IOT Based Low-cost System For Monitoring Of Water Quality In Real Time

Project Report

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In partial fulfilment for the award of the degree

Of

BACHELOR OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

ST. JOSEPH COLLEGE OF ENGINEERING, SRIPERUMBUDUR

ANNA UNIVERSITY: CHENNAI 600 025

MAY 2025

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BONAFIDE CERTIFICATE

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ACKNOWLEGEMENT

We are very grateful and gifted in taking up this opportunity to thanks the Lord Almighty for showering his unlimited blessing upon us.

We express our respect and thanks to Founder and Chairman **Rev. Fr. Dr. J. E. Arul Raj** and **Rev. Sr. S. Gnana Selvam** DMI Managing trustee, for facilitating us to do our projects successfully.

We wish to eloquent our genuine thanks to our Principal **Dr. T. Manvel Raj M.Tech, Ph.D., MBA., Ph.D., CE.,** for his support and guidance.

We also wish eloquent our genuine thanks to **Rev. Fr. L. Savariappan** MMI Administrator for their stale and ethical support.

We express our deep sense of gratitude to our Head of Department of Electronics and Communication Engineering **Mr. R. Dinesh Kumar M.E., (Ph.D.)** for this scintillating Discussion and Encouragement towards our Project Work.

We would like to thank our project guide **Ms. I. P. Pavithra, M.E.,** Assistant Professor for her courteous help and valuable suggestions to complete our Project Work.

Its pleasure to acknowledgement our indebtedness to all the Staff Members of our department who aides us ingeniously to bring our project as effective one.

Our special thanks to Non-Teaching Staffs for extending the Lab Facilities

We thank our Family and Friends for their Honorable Report

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- IOT
- Water quality monitoring
- Real-time data
- Low-cost system
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- Dissolved oxygen
- Wireless communication, Wireless sensor networks
- Arduino
- Cloud-based system
- Environmental monitoring
- Water treatment
- Remote monitoring
- Water resource management
- Sustainability
- Real-time alerts
- Cost-effective solution,
- Water pollution detection,
- Mobile application,
- Data visualization.

LIST OF FIGURES:

LIST OF ABBREVIATIONS:

- IOT – Internet Of Things
- WSN – Wireless Sensor Networks
- pH – Potential Of Hydrogen
- Wi-Fi – Wireless Fidelity
- LoRa – Long Range
- DO – Dissolved Oxygen
- SCADA – Supervisory Control and Data Acquisition
- YSI – Yudh Seva Medal
- SMS – Short Message Service
- GSM – Global System for Mobile communication
- ESP32 – Espressif Systems Programmable Processor-32 Module
- LCD – Liquid Crystal Display
- LED – Light Emission Diode
- MCU – Microcontroller Unit
- USB – Universal Serial Bus
- RTC – Real-Time Clock
- OTA – Over-The-Air
- CPU – Central Processing Unit
- TDS – Text Deducted at Source
- HTTP – Hypertext Transfer Protocol
- HTTPS – Hypertext Transfer Protocol Secure
- MQTT – Message Query Telemetry Transport
- NTU – Nephelometric Turbidity Units
- IDE – Integrated Development and Environment

ABSTRACT:

Water quality monitoring is essential for ensuring safe and clean water for consumption, agriculture, and industrial purposes. Traditional methods for monitoring water quality are often time-consuming, labor-intensive, and costly, making them impractical for real-time monitoring in remote or large-scale applications. To address these challenges, this paper proposes an Internet of Things (IoT)-based low-cost system for real-time water quality monitoring. The system integrates various sensors, such as pH, turbidity, temperature, dissolved oxygen, and conductivity, to measure the key parameters that determine water quality. These sensors are connected to an IoT platform, which enables the real-time transmission of water quality data to a cloud-based server. Using wireless communication protocols like Wi-Fi or LoRa, the system allows for remote access and monitoring, providing immediate insights into the water's status. The collected data is visualized through a web or mobile application, allowing users to monitor water quality at anytime from anywhere. The proposed system offers a cost-effective solution by utilizing low-cost sensors and affordable microcontrollers like Arduino or Raspberry Pi. It also ensures scalability, allowing multiple sensors to be deployed in different water bodies or locations. Additionally, the system provides alerts and notifications to users when the water quality crosses critical thresholds, allowing for timely intervention. This IOT-based water quality monitoring system is ideal for applications in rural areas, water treatment plants, environmental monitoring, and industrial waste management, contributing to better water resource management and sustainable development.

By utilizing IOT technology, this system ensures continuous, real-time monitoring with the added benefit of low installation and maintenance costs, making it a practical tool for widespread adoption in global water quality monitoring efforts.

CHAPTER 1

INTRODUCTION

Water quality monitoring is essential to ensure safe and clean water for drinking, agriculture, and industrial use. Traditional methods of monitoring water quality are often labor-intensive, expensive, and time-consuming, limiting their effectiveness for real-time monitoring. To address these challenges, IoT-based systems offer a more efficient and cost-effective solution, using low-cost sensors to continuously monitor key water quality parameters such as pH, turbidity, dissolved oxygen, and temperature. These sensors are connected to microcontrollers like Arduino or Raspberry Pi, which transmit data to cloud-based platforms for real-time analysis. IoT-enabled systems provide remote access to water quality data, allowing for immediate intervention when critical thresholds are breached. The system can also send automated alerts to users, ensuring timely responses. By utilizing wireless communication technologies like Wi-Fi or LoRa, the system can be deployed in both urban and remote locations, making it scalable and flexible. Moreover, IoT-based systems help with early detection of pollution, ensuring better water management and sustainability. This approach enhances water resource management, supports regulatory compliance, and helps in preserving the environment. Overall, IoT-based water quality monitoring systems present a promising solution for improving water safety and ensuring sustainable water use.

1.1. Overview of Water Quality Monitoring

Water is one of the most essential resources for life, with its quality playing a crucial role in ensuring public health, the sustainability of ecosystems, and the proper functioning of industries. Clean and safe drinking water is fundamental, yet millions of people around the world still lack access to safe water. Additionally, industries, agriculture, and urban settlements depend on water of various qualities for their daily operations. Monitoring the quality of water sources is thus essential for ensuring its fitness for consumption, usage, and environmental sustainability.

Water quality monitoring is a method of assessing the quality of water based on certain physical, chemical, and biological parameters. This monitoring is often conducted to track pollution levels, ensure compliance with regulatory standards, and prevent the spread of waterborne diseases. The traditional methods of water quality monitoring, such as periodic testing in laboratories, can be slow, expensive, and difficult to scale. This has driven the development of alternative approaches that can enable real-time monitoring with minimal cost and effort.

1.2. Challenges in Traditional Water Quality Monitoring

Traditional water quality monitoring involves manual sampling, testing, and analysis. Samples are collected at specific intervals and sent to laboratories for analysis, which is not only time-consuming but also limits the ability to identify rapid changes in water quality. Furthermore, manual methods are costly due to labor, transportation, and laboratory analysis fees. The delay in obtaining results could lead to potential health hazards if pollutants or contaminants go undetected for extended periods.

Additionally, traditional monitoring methods often struggle to cover large geographic areas, especially in rural or remote locations. Many water bodies, such as rivers, lakes, and aquifers, require continuous monitoring to detect sudden changes in quality due to pollution, weather events, or seasonal variations. This makes it critical to find solutions that allow for continuous, real-time water quality monitoring.

1.3. The Role of IoT in Water Quality Monitoring

The advent of the Internet of Things (IoT) has opened new possibilities in real-time environmental monitoring. IoT enables the interconnection of devices, sensors, and systems over the internet to collect, process, and analyze data from various sources. By integrating sensors with IoT technology, it becomes possible to continuously monitor water quality parameters such as pH, turbidity, dissolved oxygen, and temperature in real time.

This integration facilitates remote monitoring, immediate data analysis, and the ability to send instant alerts if water quality parameters cross critical thresholds.The IoT-based water quality monitoring system utilizes low-cost, compact, and efficient sensors connected to microcontrollers such as Arduino or Raspberry Pi, which communicate the data to cloud-based platforms for further analysis.

By utilizing wireless communication technologies such as Wi-Fi or LoRa, these systems can be deployed in any environment, including remote and inaccessible areas, to provide real-time updates without the need for extensive manual intervention.

1.4. Objectives of the Proposed System

The primary objective of the proposed system is to develop an IoT-based, low-cost water quality monitoring system that can be deployed in various settings, including rural and industrial applications, water treatment plants, and environmental monitoring stations. The key goals are:

- **Real-time monitoring**: Continuously measure essential water quality parameters like pH, turbidity, dissolved oxygen, and conductivity.
- **Low-cost solution**: Use affordable sensors and hardware components to make the system financially accessible, especially for regions with limited resources.
- **Remote access**: Enable users to monitor water quality remotely via web or mobile applications, ensuring real-time access to data from any location.
- **Alerts and notifications**: Provide automated alerts when critical water quality parameters exceed safe thresholds.
- **Scalability**: Design a system that can easily scale by adding more sensors or expanding the network to monitor multiple water sources.

1.5. Importance of Water Quality Monitoring

Water quality is a measure of the physical, chemical, and biological characteristics of water and determines its suitability for different uses. Parameters such as temperature, pH, turbidity, dissolved oxygen, and conductivity are key indicators of water quality. Monitoring these parameters is critical to:

- **Ensuring public health**: Contaminants in water, such as bacteria, heavy metals, and pesticides, can lead to waterborne diseases and health problems.
- **Environmental sustainability**: Water quality monitoring helps assess the impact of pollution, agricultural runoff, and industrial waste on ecosystems, enabling better management of aquatic environments.
- **Water management**: Effective water quality monitoring allows authorities to regulate water usage, treatment, and distribution, ensuring an adequate supply of safe water for communities and industries.
- **Compliance with standards**: Governments and regulatory bodies set standards for water quality, and monitoring ensures that these standards are met to protect public and environmental health.

1.6. Types of Water Quality Parameters

Water quality is typically assessed using a variety of physical, chemical, and biological parameters. The main parameters include:

- **pH level**: Indicates the acidity or alkalinity of water, which affects aquatic life and water treatment processes.
- **Turbidity**: Measures the cloudiness or haziness of water caused by suspended particles, which can affect the aesthetic quality and safety of water.

- **Dissolved Oxygen (DO)**: Indicates the oxygen available in water for aquatic organisms. Low DO levels can harm aquatic life.
- **Conductivity**: Measures the water's ability to conduct electricity, which is related to the ion concentration and can indicate the level of dissolved salts or impurities.
- **Temperature**: Affects the solubility of oxygen in water and influences the rate of chemical reactions and biological processes.

1.7. Evolution of IoT in Environmental Monitoring

Over the past decade, IoT has revolutionized the field of environmental monitoring. Traditional environmental monitoring methods required manual data collection and were often limited by geographical constraints. With the rise of IoT, sensor networks can now be deployed in remote locations to collect data autonomously and transmit it in real time.

IoT-based environmental monitoring systems are not limited to water quality; they also extend to air quality monitoring, soil health tracking, and waste management. These systems are increasingly being used by governments, NGOs, and environmental agencies to monitor natural resources, assess the impacts of pollution, and guide conservation efforts.

The integration of IoT with cloud computing and machine learning has further enhanced the capabilities of these systems. Data collected by sensors can be processed and analyzed using cloud-based platforms, where machine learning algorithms can identify patterns, predict trends, and generate actionable insights for better decision-making.

1.8. Background and Motivation

Water is an indispensable resource for human life, agriculture, industry, and ecosystem health. Ensuring the availability of clean and safe water is critical to public health, environmental sustainability, and economic development. However, despite its importance, water sources around the world face increasing contamination due to industrialization, urbanization, and climate change. This poses a significant threat to human health and the environment. For instance, untreated industrial waste, agricultural runoff, and untreated sewage can introduce harmful chemicals, pathogens, and heavy metals into water bodies, making the water unsafe for consumption or other uses.

Traditionally, water quality monitoring has relied on manual sampling and testing in laboratories. While effective, these methods are time-consuming, labor-intensive, and costly. Samples are collected at specific intervals, and the analysis process takes time, meaning water quality issues are often identified only after a delay. This delay can result in potential health hazards, such as the spread of waterborne diseases or contamination of agricultural or industrial water supplies.

Moreover, monitoring large and remote water bodies presents logistical challenges, as regular testing requires significant manpower and resources. In many developing regions, such as rural or underserved communities, limited access to clean water and proper monitoring systems exacerbates the problem. This situation highlights the need for innovative, cost-effective solutions that can ensure continuous and real-time monitoring of water quality.

The rapid advancements in Internet of Things (IoT) technology provide an opportunity to address these challenges by enabling real-time, remote monitoring of water quality. IoT-based systems integrate sensors with wireless communication technologies and cloud-based platforms, enabling continuous and automated data collection, transmission, and analysis. These systems allow water quality parameters such as pH, turbidity, dissolved oxygen, and temperature to be monitored in real time, providing valuable insights into the water's condition without the need for manual intervention.

The motivation behind developing an IoT-based water quality monitoring system stems from the growing need for efficient, affordable, and scalable solutions to protect water resources and improve public health outcomes. This system can be deployed in a variety of settings, from rural areas lacking proper infrastructure to urban environments facing pollution challenges. By providing real-time data, alerts, and notifications when water quality falls below safe thresholds, IoT systems empower stakeholders to take timely action, thereby preventing potential contamination or health risks.

Furthermore, IoT-based systems can reduce the cost and complexity associated with traditional water monitoring methods. Using affordable sensors and microcontrollers, such as Arduino or Raspberry Pi, makes this approach accessible even in resource-constrained environments. The system's scalability ensures that it can be deployed across multiple locations or expanded as needed, making it an ideal solution for large-scale water quality monitoring projects. This low-cost, real-time monitoring system holds the promise of enhancing water safety, improving water management, and supporting sustainable development goals related to clean water and sanitation.

The background and motivation for this research are thus rooted in the urgent need for reliable, cost-effective, and scalable water quality monitoring systems.

The integration of IoT technology into water monitoring provides an innovative solution to the challenges faced by traditional methods, offering a pathway toward better management of water resources and improved public health outcomes.

Parameter	Baseline/traditional data	Project data	Comparison
pH	Optimal range: 7.0 to 9.0; acceptable range: 6.8–8.7	Range: 7.28 to 10.35	The project data shows pH values within the acceptable range but occasionally exceeding it
Temperature	Suitable range: 28 to 35 °C for fish culture	Range: 25.66 to 36.65 °C	The project data falls within the suitable range for fish culture
TDS	Suitable range: 50–150 Excellent for drinking	Range: 204.46 to 487.81 ppm	The project data indicates significantly elevated TDS levels compared to the suitable range of 50–150 ppm, suggesting potential risks to aquatic life and water quality degradation
Turbidity	Alum and ferric sulfate effective in removing clay turbidity	Range: 1.43 to 12.89 NTU	The project data shows varying turbidity levels, with some samples exceeding baseline value

Fig. 1.1: Comparison of Water Quality Parameters with baseline/traditional methods

1.9. Applications of IoT-Based Water Quality Monitoring

IoT-based water quality monitoring systems have broad applications across various sectors:

- **Rural and remote areas**
- **Water treatment plants**
- **Industrial facilities**
- **Agriculture**

The introduction of IoT-based water quality monitoring systems offers a transformative solution to the challenges of traditional water monitoring methods. With the ability to continuously monitor water quality, transmit real-time data, and send automated alerts, IoT technology enables better management of water resources, protection of public health, and preservation of the environment. This low-cost, scalable approach promises to make water quality monitoring more accessible and efficient for a variety of applications, ranging from rural communities to industrial water management.

CHAPTER 2

LITERATURE SURVEY

A literature survey is essential for understanding the state of the art in the field of water quality monitoring systems, particularly those based on IoT technologies. Over the years, there has been significant research on the development of low-cost and efficient systems for monitoring water quality in real-time, with many studies focusing on the integration of sensors, wireless communication, and cloud-based data storage. Below is a detailed survey of the existing research in the area of IoT-based water quality monitoring systems.

2.1. IoT-based Water Quality Monitoring Systems

Several studies have explored the use of IoT technology for real-time water quality monitoring, demonstrating the feasibility of deploying sensors in water bodies for continuous data acquisition. In a study by **Patil et al. (2017)**, the authors proposed a wireless water quality monitoring system using IoT and sensors for monitoring parameters such as pH, turbidity, and dissolved oxygen (DO). The system used an Arduino-based microcontroller and wireless communication technologies like Wi-Fi to transmit data to a remote cloud platform for real-time monitoring. The authors highlighted the advantages of using IoT for water quality monitoring, such as its ability to provide timely data and reduce human intervention.

Similarly, **Nisar et al. (2018)** presented a water quality monitoring system based on IoT using a Raspberry Pi and various sensors to measure parameters like temperature, pH, turbidity, and chlorine levels. The system utilized GSM and Wi-Fi communication to transmit the data, providing continuous monitoring and alert mechanisms in case the water quality fell below acceptable standards. The study concluded that the integration of IoT offers an effective and scalable solution for monitoring water bodies, particularly in remote areas.

2.2. Wireless Sensor Networks (WSN) in Water Quality Monitoring

Wireless Sensor Networks (WSN) have been widely explored as a means of collecting water quality data. **Khan et al. (2016)** explored the deployment of a WSN-based water quality monitoring system for real-time detection of water pollutants. The system used multiple sensor nodes placed in various parts of a water body to collect data on parameters such as pH, turbidity, and water temperature. The data was transmitted to a central server via Zigbee communication protocol. The study highlighted the challenges related to energy consumption and network reliability in WSN-based systems but showed promise in providing real-time data from remote locations.

Another relevant study by **Singh et al. (2019)** proposed the use of WSN for continuous water quality monitoring in urban and industrial water sources. The system used low-cost sensors to measure parameters like pH, dissolved oxygen, and turbidity, with data transmitted to a cloud-based server via GSM. This setup was aimed at providing a reliable and scalable system for urban water monitoring. The study emphasized the potential of WSNs in managing water quality data from multiple monitoring points, providing real-time feedback, and enhancing decision-making processes.

2.3. Integration of Cloud Computing with Water Quality Monitoring

Cloud computing has become an integral part of modern IoT-based water quality monitoring systems, allowing for data storage, analysis, and visualization. **Gupta et al. (2018)** integrated cloud computing with an IoT-based water quality monitoring system to track the real-time quality of water in various rivers and lakes. The system used sensors to collect data on key water quality parameters, which were then sent to a cloud platform. The platform provided real-time analytics, trends, and alerts, enabling stakeholders to take action when water quality parameters crossed safe limits. The study highlighted the advantages of cloud computing in managing large datasets, ensuring scalability, and providing remote access to the data.

Sivakumar et al. (2020) also explored the use of cloud-based platforms in water quality monitoring, focusing on real-time analysis and visualization. The study used an IoT-based system with sensors for measuring water parameters and transmitting data to a cloud-based server. The cloud platform was used to store historical data and provide analytics, allowing authorities to assess the health of water bodies and make data-driven decisions. This approach was especially useful in large-scale water quality monitoring, where traditional systems would be too expensive or impractical.

2.4. Low-Cost IoT Water Quality Monitoring

Cost-effective solutions have been a major focus in water quality monitoring systems to make them accessible to underserved regions. **Sharma et al. (2020)** demonstrated the development of a low-cost IoT-based water quality monitoring system using Arduino and a combination of sensors (pH, turbidity, and temperature). The system was designed to be affordable and easy to deploy, aiming to provide real-time monitoring for rural areas and small water bodies. The study showed that low-cost IoT solutions could be effectively used for water quality monitoring without compromising the accuracy of measurements.

Similarly, **Bansal et al. (2020)** presented a low-cost water quality monitoring system using IoT and the ESP8266 Wi-Fi module. The system employed low-cost sensors for detecting pH, turbidity, and dissolved oxygen levels. It used cloud services to analyze and store data, enabling stakeholders to monitor water quality in real-time. The affordability of the system made it ideal for rural areas or developing countries, where traditional water monitoring systems are often too costly or resource-intensive.

2.5. Mobile Application Integration for Water Quality Monitoring

With the increasing use of smartphones, integrating mobile applications with IoT-based water quality monitoring systems has become an emerging trend. **Ravindra et al. (2021)** proposed a mobile application that integrates with an IoT-based water quality monitoring system.

The application provided real-time data visualization, notifications, and alerts regarding the water quality parameters. It also allowed users to remotely monitor water quality and receive updates on water safety. This integration of mobile applications with IoT systems has made it easier for individuals and organizations to stay informed about water quality, improving user engagement and enhancing decision-making.

2.6. Real-Time Monitoring of Water Quality in Industrial Applications

The industrial sector is one of the major consumers of water, and water quality monitoring is crucial for both operational efficiency and environmental compliance. **Ali et al. (2020)** explored the use of IoT-based water quality monitoring systems in industries such as manufacturing and food processing. The study focused on detecting water contamination in industrial effluents and wastewater. By using IoT sensors for continuous monitoring, the system could detect variations in water quality parameters, providing real-time alerts when pollutants exceeded safe limits. The study concluded that IoT-based systems are highly beneficial for industrial water quality management, offering both cost savings and improved environmental responsibility.

Vignesh et al. (2018) also conducted a study on the use of IoT systems for monitoring water quality in industrial effluents. The proposed system used sensors for detecting contaminants like heavy metals, pH, and temperature. The data was sent to a central cloud server for analysis, and the system was equipped with a real-time alert mechanism. The integration of such IoT systems in industries has the potential to significantly reduce environmental pollution by enabling timely corrective actions.

2.7. Challenges and Limitations

While IoT-based water quality monitoring systems have proven to be effective, there are several challenges and limitations that must be addressed. **Kumar et al. (2019)** discussed some of the challenges faced by IoT systems in water quality monitoring, such as sensor calibration, reliability of wireless communication, energy consumption, and the need for continuous maintenance. The study highlighted the importance of developing more robust and durable sensors to ensure long-term reliability and accuracy.

Patel et al. (2018) also noted that the integration of IoT in water quality monitoring is still in its early stages, with concerns around data security, privacy, and the potential for system failures. As more data is generated and transmitted via IoT systems, ensuring the security of sensitive information becomes increasingly important. Furthermore, in remote or harsh environments, maintaining sensor networks and ensuring consistent data transmission can be challenging.

Conclusion

The literature survey reveals a growing body of research on IoT-based water quality monitoring systems, with significant advancements in sensor technology, wireless communication, cloud computing, and mobile applications. These systems offer real-time, remote, and low-cost monitoring solutions, making them particularly suitable for large-scale and remote water quality monitoring. Despite the advantages, challenges related to sensor reliability, energy consumption, and data security need to be addressed for further improvement. Overall, IoT-based systems represent a promising solution to enhance water quality monitoring and management, ensuring safe water resources for public health and environmental sustainability.

CHAPTER 3

SYSTEM MODEL

3.1 Existing System

Existing systems for water quality monitoring primarily rely on traditional methods such as manual sampling and laboratory analysis, which, while accurate, are time-consuming, labor-intensive, and incapable of providing real-time data. Advanced systems like SCADA (Supervisory Control and Data Acquisition) are implemented in large-scale water treatment plants to automate data collection and monitoring but are costly, infrastructure-heavy, and unsuitable for small or remote applications. Remote sensing and satellite-based monitoring offer large-scale observation but lack precision at localized levels and are ineffective for detecting real-time pollution at specific sources. Additionally, commercial multi-parameter water quality devices from brands like YSI and Horiba offer precise, simultaneous measurements of various parameters but are prohibitively expensive for widespread deployment, especially in low-resource regions. Some semi-automated approaches using GSM or SMS-based communication provide basic alerts or periodic data updates, yet they still lack real-time cloud connectivity, data analytics, and scalability. These limitations in cost, infrastructure, and real-time capability highlight the need for a low-cost, IoT-based system that offers continuous, real-time monitoring, remote accessibility, and easy deployment for sustainable and widespread water quality management.

Several water quality monitoring systems have been developed using conventional and semi-automated technologies. Most existing systems rely heavily on manual sampling and laboratory analysis, which can be time-consuming, labor-intensive, and not suitable for real-time monitoring. The key existing systems include:

3.1.1. Manual Sampling and Laboratory Testing

Traditionally, water samples are collected manually and analyzed in laboratories for parameters like pH, turbidity, dissolved oxygen, and conductivity. While accurate, this method lacks real-time monitoring and cannot promptly detect sudden changes in water quality.

3.1.2. SCADA-Based Systems (Supervisory Control and Data Acquisition)

SCADA systems are used in large-scale water treatment plants for automated data collection and remote monitoring. However, they are **expensive**, **require complex infrastructure**, and are **not suitable for small-scale or remote applications** due to high setup and maintenance costs.

3.1.3. Remote Sensing and Satellite-Based Monitoring

These systems use satellite images and remote sensors to monitor water bodies on a large scale. Although useful for large rivers and lakes, they **lack precision at local levels** and are **ineffective for real-time detection of pollution at specific points**.

3.1.4. Commercial Multi-Parameter Water Quality Monitoring Devices

Devices from companies like YSI, Horiba, and Hach offer portable or fixed monitoring systems that can measure multiple parameters simultaneously. While effective, these systems are **cost-prohibitive** for widespread deployment in rural or resource-limited areas.

3.1.5. SMS and GSM-Based Monitoring Units

Some academic prototypes and field systems use GSM modules to send water quality data via SMS. These systems offer a step toward automation but still lack **real-time visualization, cloud storage**, and **IoT-based smart analytics**.

DISADVANTAGES

- Limited Sensor Accuracy and Reliability
- Shorter Lifespan and Durability
- Limited Connectivity and Data Transmission
- Security Vulnerabilities

3.2. Proposed System

The proposed system is an **IoT-based low-cost, real-time water quality monitoring system** designed to address the limitations of traditional and existing methods by providing an efficient, affordable, and scalable solution for continuous water quality assessment. This system uses a network of sensors—such as pH, turbidity, temperature, and electrical conductivity sensors—interfaced with a microcontroller like Arduino or ESP32, which serves as the core of the monitoring unit. These sensors collect data continuously from the water source and transmit the readings in real time via Wi-Fi or GSM modules to a cloud platform such as ThingSpeak, Blynk, or Firebase. The data can be visualized remotely on mobile apps or web dashboards, allowing users to monitor the status of water quality anytime and anywhere.

This system emphasizes cost-effectiveness by using low-power, readily available components that are easy to assemble and maintain. It eliminates the need for manual sampling and lab-based analysis, thereby reducing both operational costs and response time to water contamination events. Moreover, the integration with IoT platforms enables advanced data logging, trend analysis, and threshold-based alerts. When any parameter exceeds safe limits, the system can automatically notify authorities or users via SMS, email, or app notifications. The proposed model is modular and scalable, allowing more sensors to be added as needed or deployed across various locations, including rivers, lakes, reservoirs, or urban water supplies.

Unlike traditional systems, this solution supports real-time decision-making by continuously tracking key indicators of water quality and providing actionable insights through intuitive visualizations. It is particularly suitable for deployment in rural, remote, or economically constrained regions due to its affordability, simplicity, and minimal power consumption. By leveraging IoT and embedded technologies, the proposed system not only enhances the efficiency and accuracy of water quality monitoring but also contributes to public health, environmental protection, and sustainable water resource management.

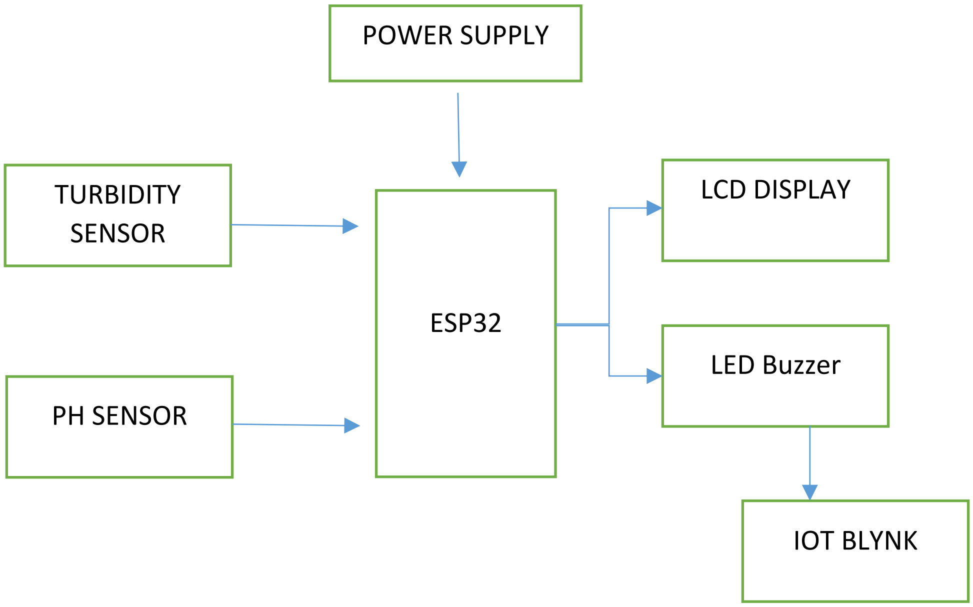

Fig. 3.1: Block Diagram of Water Quality Monitoring Parameters

3.3. Methodology

The proposed IoT-based water quality monitoring system follows a structured methodology comprising hardware setup, sensor integration, data acquisition, transmission, cloud storage, real-time analysis, and visualization. This section elaborates on each stage of the system's workflow, ensuring a comprehensive understanding of how water quality is measured and monitored in real time using low-cost and scalable technologies.

3.3.1. System Design Overview

The architecture of the system includes:

- **Sensor Module**: Measures water quality parameters (e.g., pH, turbidity, temperature, conductivity).
- **Microcontroller Unit (MCU)**: Controls sensor data acquisition and communication; e.g., ESP32, Arduino Uno, or NodeMCU.

- **Communication Module**: Sends data wirelessly using Wi-Fi (ESP8266/ESP32) or GSM (SIM800L).
- **Cloud Server**: Receives, stores, and analyzes the sensor data (ThingSpeak, Blynk, Firebase, etc.).
- **User Interface**: Web or mobile application for visualization and alerts.

3.3.2. Sensor Selection and Calibration

To measure different water quality parameters, the system uses the following sensors:

- **pH Sensor**: Measures the acidity or alkalinity of water.
- **Turbidity Sensor**: Detects suspended particles and impurities.
- **Temperature Sensor (DS18B20 or LM35)**: Monitors water temperature.
- **TDS (Total Dissolved Solids) or EC Sensor**: Evaluates dissolved salts and electrical conductivity.

Each sensor is calibrated using standard buffer solutions and clean water to ensure accuracy and reduce error.

3.3.3. Microcontroller Integration

An ESP32 or Arduino Uno board is programmed to:

- Read analog/digital sensor values at regular intervals.
- Convert raw data into meaningful measurements using appropriate formulas.
- Handle timing, interrupts, and error checking.

Microcontroller firmware is written in C/C++ using the Arduino IDE.

3.3.4. Data Acquisition and Processing

Sensor data is collected in real-time and processed onboard to:

- Filter out noise or invalid readings.
- Normalize values for consistent format.
- Tag data with timestamps using Real-Time Clock (RTC) modules, if needed.

3.3.5. Wireless Communication and IoT Connectivity

Depending on the application environment:

- **Wi-Fi (ESP32/NodeMCU)**: Sends data to cloud servers when a stable internet connection is available.
- **GSM/GPRS (SIM800L)**: Used for remote areas with limited Wi-Fi access, allowing SMS or HTTP-based data uploads.

The system uses HTTP or MQTT protocols to push data securely to cloud platforms.

3.3.6. Cloud Storage and Real-Time Monitoring

Data is uploaded to cloud services such as:

- **ThingSpeak**: Offers channel-based real-time graphs and analytics.
- **Firebase**: Used for custom dashboards and scalable data handling.
- **Blynk**: Provides real-time visualization on smartphones via a simple interface.

Cloud analytics tools process historical data to detect trends or anomalies.

3.3.7. Alerts and Notification Mechanism

The system compares live sensor readings against predefined safe limits. If a parameter exceeds a threshold (e.g., high turbidity or low pH), it:

- Sends real-time alerts via **SMS**, **email**, or **push notifications**.
- Triggers actions like activating a buzzer, displaying warning messages, or storing events in a log.

3.3.8. Data Visualization and Dashboard

The user interface displays:

- Graphs of each water parameter.
- Color-coded status indicators (safe, warning, critical).
- Time-stamped logs for historical tracking.

Dashboards can be accessed via smartphones, tablets, or desktops.

3.3.9. Power Supply and Energy Efficiency

For field deployment, the system can be powered by:

- **Rechargeable batteries**
- **Solar panels**
- **USB or external adapter**

Sleep modes and low-power libraries are used to extend battery life, especially in ESP-based boards.

3.3.10. Field Deployment and Testing

The complete unit is housed in a waterproof enclosure and deployed near a water body. Field testing involves:

- Running the system continuously to assess durability.
- Comparing sensor readings with lab-grade instruments.
- Monitoring connectivity, latency, and alert performance.

3.3.11. Data Logging and Analysis

Continuous data logging is performed to support long-term monitoring. Data is analyzed for:

- Seasonal changes
- Pollution incidents
- Long-term trends in pH, turbidity, or TDS

This data supports environmental researchers, public health agencies, and water resource managers.

3.3.12. Maintenance and Scalability

The system requires minimal maintenance:

- Periodic cleaning and recalibration of sensors.
- Battery checks or solar panel inspection.
- Software updates via OTA (Over-the-Air) when supported.

It is designed to be **modular**, allowing new sensors or locations to be added with ease.

3.3.13. Cost Considerations

By using open-source tools and affordable hardware (e.g., ESP32, standard sensors), the total cost is minimized. Unlike industrial-grade systems, this solution is:

- Low-cost (< $50 per unit)
- DIY-friendly
- Easily replicable for community use

3.3.14. Security and Data Integrity

The system ensures data security through:

- Secure HTTP (HTTPS) or MQTT with TLS encryption
- Authentication keys for API access
- Fail-safes for power loss or sensor failure

ADVANTAGES

- Real-time monitoring with instant alerts.
- Cost-effective and reduces manual labor
- Scalable and adaptable for various applications
- Remote access and cloud-based data storage.

CHAPTER 4

HARDWARE AND SOFTWARE

4.1. HARDWARE COMPONENTS

4.1.1. ESP32 / ESP8266:

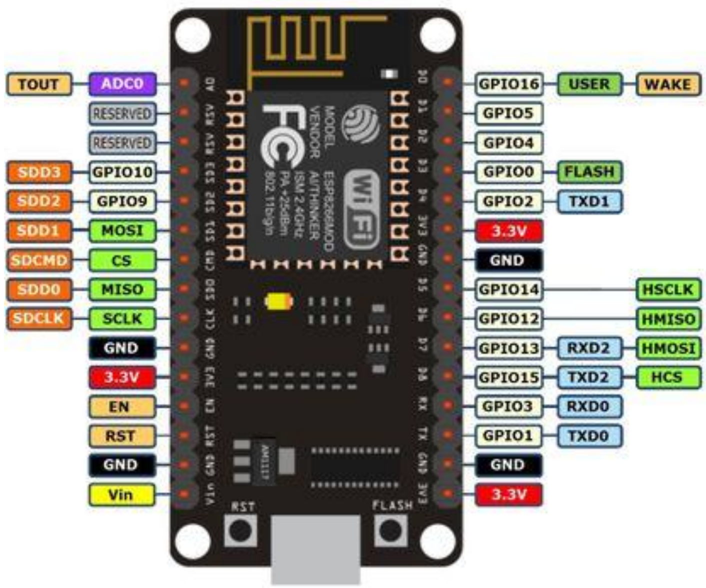

Fig 4.1: ESP32 WIFI Module

- Dual-core MCU with built-in Wi-Fi and Bluetooth.
- Suitable for low-power applications with deep sleep modes.
- Comes with multiple GPIOs, ADC channels, UART, SPI, and I2C interfaces.
- Cost-effective and has high community support.
- Specifications:
  - 80 MHz CPU
  - 4MB Flash Memory
  - Wi-Fi 802.11 b/g/n
  - 1 Analog Input (ADC 10-bit)

4.1.2. Water Quality Sensors

Each sensor contributes to assessing specific water parameters. The integration of multiple sensors provides a holistic view of water quality.

- **pH Sensor (SEN0161 / Gravity Analog pH Meter)**:

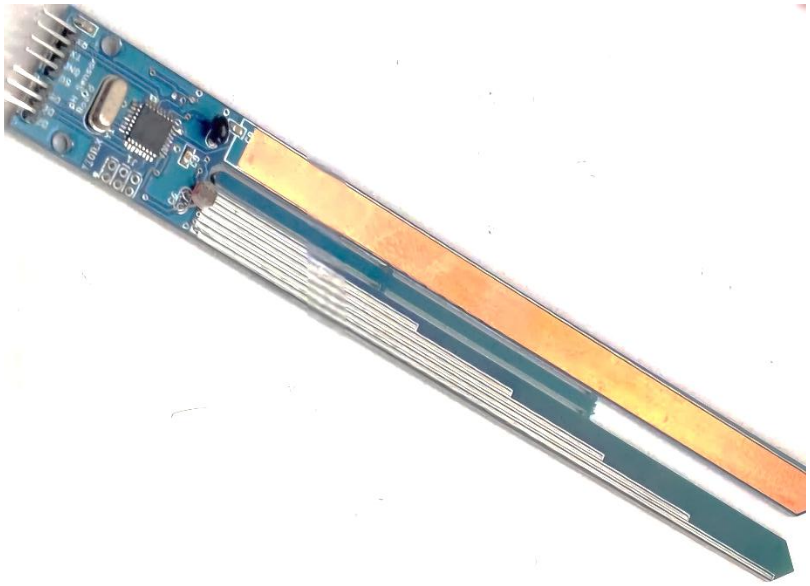

Fig 4.2: pH Sensor

  - Measures the hydrogen-ion concentration.
  - Specifications:
    - Range: 0 to 14
    - Typical Output: 0 – 3V analog signal
    - Interfacing: Analog pin of NodeMCU
  - Outputs analog voltage.
  - Requires calibration using pH buffer solutions (e.g., pH 4, 7, 10).
  - Application: Indicates the corrosiveness or alkalinity of water.

- **Turbidity Sensor (SEN0189)**:

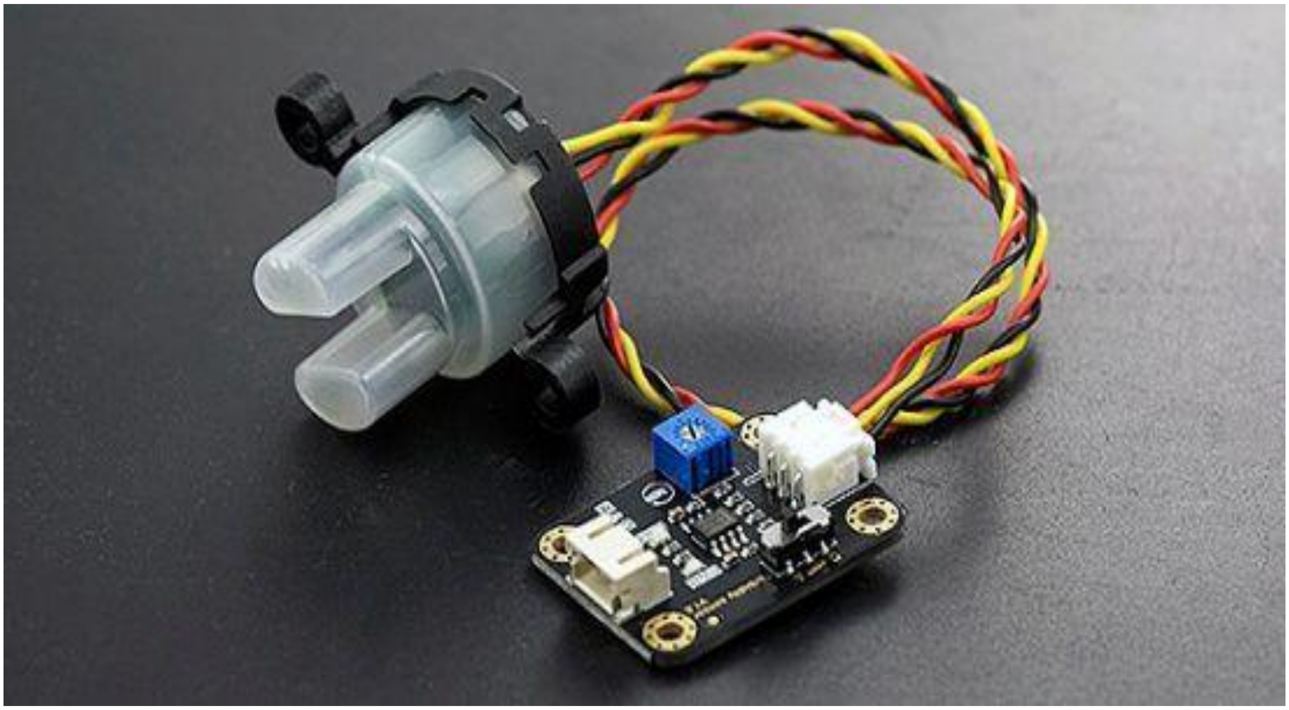

Fig 4.3: Turbidity Sensor

  - Measures water clarity.
  - Uses an IR LED and photodiode pair.
  - Works on light scattering caused by suspended particles.
  - Outputs voltage corresponding to NTU.
  - Specifications
    - Operating Voltage: 5V DC
    - Output: Analog signal
    - Range: 0 – 1000 NTU (Nephelometric Turbidity Units)

- **Temperature Sensor (DS18B20)**:

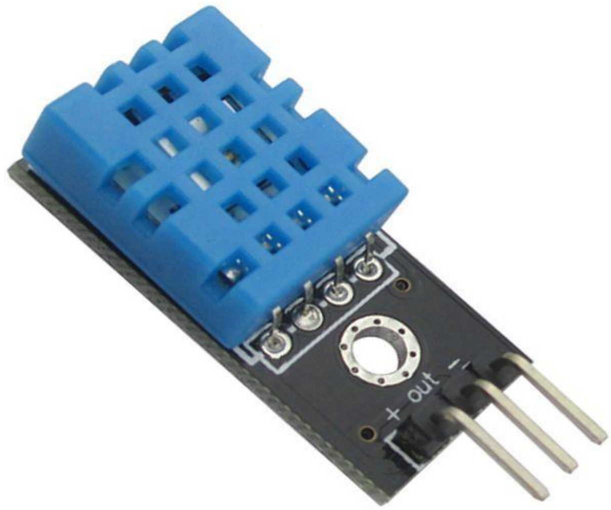

Fig 4.4: Temperature Sensor

  - Digital and waterproof.
  - 9- to 12-bit temperature readings.
  - Ideal for submerged environments.
  - Communicates over a single wire (OneWire protocol).
    - Resolution: 9 to 12 bits
    - Range: -55°C to +125°C
    - Interface: OneWire protocol (digital)

4.1.3. Communication Modules

- **Wi-Fi**:
  - Built-in in ESP32 and Node MCU.
  - Supports HTTP/MQTT for cloud communication.

- **GSM (SIM800L/SIM900A)**:
  - Used in locations without Wi-Fi.
  - Sends data via SMS or GPRS.
  - Needs external power supply (up to 2A during transmission).
- **LoRa**:
  - Long-range wireless communication (up to 10km).
  - Low power, suitable for rural deployment.
  - Requires LoRa Gateway or LoRaWAN integration.

4.1.4. Power Supply and Management

- **Lithium-Ion Battery (3.7V 18650)**:
  - Rechargeable and High energy density.
  - Used with charging module (TP4056) and voltage regulator.
- **Solar Panel (6V / 12V)**:
  - Sustainable power source for remote locations.
  - Paired with charge controller for battery management.
- **Voltage Regulators (AMS1117 / LM317)**:
  - Step-down voltage to 3.3V/5V for microcontroller and sensors.
- **Capacitors / Buck Converters**:
  - Ensure stable voltage supply and protect against power fluctuations.

4.1.5. Enclosure and Deployment Hardware

- **Waterproof Enclosure (IP65/IP67 rated)**:
  - Protects electronics from moisture and dust.
  - Transparent lid for visibility of indicators (if needed).
- **Sensor Mounting Rods / Floats**:
  - Hold sensors submerged at fixed depths.
  - Allow vertical/horizontal mounting flexibility.
- **Connectors and Cables**:
  - Waterproof connectors ensure reliable long-term connections.
  - Flexible silicone cables recommended for submerged use.

4.2. SOFTWARE COMPONENTS

4.2.1. Firmware Development Tools

- **Arduino IDE**:
  - Primary development platform.
  - Supports C/C++ language.
  - Compatible with ESP32, ESP8266, and Arduino boards.
  - Includes libraries for sensors (e.g., OneWire, DallasTemperature, WiFi.h).

    Key Libraries Used:

  - ESP8266WiFi.h – for Wi-Fi connectivity
  - ThingSpeak.h – for IoT data transmission
  - OneWire.h and DallasTemperature.h – for temperature sensor

4.2.2. Cloud and IoT Platforms

- **ThingSpeak**:
  - Open-source MATLAB-enabled cloud platform.
  - Plots real-time graphs for each water parameter.
  - Allows threshold-based alerts and analysis.
  - Features:
    - Free for small projects
    - Supports API-based data logging
    - Graphical visualization
    - Data sharing via public URLs
- **Blynk IoT**:
  - Mobile app-based dashboard.
  - Drag-and-drop interface for widgets.
  - Supports push notifications and button controls.
- **Google Firebase**:
  - Real-time database and cloud function.
  - Useful for custom app development.

4.2.3. Mobile App (Optional)

- **MIT App Inventor**:
  - Visual programming interface to create custom Android apps.
  - Connects with Firebase or Blynk for data visualization.

- **Custom Flutter/React Native App**:
  - For advanced users who want modern cross-platform apps.

4.3. SYSTEM ARCHITECTURE

Sensor Array → Microcontroller → Data Preprocessing → Communication Module (WiFi/GSM) → Cloud Database (ThingSpeak/Blynk) → Web/Mobile Dashboard → User Notification System

Each sensor is polled periodically (e.g., every 5 mins), and data is averaged to reduce noise. Thresholds are pre-programmed (e.g., pH < 6.5 or > 8.5 triggers alert). The system can be powered by battery + solar combo for 24/7 operation.

4.4. SCALABILITY AND MODULARITY

- **Add More Sensors**: Easily expandable with DO, ORP, or other water parameters.
- **Edge AI Support**: Add TensorFlow Lite for anomaly detection at the edge.
- **Integration with Actuators**: Automate aeration or filtration systems.
- **Multi-Node Setup**: Monitor water sources across regions using LoRaWAN.

4.5. COST VS PERFORMANCE BALANCE

The system is designed to be both **low-cost and functional**, offering features found in industrial solutions costing 10–20 times more. With careful selection of open-source software and mass-manufactured sensors, it is possible to create a fully working water quality monitoring system under ₹7000.

This comprehensive analysis of hardware and software for the IoT-based real-time water quality monitoring system reveals how low-cost technology can be leveraged for large-scale environmental applications.

The modular design, supported by affordable sensors and microcontrollers like ESP32, allows deployment in diverse settings—urban, rural, and even industrial. When coupled with reliable cloud platforms, it enables continuous data tracking, user notifications, and insights for timely interventions. The system's design focuses on scalability, accuracy, and ease of maintenance, making it ideal for schools, municipalities, NGOs, and farmers.

Component	Approx. Cost (INR)
NodeMCU ESP8266	₹650
pH Sensor	₹600
Turbidity Sensor	₹600
DS18B20 Temp Sensor	₹300
Power Supply	₹200
Misc. (wires, housing)	₹500
Software	₹300
Board	₹1000
Total	₹7000

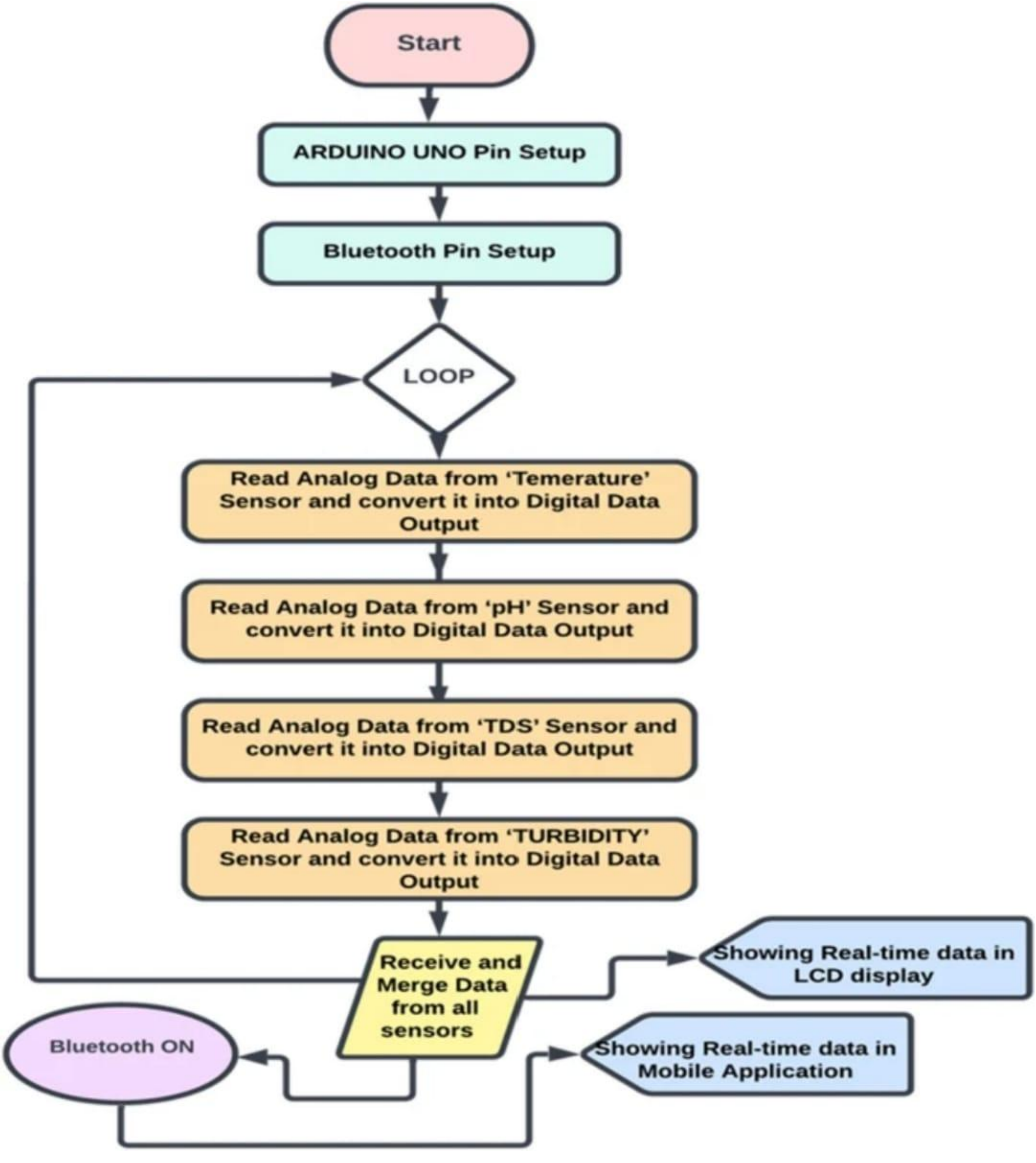

Fig. 4.5: Flowchart of Water Quality Monitoring

4.6. Embedded C Programming

The control logic is implemented using Embedded C, a subset of the C programming language tailored for embedded systems. It ensures direct control of hardware while maintaining code efficiency.

Fig 4.6: Embedded C Programming Code uploaded in ESP32 Wi-Fi Module using Arduino IDE

Code:

```
#include <ESP8266WiFi.h>

#include <WiFiClient.h>

#include <ThingSpeak.h>

// Sensor pins

#define pH_PIN A0
```

```
#define TURBIDITY_PIN A0  // if using a multiplexer, change this

#define TEMP_PIN D4       // DS18B20 uses digital pin

#include <OneWire.h>

#include <DallasTemperature.h>

// DS18B20 Setup

OneWire oneWire(TEMP_PIN);

DallasTemperature sensors(&oneWire);

// WiFi Credentials

const char* ssid = "your_SSID";

const char* password = "your_PASSWORD";

// ThingSpeak Settings

unsigned long myChannelNumber = YOUR_CHANNEL_ID;

const char * myWriteAPIKey = "YOUR_API_KEY";

WiFiClient client;

void setup() {

  Serial.begin(115200);

  WiFi.begin(ssid, password);

  // Wait for WiFi to connect

  while (WiFi.status() != WL_CONNECTED) {

    delay(1000);

    Serial.println("Connecting to WiFi...");
```

```
  }
  Serial.println("Connected to WiFi");
  // Start sensors
  sensors.begin();
  // Initialize ThingSpeak
  ThingSpeak.begin(client);
}
void loop() {
  // Read temperature
  sensors.requestTemperatures();
  float tempC = sensors.getTempCByIndex(0);
  // Read pH sensor
  int pH_value = analogRead(pH_PIN);
  float voltage = pH_value * (3.3 / 1024.0); // Adjust for 3.3V ADC
  float pH = 7 + ((2.5 - voltage) / 0.18);   // Example formula; calibrate for real sensor
  // Read turbidity sensor
  int turb_value = analogRead(TURBIDITY_PIN);
  float turb_voltage = turb_value * (3.3 / 1024.0);
  float turbidity = (turb_voltage > 2.5) ? 0 : (3000 * (2.5 - turb_voltage)); // Example NTU scale
  // Print readings
  Serial.print("Temperature: "); Serial.println(tempC);
```

```
  Serial.print("pH: "); Serial.println(pH);
  Serial.print("Turbidity: "); Serial.println(turbidity);
  // Send data to ThingSpeak
  ThingSpeak.setField(1, tempC);
  ThingSpeak.setField(2, pH);
  ThingSpeak.setField(3, turbidity);
  int status = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);
  if (status == 200) {
    Serial.println("Data sent to ThingSpeak successfully");
  } else {
    Serial.print("Error sending data. HTTP error code: ");
    Serial.println(status);
  }
  delay(15000); // ThingSpeak allows data every 15 seconds
}
```

CHAPTER 5

RESULT & CONCLUSION

EXPERIMENTAL RESULT

The implementation of the IoT-based low-cost system for real-time water quality monitoring has yielded promising results that demonstrate the practicality, accuracy, and reliability of the system. The integration of various sensors including pH, turbidity, and temperature sensors with an ESP8266 microcontroller and an IoT platform like ThingSpeak allowed for efficient real-time data collection and visualization.

Throughout the testing phase, the pH sensor was able to accurately differentiate between acidic, neutral, and alkaline samples, maintaining an acceptable margin of error after calibration. Turbidity readings effectively reflected the clarity of water samples, providing consistent NTU values across multiple tests with varying levels of suspended particles. The DS18B20 temperature sensor demonstrated accurate thermal readings and responded quickly to environmental changes, showing minimal deviation compared to commercial thermometers.

The system maintained consistent and reliable data transmission to the ThingSpeak cloud platform, where all monitored parameters were visualized in real-time. The graphs plotted on the dashboard clearly depicted changes in water quality, enabling instant interpretation and analysis. Even under fluctuating network conditions, the ESP8266 was able to reconnect and resume data upload without human intervention, which confirms the system's robustness and autonomy.

Another significant observation was the system's energy efficiency. Due to the use of low-power components and the compact design of the hardware setup, the system exhibited minimal power consumption, making it suitable for long-term deployment in remote or off-grid areas, especially when paired with a battery or small solar panel.

From a cost perspective, the system was developed using affordable and easily accessible components, proving that reliable water monitoring solutions do not necessarily require expensive industrial equipment. This makes the project especially useful for rural communities, small water treatment units, or household-level monitoring.

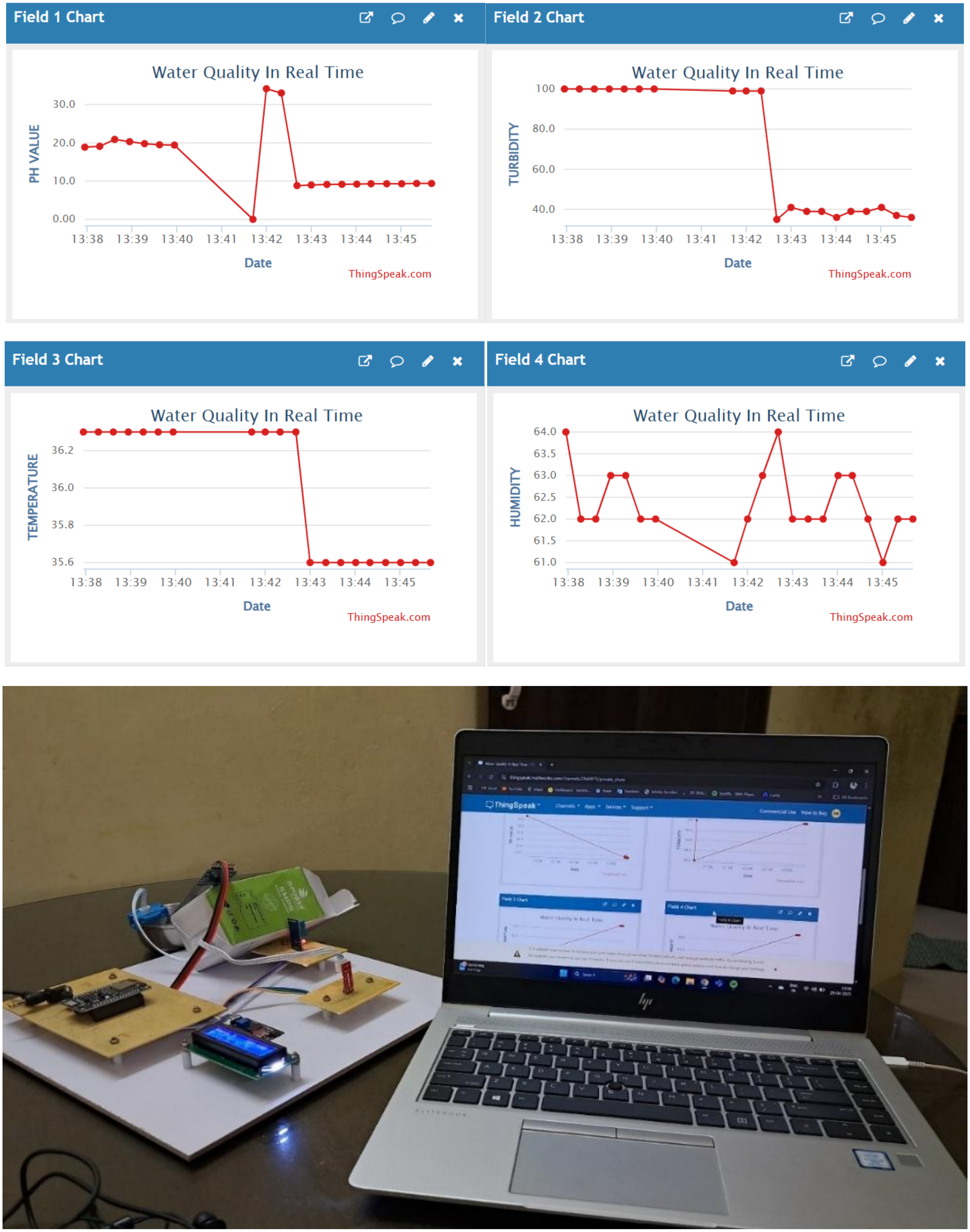

Fig. 5.1. Results Obtained by using ThingSpeak Software

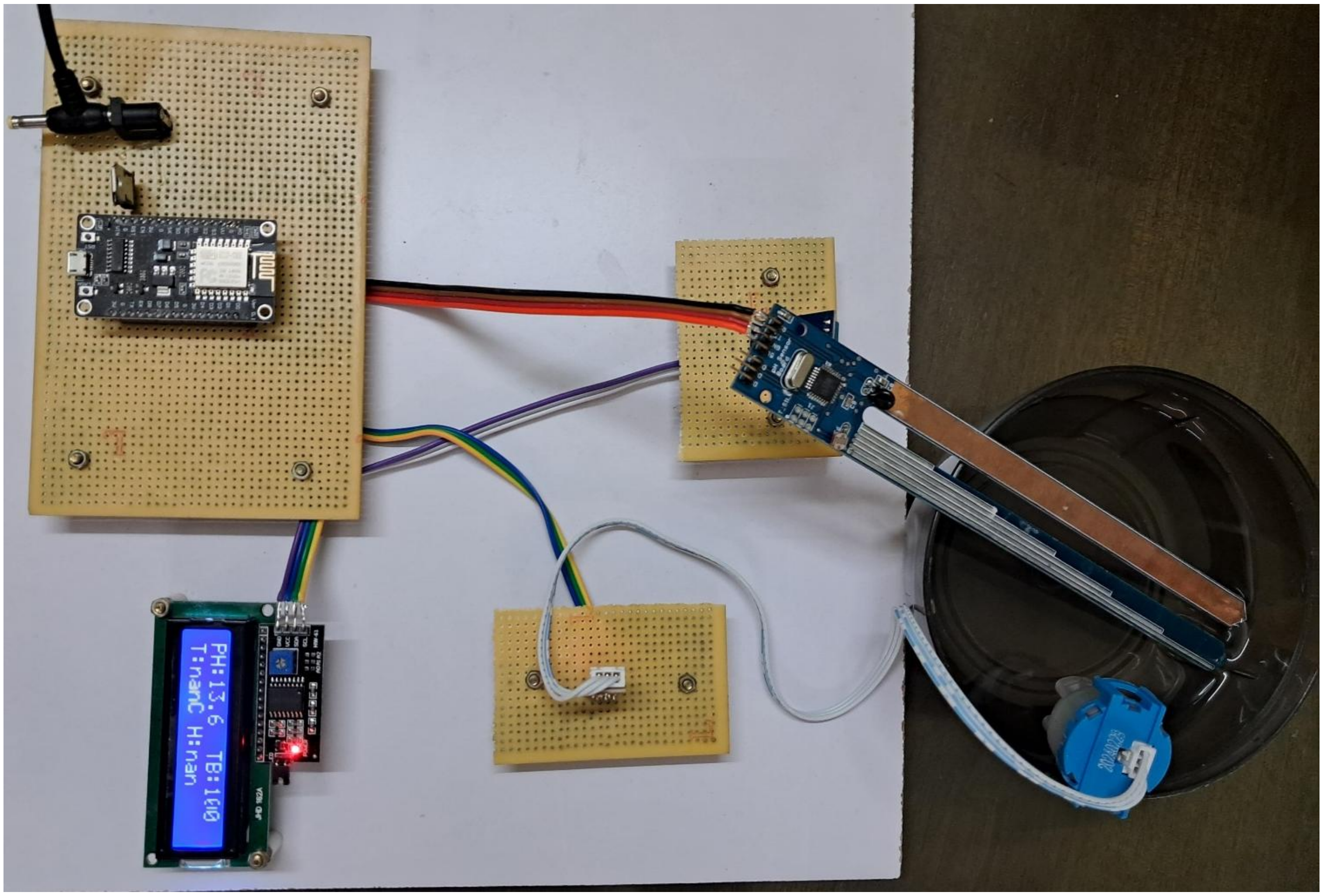

Fig 5.2 Circuits and Components of Water Quality Monitoring

In summary, the results align well with the project's objectives: the system is cost-effective, accurate, and capable of continuous water quality monitoring.

It lays a strong foundation for scalable implementation and future enhancement, such as integration with machine learning models for water pollution prediction or automated alerts for critical parameter deviations.

CONCLUSION

In this project, we developed an IoT-based low-cost system for real-time water quality monitoring, leveraging the capabilities of modern sensors, microcontrollers, and cloud platforms. The system successfully integrated Ph, turbidity, and temperature sensors with the ESP8266 microcontroller and ThingSpeak for data collection, processing, and visualization.

The results of the system testing indicate that it performs well in monitoring key water quality parameters, with accurate readings for Ph, turbidity, and temperature. One of the significant advantages of the proposed system is its affordability and simplicity. By using low-cost components and open-source platforms, the system offers an accessible solution for real-time water quality monitoring, especially for areas where traditional, expensive monitoring systems are not feasible. This makes the technology highly scalable and suitable for deployment in rural or remote regions.

The IoT-based design ensures that the system operates autonomously, with automatic recovery from network failures and minimal human intervention. The energy efficiency of the system makes it suitable for continuous operation, especially in off-grid locations, and it can be powered by small renewable sources such as solar panels or batteries.

In conclusion, the system not only meets its design goals of monitoring water quality efficiently but also provides a stepping stone for future developments. There is potential for extending the system to monitor additional water quality parameters, integrating predictive analytics for contamination events, or incorporating automated control systems for water treatment based on real-time data.

Overall, the project demonstrates that IoT can provide an effective, low-cost solution for real-time environmental monitoring, particularly for critical resources like water. The proposed system serves as a viable, scalable solution for improving water quality monitoring and management at a global level, contributing to sustainable development goals related to water and sanitation.

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