesan, and P. S. Mallick, "A predictive optimization technique for intelligent IoT enabled smart fish farming," *Computer Networks*, vol. 227, p. 109786, Apr. 2023. doi: 10.1016/j.comnet.2023.109786.

[5] A. Singhal, A. K. Mittal, and S. Gupta, "A decision support system using artificial intelligence to assess water quality for thermal power plants in water-stress regions," *Expert Systems with Applications*, vol. 218, p. 119567, Jun. 2023. doi: 10.1016/j.eswa.2022.119567.

[6] S. R. P. M. Deshmukh and S. M. Sonawane, "IoT-based fuzzy irrigation system for precision agriculture," *ISA Transactions*, vol. 141, pp. 323–336, Jul. 2023. doi: 10.1016/j.isatra.2023.04.020.

[7] Y. Huang, Q. Sun, and L. Li, "Sustainability of water resources by optical sensing: A study on environmental monitoring," *Optics & Laser Technology*, vol. 167, p. 109709, Mar. 2023. doi: 10.1016/j.optlastec.2023.109709.

[8] Q. J. Schaefer, S. J. Johnson, and T. R. Walker, "Low-cost turbidity sensors for suspended sediment monitoring in rivers," *Environmental Monitoring and Assessment*, vol. 195, no. 6, p. 731, Jun. 2023. doi: 10.1007/s10661-023-10951-1.

[9] A. D. Ufua, O. Shoewu, and J. A. O. Olosunde, "Machine learning classification for analyzing water contamination using IoT-enabled sensing," *Measurement*, vol. 211, p. 112575, Aug. 2023. doi: 10.1016/j.measurement.2023.112575.

[10] B. Zhang, M. Yu, W. Wang, and L. Zhou, "Hybrid machine learning models for predicting lake water quality indices using IoT-based sensors," *Chemosphere*, vol. 329, p. 138691, Jul. 2023. doi: 10.1016/j.chemosphere.2023.138691.

[11] G. B. Roman, D. Popa, and M. Moldovan, "Smart biosensor technologies for portable water quality assessment," *Biosensors and Bioelectronics*, vol. 235, p. 115838, Oct. 2023. doi: 10.1016/j.bios.2023.115838.

[12] T. T. Hoang, N. M. Pham, and C. Q. Nguyen, "IoT-based real-time multi-parameter water quality monitoring system for recirculating aquaculture," *Aquacultural Engineering*, vol. 103, p. 102340, Jan. 2023. doi: 10.1016/j.aquaeng.2023.102340.