

# IoT-Based Water Quality Analysis System

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**Abstract**—The increasing demand for clean and safe drinking water has made real-time water quality monitoring a crucial necessity, especially in industrial and rural regions. Traditional water testing methods are manual, time-consuming, and often inaccessible in remote environments. This paper presents an Internet of Things (IoT)-based water quality analysis system designed to provide continuous monitoring and real-time data reporting of essential water parameters, including pH, Total Dissolved Solids (TDS), temperature, and turbidity. The system utilizes low-cost sensors interfaced with a NodeMCU ESP8266 microcontroller for data acquisition. Collected data is transmitted wirelessly to a cloud-based IoT platform (ThingSpeak), enabling remote access through mobile or web applications. Users receive real-time updates, and threshold-based alerts help detect potential water quality issues proactively. The system was tested under operational conditions. The results obtained were compared against World Health Organization (WHO) and Bureau of Indian Standards (BIS) guidelines to validate its accuracy and reliability. This affordable and scalable solution demonstrates significant potential for integration into small-scale industries, municipal systems, and household-level water monitoring infrastructures.

**Index Terms**—IoT, Water Quality Monitoring, ESP8266, TDS Sensor, pH Sensor, Turbidity Sensor, ThingSpeak, Real-Time Monitoring.

## I. INTRODUCTION

Water is one of the most critical resources for sustaining life, agriculture, and industry. However, increasing urbanization, industrialization, and environmental negligence have led to a severe decline in water quality across the globe [1]. In India, the challenge of ensuring potable water is especially acute in rural and semi-urban areas where access to timely water testing is limited [2].

Conventional water quality assessment involves collecting samples and transporting them to laboratories for testing. This process is labor-intensive, time-consuming, and lacks the capacity for

continuous monitoring. Moreover, it does not provide real-time feedback, which is vital in preventing the consumption or use of contaminated water [3].

The rapid evolution of the Internet of Things (IoT) has enabled the creation of smart environmental monitoring systems. IoT-based water quality systems can collect, process, and transmit data in real time, enabling automated decision-making and timely alerts [4]. These systems are especially beneficial for decentralized water sources like borewells, overhead tanks, and industrial discharge outlets, where human monitoring is either impractical or uneconomical.

This paper presents the design and development of an IoT-based Water Quality Analysis System, implemented under the operational conditions. The system monitors essential parameters such as pH, Total Dissolved Solids (TDS), temperature, and turbidity using low-cost sensors. These sensors are interfaced with the NodeMCU ESP8266 microcontroller, which transmits data to a cloud-based platform (ThingSpeak) for real-time visualization and alert generation.

The proposed system provides an affordable, scalable, and accessible solution suitable for small industries, municipal applications, and household-level water monitoring. The system's performance is validated by comparing real-time data with WHO and BIS standards, ensuring accuracy, reliability, and regulatory compliance.

## II. SYSTEM COMPONENTS

The effectiveness of any IoT-based monitoring system relies heavily on the choice and integration of its hardware components. This system is designed with low-cost, reliable, and power-efficient modules that enable real-time, remote sensing of critical water quality parameters. The following subsections provide an in-depth discussion of each component used.

#### A. NodeMCU ESP8266 Wi-Fi Microcontroller

At the heart of the system lies the NodeMCU ESP8266 microcontroller, which combines a programmable microcontroller with built-in Wi-Fi connectivity. It is based on the Tensilica L106 32-bit RISC processor and operates at 80 to 160 MHz. It contains 11 GPIO pins, UART, SPI, and I2C communication interfaces, making it suitable for sensor-rich environments.

The ESP8266 is programmed using the Arduino IDE, which offers a wide range of open-source libraries and development flexibility. Its low power consumption and compact size make it ideal for portable and energy-efficient deployments. In this system, the NodeMCU continuously acquires analog or digital signals from various sensors and transmits the processed data to a cloud platform over a Wi-Fi network.

Key specifications:

- Operating Voltage: 3.3V
- Flash Memory: 4MB
- Wi-Fi: 802.11 b/g/n
- ADC Resolution: 10-bit (single channel)

To ensure signal integrity, an analog multiplexer (CD4051) or voltage divider network may be used if multiple analog sensors are employed, as the ESP8266 supports only one analog input pin (A0).

#### B. pH Sensor Probe with Signal Conditioning Circuit

The pH sensor module is used to measure the hydrogen ion concentration in water. The sensor probe produces a small millivolt signal proportional to the pH level, which is then amplified and conditioned by the onboard signal amplifier to produce a readable analog voltage.

This module includes:

- Glass electrode pH probe
- Signal amplifier circuit with BNC connector
- Offset calibration potentiometer

The pH sensor must be calibrated using standard buffer solutions (pH 4, pH 7, and pH 10) to ensure accuracy. The voltage range (typically 0–3V) is mapped to the 0–14 pH scale using a linear mapping function within the ESP8266 firmware. The ideal drinking water pH range lies between 6.5 and 8.5 according to WHO standards [10].

#### C. TDS Sensor and Probe

The Total Dissolved Solids (TDS) sensor measures the

ionic concentration of minerals and salts in the water. It operates based on the principle of conductivity — higher the concentration of ions, greater the conductivity.

The sensor consists of:

- Dual-pin stainless steel probe
- Analog signal converter module
- Compensation algorithm for temperature

Since conductivity is temperature-dependent, a compensation formula is used to adjust TDS values:

$$TDS = k \times EC \times (1 + \alpha(T - 25))$$

where:

- $EC$  = Electrical Conductivity
- $\alpha$  = Temperature coefficient
- $T$  = Measured temperature
- $k$  = Calibration constant

The output is given in parts per million (ppm), and acceptable drinking water typically has a TDS level below 500 ppm [11]. The analog signal is connected to the A0 pin of the NodeMCU.

#### D. Turbidity Sensor (TSM/NTU-Based)

Turbidity indicates the presence of suspended particles or microbial content, which scatter light. This sensor operates using an infrared LED and photodiode in a 90-degree configuration.

Components:

- IR LED transmitter and receiver
- Analog voltage output proportional to particle density
- Waterproof casing for submersion

The sensor outputs a voltage inversely proportional to the turbidity in Nephelometric Turbidity Units (NTU). Typical clean water shows values less than 5 NTU. The ESP8266 maps the analog voltage to calibrated NTU values using experimental curve fitting. To improve accuracy, sensor output is averaged over several readings and filtered using a moving average algorithm.

#### E. DS18B20 Digital Temperature Sensor

Temperature monitoring is crucial because it influences both pH and microbial growth rates. The DS18B20 is a digital sensor that communicates via the One-Wire protocol and provides 9–12 bit temperature readings.

Key features:

- Operating range:  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$
- Accuracy:  $\pm 0.5^{\circ}\text{C}$  (in  $-10^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  range)
- Unique 64-bit ROM address
- Waterproof stainless steel probe

Multiple sensors can be chained using a single GPIO pin due to One-Wire addressing. In the firmware, the temperature reading is used to perform real-time compensation for the TDS sensor.

#### F. Power Supply System

The complete setup requires a regulated 5V power supply for sensors and 3.3V for the NodeMCU. For lab testing, a USB power bank or adapter is sufficient. For remote deployment, a solar-powered system using a 6V solar panel and 18650 lithium-ion battery with TP4056 charging module is recommended.

Voltage regulators like AMS1117 are used to step down voltage for compatibility. Protection circuits include reverse-polarity diodes and capacitors for input noise filtering.

#### G. Cloud Platform: ThingSpeak

ThingSpeak is an open-source IoT analytics platform used to store, analyze, and visualize sensor data online. It supports HTTP POST and GET protocols and MATLAB-based data processing.

Features:

- Real-time data plotting
- Field-wise parameter configuration (e.g., pH, TDS)
- Threshold-based alerts via email or IFTTT
- Data export in CSV/XML formats for analysis

The NodeMCU connects to a Wi-Fi hotspot, formats sensor data into HTTP POST requests, and sends them periodically to predefined ThingSpeak channels. Field keys and API authentication tokens ensure data security and integrity.

### III. METHODOLOGY

The proposed IoT-based water quality analysis system is designed to collect, process, transmit, and visualize real-time data related to multiple water quality parameters. The methodology integrates hardware interfacing, firmware logic, network communication, and cloud-based analytics into a coherent system for continuous monitoring. The following subsections describe the implementation process in detail.

#### A. System Design Overview

The entire system is structured in three logical layers: the sensing layer, the processing and transmission layer, and the cloud layer. The sensing layer includes analog and digital sensors that capture environmental data. These are connected to the processing layer, which consists of the NodeMCU

ESP8266 microcontroller programmed to read data at scheduled intervals and push the results to an IoT analytics platform over Wi-Fi.

All data is transmitted using the HTTP protocol with API-key-based authentication to ensure secure uploads. The cloud layer receives, stores, visualizes, and analyzes the incoming data using dynamic dashboards and user-defined threshold alerts.

#### B. Sensor Data Acquisition

Each sensor is initialized and calibrated at system startup. Sensor values are sampled at regular intervals (e.g., every 30 seconds) using the following process:

- 1) **pH Sensor:** The analog voltage is read and converted to a pH value using a calibration formula derived from standard buffer solutions. The value is then constrained between 0–14 and filtered using a moving average method.
- 2) **TDS Sensor:** The conductivity reading is adjusted for temperature compensation using real-time input from the DS18B20 sensor. A calibrated constant is applied to convert raw voltage to TDS in ppm.
- 3) **Turbidity Sensor:** The analog value is mapped to NTU values using a nonlinear regression equation determined from lab calibration. Noise filtering is used to prevent spikes due to particle movement.
- 4) **Temperature Sensor:** The DS18B20 digital sensor communicates over One-Wire protocol, and readings are retrieved with  $0.5^{\circ}\text{C}$  accuracy. These readings are also used to compensate for temperature-sensitive sensors like TDS.

All values are validated for sensor drift, missing data, and out-of-range anomalies before transmission.

#### C. Microcontroller Programming Logic

The NodeMCU ESP8266 is programmed using the Arduino IDE in C++. The loop function includes:

- Initialization of serial communication, Wi-Fi credentials, and sensor pins
- Periodic sampling of all sensor values (every 30

- seconds or configurable interval)
- Local filtering and transformation of raw signals into usable data
- Formatting of payload (e.g., JSON or URL-encoded string)
- HTTP POST request to the ThingSpeak cloud server using a unique API key

The Wi-Fi reconnection logic ensures automatic recovery in case of temporary disconnection, making the system suitable for field deployment.

#### D. Cloud Integration and Data Logging

The system integrates with ThingSpeak, a cloud IoT platform that supports time-series databases and live data plotting. Each water quality parameter is assigned to a field in a dedicated channel. Every POST request uploads one complete data frame including:

- Timestamp (automatically recorded by the server)
- pH value
- TDS value (in ppm)
- Turbidity (in NTU)
- Temperature (in °C)

The platform retains historical data, supports export to CSV or MATLAB-compatible formats, and provides REST APIs for integration with mobile or enterprise dashboards.

#### E. Threshold Alert System

To enhance utility, the cloud platform is configured with conditional triggers. When any sensor value crosses the pre-defined safe limit (e.g.,  $\text{pH} < 6.5$  or  $\text{TDS} > 500$  ppm), an alert system is activated. This includes:

- Visual color-coded warning on dashboard
- Optional email/SMS alert using IFTTT or Webhooks
- System log entry for anomaly detection

These alerts help users take preventive actions quickly, ensuring safety and compliance with water quality standards.

#### F. Data Validation and Calibration

Before deployment, the system is calibrated under controlled lab conditions using reference solutions. Each sensor is validated for:

- Linearity and response curve
- Drift over time

- Temperature influence
- Repeatability and noise

Periodic recalibration is performed using buffer solutions for the pH sensor and conductivity standards for the TDS sensor. The software includes correction offsets to maintain accuracy in varying environmental conditions.

#### G. Operational Workflow Summary

The real-time operational loop can be summarized as follows:

- 1) Sensors collect data from water source
- 2) NodeMCU reads, processes, and formats values
- 3) Wi-Fi is used to transmit data to the cloud
- 4) Cloud dashboard logs and visualizes data
- 5) Thresholds are monitored for alerts
- 6) Historical logs are retained for trend analysis

This modular design ensures that the system is extensible (more sensors can be added), robust (resilient to data loss), and portable (low power usage).

## IV. RESULTS AND ANALYSIS

After the successful development and deployment of the IoT-based water quality analysis system, a comprehensive series of test runs were conducted to assess its functionality, stability, and accuracy. The parameters measured—pH, Total Dissolved Solids (TDS), turbidity, and temperature—were evaluated in different water samples and compared against recognized standards such as those set by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS).

#### A. pH Measurement Analysis

pH values of several water samples were measured during different hours of the day to evaluate consistency and sensor stability. The pH readings consistently ranged between 6.8 and 7.6, staying well within the acceptable range of 6.5 to 8.5 for potable water. The sensor showed minor fluctuations due to temperature and electrode drift, which were compensated in software through periodic calibration and filtering algorithms.

Observations:

- Response time of the pH sensor was under 10 seconds.
- Variability remained within  $\pm 0.2$  pH, indicating

- good precision.
- pH values dropped slightly during the evening hours due to temperature effects and local water chemistry, which were corrected using offset compensation.

#### B. TDS Measurement Analysis

The TDS sensor displayed values in the range of 120 to 420 ppm across multiple water samples. These values were well within the WHO-recommended upper limit of 500 ppm for drinking water.

Observations:

- Readings from the TDS sensor closely matched those obtained using a commercial digital TDS meter (deviation  $\pm 5\%$ ).
- Compensation for water temperature was found to be effective in improving TDS accuracy during field tests.
- Regular cleaning of the probe was necessary to maintain consistency in readings.

#### C. Turbidity Measurement Analysis

Turbidity readings were converted into NTU (Nephelometric Turbidity Units) using calibration curves established during lab testing. Clean municipal water exhibited NTU values between 1.2 and 3.5, which falls within the permissible range ( $< 5$  NTU).

Observations:

- Higher turbidity was detected in rainwater collections and samples from open wells.
- Sensor accuracy was sensitive to ambient lighting and air bubbles, which were mitigated through sensor shielding and averaging algorithms.
- Real-time detection allowed tracking of sudden increases in turbidity, useful for contamination monitoring.

#### D. Temperature Measurement Analysis

The DS18B20 digital sensor provided stable and accurate readings, with variations within  $\pm 0.3^\circ\text{C}$ . Water samples recorded temperatures between  $24.5^\circ\text{C}$  and  $30.2^\circ\text{C}$  depending on ambient conditions.

Observations:

- Sensor showed excellent repeatability and minimal noise.
- The temperature data was effectively used for TDS correction.

- No significant drift or recalibration was required during the test period.

#### E. Cloud Data Visualization and Performance

Sensor data was uploaded to the ThingSpeak cloud platform every 30 seconds. The real-time plots and channel feeds were accessible remotely via mobile or desktop browsers.

Performance Highlights:

- Uptime reliability of Wi-Fi transmission was approximately 98% over a 7-day test window.
- Latency between sensor capture and cloud reflection was under 4 seconds.
- Custom thresholds were set to highlight values exceeding acceptable limits, enabling real-time alerts.
- Data logs were exported and used for offline analysis, confirming system stability over time.

#### F. Comparative Evaluation with Manual Testing

To validate the accuracy of the IoT system, parallel testing was performed using commercial digital water testing instruments. The average deviations observed were:

- pH:  $\pm 0.15$
- TDS:  $\pm 12$  ppm
- Turbidity:  $\pm 0.4$  NTU
- Temperature:  $\pm 0.3^\circ\text{C}$

The results confirm that the developed system delivers performance levels comparable to commercial instruments at a significantly lower cost and with the added benefit of remote monitoring and continuous logging.

#### G. Stability and Power Consumption

The system operated continuously for several hours without requiring reset. The total power draw was found to be less than 200 mA, making it viable for battery or solar-powered deployment. Internal tests showed that the system maintained consistent sensor output and cloud connectivity even under varying Wi-Fi signal strengths and fluctuating power supply voltages.

## V. APPLICATIONS

The proposed IoT-based water quality analysis system has wide-ranging applications due to its modular architecture, portability, and affordability. It addresses both individual and institutional needs for continuous

water monitoring.

- **Residential Water Monitoring:** The system can be used in households to monitor stored water in tanks or wells, ensuring it remains within safe limits. Real-time alerts can prevent consumption of contaminated water.
- **Industrial Quality Control:** Small- and medium-scale industries can deploy the system in water treatment plants, cooling towers, and chemical processing units to maintain water quality within regulatory limits.
- **Agricultural Use:** Farmers can monitor the quality of irrigation water, especially in regions where groundwater salinity, TDS, or pH imbalance affects crop yields. The system can help avoid long-term soil degradation.
- **Municipal Distribution Systems:** In urban and rural municipal water supply networks, the system can be deployed at distribution endpoints to detect contamination, leakages, or illegal discharge into pipelines.
- **Remote or Disaster-Prone Areas:** In flood-affected or geographically remote regions, the system can assist humanitarian agencies in testing water potability on-site without depending on laboratory facilities.
- **Research and Education:** Academic institutions and training centers can use this system in practical labs to demonstrate real-time data acquisition, IoT implementation, and environmental monitoring concepts.

## VI. ADVANTAGES

The implementation of this system offers several advantages over traditional water testing methods and high-end industrial systems.

- **Real-Time Monitoring:** Continuous and automatic data capture eliminates the delay associated with manual sample collection and laboratory testing.
- **Cost Efficiency:** The use of low-cost sensors and open-source platforms like NodeMCU and ThingSpeak makes the system affordable, especially for rural and small-scale applications.
- **Remote Accessibility:** Users can access water quality data from anywhere using cloud integration. Alerts can be configured to notify users immediately when quality degrades.

- **Scalability:** The system can be easily extended to include additional sensors (e.g., chlorine, nitrate, ORP) or multiple monitoring points within a network.
- **Low Power Consumption:** Optimized code and sensor polling intervals help conserve power, enabling deployment in areas powered by battery or solar energy.
- **Customizable Thresholds and Logging:** Alert thresholds can be configured by users based on application-specific tolerances, and historical logs can aid in trend analysis.

## VII. LIMITATIONS

Despite its advantages, the current version of the system has some constraints that may affect performance in certain environments.

- **Single Analog Input:** The ESP8266 microcontroller has only one ADC pin, requiring multiplexing or analog-to-digital converters for multiple analog sensors.
- **Sensor Degradation:** Low-cost sensors, especially pH and turbidity probes, may degrade over time or require frequent recalibration and cleaning.
- **Wi-Fi Dependency:** The system relies on continuous internet connectivity to function. In rural or remote areas with unstable networks, data loss or delay can occur.
- **Limited Sensor Accuracy:** While sufficient for general monitoring, the sensors used may not match laboratory-grade accuracy, especially for regulatory reporting.
- **Security Concerns:** Data is transmitted over public networks, which may raise concerns about security and data integrity unless HTTPS or token-based encryption is implemented.

## VIII. FUTURE SCOPE

Several enhancements can be introduced in future versions of the system to overcome limitations and broaden its applicability.

- **Expanded Sensor Suite:** Integration of additional sensors such as dissolved oxygen, chlorine, nitrate, or heavy metal detectors can provide a more comprehensive water quality profile.
- **Machine Learning for Predictive Analysis:** Historical data can be used to implement predictive

models that forecast contamination trends or detect sensor faults.

- Mobile Application Development: A cross-platform mobile app can be developed to enable real-time notifications, sensor health status, and dynamic configuration without code changes.
- Edge Computing: Incorporating edge processing with platforms like Raspberry Pi can allow local decision-making, faster alerts, and reduced cloud dependence.
- Energy Optimization: Use of deep sleep modes, power-efficient communication protocols like MQTT, and solar charging systems can enable long-term autonomous deployments.
- Secure Communication Protocols: Future iterations can implement HTTPS, TLS, or MQTT-SN protocols for end-to-end encrypted data transmission.

#### IX. CONCLUSION

This paper presented the design, development, and evaluation of an IoT-based water quality analysis system capable of real-time monitoring and cloud-based data visualization. The system successfully integrates low-cost sensors for measuring pH, TDS, turbidity, and temperature, along with a NodeMCU ESP8266 microcontroller for data acquisition and transmission. Cloud connectivity via ThingSpeak enables continuous logging, remote access, and threshold-based alerting, thereby improving the reliability and responsiveness of water quality management.

The results indicate that the system performs with acceptable accuracy compared to conventional handheld meters and commercial instruments. Its modular architecture, low power consumption, and affordability make it well-suited for residential, agricultural, and industrial applications, especially in remote or resource-constrained environments.

While current limitations include dependence on Wi-Fi, limited sensor accuracy, and basic security, the system provides a scalable foundation for future improvements such as machine learning-based forecasting, secure data transmission, and integration of advanced sensors. By enabling preventive intervention and data-driven decision-making, the proposed system contributes to public health, environmental sustainability, and digital

transformation in water resource management.

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