



An IoT Enabled Real Time Monitoring System for Potable Water Quality Assessment Using ESP32 and Multisensor Fusion

¹Vaibhav Kisan Ingle, ²Dhiraj Gunwantrao Wankhede, ³Pooja Govindsingh Pawar, ⁴Iffat Rehman

¹Assistant Professor, ²Assistant Professor, ³Assistant Professor ⁴Assistant Professor

¹Civil Engineering Department,

¹Siddhivinayak Technical Campus, Shegaon, Maharashtra, India

Abstract : Reliable access to clean drinking water remains a fundamental health necessity, but standard water analysis techniques are often costly and lack frequency. This work proposes an innovative, low-cost solution that uses Internet of Things (IoT) technology to perform ongoing, real-time assessments of drinking water quality. Built with an ESP32 controller and various sensors targeting pH, turbidity, total dissolved solids, conductivity, and fluoride the device sends collected data to the Blynk cloud, where users can view results through a smartphone application. Field applications across different sources confirmed its capacity to recognize contamination risks. Fluoride concentration was measured using a color-based analytical process. With its lightweight and energy-saving design, this system enables frequent water testing at scale. It directly supports Sustainable Development Goal 6 by encouraging proactive and informed water quality management practices.

Index Terms - IoT water sensing, ESP32 application, Real-time analysis, Conductivity and TDS metrics, Fluoride sensing, Blynk integration, SDG 6

I. INTRODUCTION

Clean and safe drinking water is a basic human right and a key component of public health and well-being. Yet, with rapid urban development, industrial growth, and ongoing environmental challenges, providing this essential resource has become increasingly complex. Factors such as pollution, deteriorating infrastructure, and insufficient monitoring systems contribute to rising incidents of contamination and waterborne illnesses worldwide. While conventional methods for testing water quality are generally reliable, they are labor-intensive, slow, costly, and often fail to deliver real-time data making it difficult to respond promptly to emerging threats. To address these limitations, this project introduces an IoT-enabled solution for monitoring drinking water quality. The system is built around the ESP32 microcontroller, which gathers data from multiple sensors that assess key indicators of water purity. Integrating cloud storage with mobile app access, the platform provides real-time tracking, immediate alerts, and remote accessibility. This approach offers a practical, scalable, and affordable way to enhance water safety, protect public health, and promote more sustainable water management practices.

1.1 Problem Statement

Clean and safe drinking water is vital for health, yet its quality is increasingly threatened by urbanization, industrial expansion, and environmental degradation. Traditional water quality monitoring methods are slow, costly, and lack real-time capabilities, making it difficult to detect contamination quickly. This project proposes an IoT-based water quality monitoring system that uses sensors and wireless communication to provide continuous, real-time data, offering an efficient, low-cost solution for ensuring water safety in both urban and rural areas.

1.2 Scope of the Study

This study aims to create a smart monitoring system for evaluating drinking water quality in real time using IoT technology. The system is built around the ESP32 microcontroller and incorporates sensors that track parameters such as pH, turbidity, dissolved oxygen, and microbial contamination. Cloud services are used to store and display the collected data, which can be accessed remotely through web or mobile platforms. The scope includes sensor setup, device assembly, and performance testing under different water conditions, and ensuring low power usage for operation in remote or emergency settings.

1.3 Aim & Objective

The aim of this study is to design and implement an IoT-based potable water quality monitoring system that provides real-time data for proactive decision-making, ensuring safe drinking water. The objectives include developing a cost-effective system using low-cost sensors to measure key water quality parameters, creating a cloud-based platform for real-time data visualization, implementing an alert system for contamination detection, and ensuring the system's portability and energy efficiency for deployment in both urban and rural areas.

II. LITERATURE REVIEW

1. **Smart Monitoring of Water Quality Using IoT (Deva Priya, N.):** In this study, an IoT-based framework was developed using analog pH and turbidity sensors integrated with an Arduino board. While it provided real-time monitoring, the system's functionality was limited by a narrow range of sensors and lacked a mobile-friendly interface. The current project builds on this foundation by adopting the ESP32 microcontroller and incorporating additional sensors to monitor TDS, conductivity, and fluoride levels. Furthermore, mobile integration enhances user accessibility and system usability, making it a more robust solution.
2. **IoT Applications in Industrial Water Monitoring (Divya, G. & Vidhya Krishnan, A.):** This research targeted water quality surveillance in industrial environments, employing sensors for temperature and turbidity with an Arduino Uno setup. While the system was effective in tracking basic parameters, it suffered from issues related to energy consumption and lack of portability. The solution presented in this study overcomes those limitations by utilizing the ESP32, which supports low-power operations and seamless wireless connectivity. Real-time updates are available through a mobile application, enabling greater scalability and operational flexibility.
3. **Continuous Water Quality Monitoring System (Tayti Bhatt, D. & Patel, J.):** A monitoring system using Raspberry Pi 3 and sensors for pH and conductivity was introduced for real-time applications. However, the system's high energy demand made it unsuitable for field operations, especially in isolated regions. In contrast, the current design adopts the ESP32 microcontroller for its energy-efficient capabilities, making it suitable for battery-powered, off-grid use. It also includes mobile access, allowing users to track water quality remotely and in real time.
4. **Arduino-Based Water Quality Sensing (Huang, H. et al.):** This system was based on the Arduino Nano platform, focusing on pH level monitoring and Bluetooth for data transmission. Its main drawbacks were limited sensor integration and restricted communication range. The system proposed here addresses these concerns by employing ESP32 for Wi-Fi connectivity, along with a broader range of sensors. These enhancements make the system suitable for varied applications, including environmental studies and industrial deployments, while offering greater range and real-time data access.
5. **Real-Time Monitoring with IoT (Padma, M. et al.):** In this work, an ESP8266-based system was designed for urban water monitoring, measuring pH and turbidity. However, the system lacked flexibility and offered limited parameter coverage. The current project improves on this by adding sensors for TDS, conductivity, and fluoride, while also utilizing the more efficient ESP32 for better power management. This redesign allows for real-time monitoring in both urban and remote areas, expanding its applicability across multiple environments.

2.1 Summary of Literature Review on Smart Water Quality Monitoring Systems

The reviewed literature showcases the development of IoT-based water quality monitoring systems, emphasizing advancements in sensor integration, data transmission, and portability. Early systems, such as those by Deva Priya, Divya, and Vidhya Krishnan, utilized basic sensors with limited capabilities and lacked mobility or comprehensive monitoring. Recent projects improve on these by incorporating advanced microcontrollers like ESP32, enhancing energy efficiency, sensor variety (e.g., TDS, fluoride), and mobile access. These innovations make systems more adaptable for urban and remote field deployments, offering real-time monitoring, remote alerts, and expanded sensor coverage. These improvements significantly enhance the functionality, scalability, and practicality of water quality monitoring solutions for diverse applications.

III. Development and Implementation of an IoT-Based Potable Water Quality Monitoring System for Enhanced Public Health and Safety

Ensuring access to safe drinking water is essential for protecting human health, yet contamination from industrial discharges, agricultural runoff, and failing infrastructure poses serious risks especially in rural and underserved areas. This project introduces a cutting-edge Internet of Things (IoT) solution designed to continuously monitor water quality in real time, providing a reliable safeguard for potable water sources.

IoT technology connects intelligent devices capable of automatically sensing and transmitting data. For water quality assessment, the system employs multiple sensors to track parameters including pH, turbidity, temperature, total dissolved solids (TDS), electrical conductivity, and harmful contaminants such as fluoride, nitrates, and heavy metals. These sensor measurements are managed by a microcontroller, typically an ESP32 or Arduino, which sends the collected information to cloud servers for immediate processing and storage. Unlike traditional approaches reliant on manual sample collection and laboratory testing, this system enables automated, ongoing surveillance that is particularly advantageous in remote or resource-limited locations. Its modular and energy-conscious design ensures adaptability across a variety of settings—from urban centers to isolated communities. The system also provides instant alerts when water quality metrics deviate beyond safe thresholds, facilitating swift intervention and minimizing health hazards.

The architecture consists of sensor units, a microcontroller, communication technologies such as Wi-Fi, GSM, or LoRa, cloud-based platforms for data analysis, and interfaces like mobile apps or web portals for real-time monitoring. This arrangement supports continuous data logging and trend visualization, empowering decision-makers with actionable insights. By using economical and low-power hardware components, the system remains affordable and effective in both grid-connected and off-grid scenarios. The primary aims include guaranteeing potable water safety, enabling remote and continuous monitoring, decreasing dependence on labor-intensive testing, and promoting environmental sustainability. Moreover, by delivering transparent water quality data to local communities, the system encourages public participation and awareness in managing water resources.

In summary this IoT-driven framework represents a scalable, cost-effective, and user-friendly method for monitoring water quality. Its low energy consumption, flexible deployment, and comprehensive sensing capabilities make it a valuable asset in the worldwide effort to secure safe drinking water and protect public health.

IV. Methodology

Creating a system that keeps a constant check on the quality of drinking water by measuring several key indicators. At the heart of the system is the ESP32 microcontroller, which gathers information from various sensors and sends it wirelessly to a mobile device, allowing users to monitor water conditions in real-time.

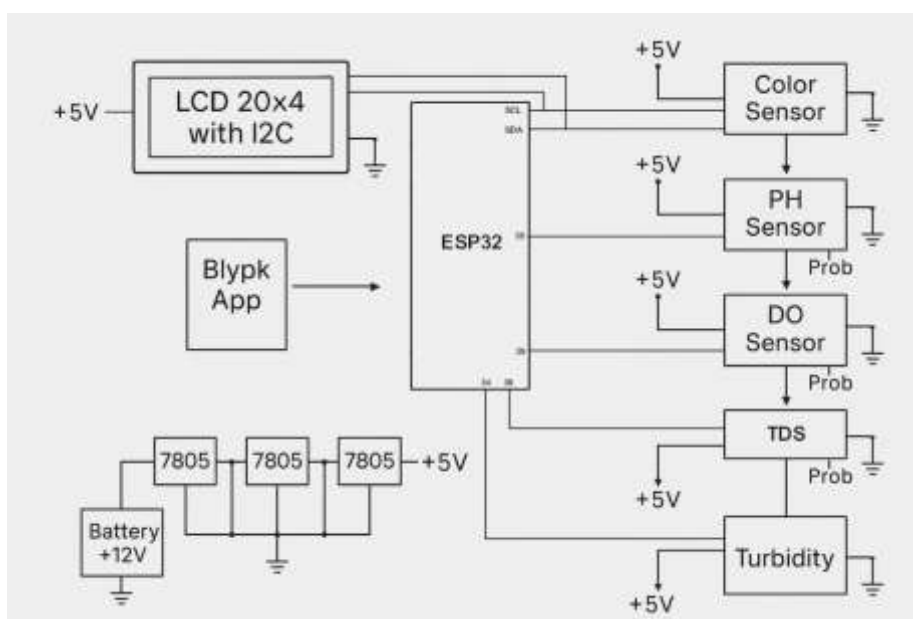


Figure No. 1, "Block Diagram"

➤ Power Setup

The system draws energy from a 12V battery source. Because electronic components in the setup operate at a lower voltage, the 12V supply is converted down to 5V using voltage regulator circuits. This step ensures all sensors and the microcontroller receive a safe and steady power supply. A common ground is established across the system to maintain consistent electrical reference points.

➤ Sensor Arrangement and Data Collection

Several sensors are connected to the ESP32 to measure different water quality factors. A sensor measuring pH provides information about the water's acidity or alkalinity, sending an analog voltage signal to a dedicated input pin on the microcontroller. Sensor measures turbidity by detecting particles suspended in the water, indicating its clarity. The dissolved oxygen sensor provides data on oxygen concentration, which is vital for aquatic ecosystems. The TDS sensor measures the concentration of dissolved solids such as salts and minerals. Finally, a color sensor identifies any changes in water color that might signal contamination. All sensors receive power from the regulated 5V supply. Their output signals, mostly analog voltages, are read by specific ESP32 input pins, where they are processed and interpreted.

➤ Data Display and Wireless Communication

The system includes a small LCD screen to display real-time water quality data directly at the monitoring site. Simultaneously, the ESP32 uses its built-in Wi-Fi or Bluetooth modules to send this data to the Blynk mobile application. This allows users to remotely monitor water quality and receive alerts without being physically present at the measurement location.

4.1. Components

Table No. 1, “Key Components of the IoT-Based Water Quality Monitoring System”

Component	Description	Key Features	Application
ESP32 DOIT DevKit V1 (38-Pin)	Main microcontroller for data processing and wireless communication.	- Dual-core processor (240 MHz) - Built-in Wi-Fi/Bluetooth - 38 GPIO pins, ADC/DAC support - Micro-USB programming	IoT projects, sensor networks, portable devices
pH Sensor (ELECROW Crowtail v2.0)	Measures water acidity/alkalinity (0–14 pH range).	- BNC electrode interface - Analog output - Onboard calibration	Drinking water analysis, hydroponics, environmental monitoring
Turbidity Sensor	Detects suspended particles to assess water clarity.	- Infrared LED + photodetector - Analog/digital output - 5V operation	Wastewater treatment, aquaculture, lab testing
TDS Sensor (Gravity Analog)	Measures dissolved solids (salts, minerals) in water.	- 0–1000 ppm range - Waterproof probe - Analog output (0–2.3V)	Water purity checks, hydroponics, industrial use
Fluoride Detection (TCS34725 RGB Sensor)	Colorimetric method for fluoride level estimation.	- I ² C interface - RGB + clear light sensing - Reagent-based reaction	Rural water testing, low-cost fluoride screening
Lithium-Ion Battery	Rechargeable power source for portability.	- High energy density - BMS protection - Lightweight	Field deployments, off-grid applications

4.2 Sensor Integration

The water quality monitoring setup built around the ESP32 microcontroller incorporates five essential sensors to assess various water parameters. These include sensors for measuring pH, total dissolved solids (TDS), turbidity, dissolved oxygen, and color. Each sensor is powered by a stable 5-volt regulated supply and connects to specific input pins on the ESP32. Communication occurs via analog signals or the I²C protocol, allowing the system to gather real-time data efficiently. This integration supports detailed water quality evaluation and facilitates both on-site display and remote monitoring through wireless transmission.

Table No. 2, “Sensor Integration Architecture in ESP32-Based Water Quality Monitoring System”

Sensor	Power Supply	ESP32 Connection	Signal Type	Measurement Principle	Key Parameter
Color Sensor	+5V & GND	I ² C (GPIO 21/22)	Digital	RGB light absorption analysis	Contaminant detection
pH Sensor	+5V & GND	GPIO 35 (Analog)	Analog	Hydrogen ion concentration	0-14 pH scale
Dissolved Oxygen	+5V & GND	GPIO 39 (Analog)	Analog	Electrochemical reaction	mg/L O ₂ concentration
TDS Sensor	+5V & GND	GPIO 34 (Analog)	Analog	Electrical conductivity measurement	ppm dissolved solids
Turbidity Sensor	+5V & GND	GPIO (Analog)	Analog	Light scattering (NTU)	Water clarity

V. COMPARATIVE STUDY OF IOT-BASED POTABLE WATER QUALITY MONITORING SYSTEMS

5.1 Comparison Parameters

The growing need for clean drinking water has led to advancements in water quality monitoring, with IoT-based systems emerging as a superior alternative to traditional methods. This section compares conventional approaches with IoT-enabled solutions, evaluating cost, performance, scalability, and suitability.

1. Traditional Vs. IOT-Based Monitoring

Table No. 3, “Comparison of Traditional and IoT-Based Monitoring Systems”

Feature	Traditional Monitoring	IoT-Based Monitoring
Data Collection	Manual sampling & lab testing	Automated, real-time sensor data
Time Consumption	High (transportation & lab delays)	Low (instantaneous transmission)
Cost Over Time	High (recurring lab expenses)	Low (one-time setup cost)
Accuracy	High (lab-grade precision)	Moderate to High (depends on sensors)
Coverage	Limited (few sampling points)	Wide (scalable network)
Alert Mechanism	None (delayed reporting)	Instant (SMS, email, app notifications)
Data Logging	Manual (prone to errors)	Automated (cloud storage & analytics)

IoT-based systems excel in real-time monitoring, remote accessibility, and scalability, while traditional methods remain necessary for high-precision lab validation.

2. Comparison of IOT-Based Implementations

Table No. 4, “Comparison of IoT-Based Monitoring System Implementations”

Parameter	Basic System	DIY System		Research-Grade
Cost (₹)	2,500–7,000	15,000–50,000+	10,000–25,000	50,000+
Sensors	pH, TDS, Turbidity	Multi-parameter	Custom configurations	High-precision
Connectivity	Wi-Fi, GSM	LoRa, NB-IoT	Cloud-integrated	Hybrid (GSM + Satellite)
Accuracy	Moderate	High (calibrated)	High	Lab-grade
Use Case	Schools, rural pilots	Smart cities	Municipal water supply	Academic research
Power Supply	Battery/Solar	Solar + Backup	Grid-powered	Industrial-grade

3. Suitability for Different Environments

- Urban Areas: Commercial IoT systems with LoRa/NB-IoT and cloud dashboards.
- Rural/Remote Areas: Low-cost GSM/solar-powered DIY systems.
- Research: Customizable, high-accuracy setups for data-intensive studies.

5.2 Materials

A detailed comparison of components aids in selecting the right system:

1. Sensor Comparison

Table No. 5, “Comparison of Water Quality Sensors”

Sensor	Parameter	Accuracy	Application
pH Sensor	Acidity/Alkalinity	±0.2 pH	Essential for safety
TDS Sensor	Dissolved solids	Moderate	Purity indicator
Turbidity Sensor	Water clarity	Moderate	Detects contaminants
Conductivity Sensor	Ion concentration	High	Pollution monitoring

2. Communication Technologies

Table No. 6, “Overview of Communication Options in IoT Monitoring”

Type	Range	Power Use	Cost	Best For
Wi-Fi	20–50 m	Moderate	Low	Indoor/urban use
GSM	Network-based	High	Moderate	Remote areas
LoRa	Up to 10 km	Very Low	Moderate	Large-scale deployments
NB-IoT	Wide coverage	Low	High	Industrial use

3. Power Sources

Table No. 7, “Comparison of Power Sources for IoT Monitoring Systems”

Source	Lifespan	Cost	Suitability
Battery	3–6 months	Moderate	Portable systems
Solar	1+ years	High	Off-grid/rural areas
Grid (AC)	Continuous	Low	Urban installations

5.3 Cost & Payoff

- **Initial Cost:** ₹2,500–₹7,000 (basic) to ₹50,000+ (advanced).
- **Long-Term Benefits:**
 - Early contamination detection → Prevents diseases.
 - Eliminates manual testing costs.
 - Scalable for community-wide use.
 - Remote monitoring reduces fieldwork.

VI. BRIEF SUMMARY

This research presents the design and evaluation of an IoT-based potable water quality monitoring system. It addresses the limitations of traditional water testing methods by providing a real-time, automated solution using affordable sensors and microcontrollers like the ESP32. The system monitors key water parameters such as pH, TDS, turbidity, temperature, conductivity, and fluoride, with data transmitted via wireless technologies (Wi-Fi, GSM, LoRa) to cloud platforms for remote access and visualization.

The study shows that this approach is more cost-effective, scalable, and efficient compared to conventional methods. Though the initial investment ranges from ₹2,500 to ₹50,000, it pays off in the long run by reducing health risks and improving water management. The system is especially beneficial for rural and remote areas where manual testing is impractical.

6.1 Conclusions

Access to safe drinking water is a persistent global challenge, particularly in underserved areas. This study demonstrates the potential of IoT technology in bridging that gap. Using cost-effective hardware and real-time data access, the system offers a practical alternative to manual testing, enabling early detection of contamination and improving public health outcomes. It supports broader goals like Smart Cities and SDG 6 (Clean Water and Sanitation) by making water monitoring more accessible and efficient.

Despite its advantages, the system does face challenges such as sensor accuracy, power supply issues in off-grid areas, and data security concerns. Nevertheless, it presents a viable and impactful solution for various scales—from small communities to municipal water systems.

6.2 Discussions

The IoT-based system enables continuous, remote water quality monitoring, overcoming many drawbacks of manual testing. Its integration with cloud services allows users to receive alerts when water quality drops below safety standards, enhancing preventive actions. However, the system's reliability depends on factors like network availability, sensor calibration, environmental durability, and energy efficiency.

Power constraints, particularly in off-grid environments, and issues like data privacy and cybersecurity, require attention as deployment scales up. Nonetheless, the system's flexibility and real-time capabilities make it a strong tool for ensuring water safety in diverse contexts.

6.3 Limitations

1. **Sensor Accuracy** - Low-cost sensors may provide less precise readings and need regular calibration.
2. **Limited Parameter Detection** - The system does not detect microbes, heavy metals, or pesticides.
3. **Network Dependency** - Real-time monitoring is affected by weak or unstable internet/cellular networks.
4. **Power Challenges** - Solar and battery power may be insufficient in some conditions.
5. **Environmental Robustness** - The hardware may degrade under harsh weather or field conditions.
6. **Data Security** - Cloud storage raises concerns about data protection and unauthorized access.
7. **Scalability** - Managing and maintaining numerous units across locations can be complex and resource-intensive.

6.4 Future Scope

1. **Advanced Sensing** - Integrate sensors for biological and chemical contaminants.
2. **AI & ML Integration** - Use predictive models to anticipate contamination events.
3. **Edge Computing** - Enable real-time processing without relying on constant cloud access.
4. **User Interfaces** - Develop apps or dashboards for easier data access and alerts.
5. **Smart City Integration** - Scale the system for municipal and industrial applications.
6. **Improved Power Solutions** - Incorporate solar tech and energy-harvesting for reliability.
7. **Blockchain Use** - Secure and verify water data records for compliance and transparency.
8. **Partnerships** - Collaborate with governments and NGOs to expand reach, especially in underserved areas.

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