IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 10, May 2025

Impact Factor: 7.67

Implementation of a Real-Time Water Quality Monitoring System Using Raspberry Pi and IoT

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Abstract: *The availability of clean and safe water aids public health and environmental sustainability. Conventional water quality monitoring systems are generally time-consuming, costly, and non-real-time. This paper documents deploying an Internet of Things -based real-time water quality monitoring system based on Raspberry Pi 3B+, which can monitor vital water parameters like pH, turbidity, and flow rate. The system uses multiple sensors, such as pH, turbidity, and flow sensors. Analog sensor values are read through the ADS1115 ADC module, and real-time value is displayed on a 20x4 I2C LCD. Sensor reading is sent periodically to ThingSpeak cloud service for live monitoring, analysis, and history logging. Besides data logging, the system utilizes the Twilio API for SMS alerting registered users in the event of a drop in water quality parameters below safety levels (e.g., high turbidity or abnormal pH), initiating corrective action and timely alertness. The Python system computes water consumption and estimates billing based on flow measurements. The deployment displays cost-effective, portable, and scalable solution capability, which is enough for application in water distribution networks for urban and rural setups. The model can support forecasting analysis using a machine learning algorithm with additional sensor input (temperature, TDS). Overall, the innovative water quality monitoring system favors creating sustainable solutions to water management along the guidelines of innovative city initiatives.*

Keywords: IoT, Navigation, Mobility, Sensors, Machine Learning, Feedback

I. INTRODUCTION

Water is one of the most critical natural resources necessary for sustaining life. Its quality directly influences public health, agricultural productivity, industrial operations, and ecological balance. With the increasing population and industrialization, water sources are being polluted at an alarming rate, leading to an urgent need for effective and continuous monitoring. Ensuring access to clean and safe drinking water is also a key component of the United Nations' Sustainable Development Goals (SDGs), specifically Goal 6: "Clean Water and Sanitation." Despite its importance, many regions worldwide, particularly developing countries, struggle with monitoring and maintaining water quality due to the lack of infrastructure, skilled personnel, and real-time detection mechanisms.Classic water quality monitoring techniques often involve time-consuming and labor-intensive manual sampling and laboratory analysis, which is precise but time-consuming and unsuitable for continuous or remote monitoring. Sampling and analysis delays can delay the identification of contaminants with severe public health implications. The techniques must involve expensive analysis equipment and expertise, rendering them inaccessible and scalable, especially in remote or low-resource areas.As part of an attempt to overcome such limitations, technologies in embedded systems and the Internet of Things (IoT) have created low-cost, scalable, and real-time water quality monitoring systems. IoT-enabled monitoring systems provide for automated sensor measurement acquisition, processing, and reporting to cloud computing systems or a central monitoring station. The systems can be mounted in different environments, including rivers, reservoirs, municipal water mains, agricultural fields, and industrial wastewater outfalls, to monitor significant water parameters continuously.Raspberry Pi has become popular amongst the available embedded platforms because it is affordable, capable of processing, small in size, and supports GPIO while being compatible with many sensors and communication modules. Raspberry Pi 3B+ is especially useful for having adequate computational power to accomplish data acquisition, processing, and transmission functions at low power consumption. It also offers Python programming support, making rapid application development and tailoring feasible.

This project entails designing and implementing a real-time water quality monitoring system based on Raspberry Pi 3B+. The system can monitor three significant parameters: pH, turbidity, and flow rate. These parameters have been chosen as they directly influence the portability and usage of water. The pH of the water determines whether it is acidic or alkaline, and the extremes are toxic to human health, aquatic organisms, and agricultural purposes. Turbidity is a measure of the cloudiness or haziness of water due to suspended particles; high turbidity may be a sign of disease-causing pathogens. The flow rate will be measured to monitor water consumption, pipe leaks, or clogging.

The sensors utilized in this project include a pH sensor, turbidity sensor, and flow sensor. Raspberry Pi does not natively support analog input, so an ADS1115 analog-to-digital converter (ADC) interfaces analog sensors such as pH and turbidity. The configuration also includes a 20x4 I2C LCD to show real-time measurements from sensors and computed parameters such as the total amount of water used and an estimated bill value based on predefined consumption rates. The system uses the ThingSpeak IoT platform for remote monitoring and data analysis. ThingSpeak Offers a simple means of viewing and storing sensor data over the web and retrieving the data remotely for administrators and users. The data is transmitted from Raspberry Pi to ThingSpeak via HTTP requests. The application also has an alert system based on Twilio, a cloud communications API. Once the system detects water quality parameters outside the preselected safe limit (e.g., too high turbidity or beyond range pH), it triggers an SMS warning to a registered mobile phone. This will enable users to take action instantly on any water quality issues.

The application is developed using Python, with packages such as RPi.GPIO, adafruit_ads1x15, RPLCD, and requests. Python's simplicity and robust library support make it ideal for creating embedded apps. The application reads from the sensors, interprets the readings, updates the LCD, uploads the data to the cloud, and watches out for threshold violations to send notifications.

The deployment displays a robust, scalable, cost-effective solution for monitoring water quality. It applies to many applications, including home water monitoring, agricultural irrigation systems, municipal water supply networks, and industrial wastewater discharge monitoring. Moreover, the system enables future expansion, including co-merging with other sensors (e.g., temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC)), solar power support for the deployment in off-grid locations, and machine learning algorithms for predictive repair and anomaly detection.

In addition to its technological importance, the proposed system promotes environmental consciousness and public participation. With real-time water quality information availability, the system enables people and communities to make appropriate water usage and conservation decisions. It also offers a valuable tool for environmental researchers and policy-makers. Makers must get longitudinal data, identify pollution trends, and develop appropriate interventions.

Besides, the modular nature of the system enables educational and research applications. Enthusiasts and students can replicate the configuration to learn about embedded systems, environmental science, and data analysis. Hardware and software components, in combination, provide a hands-on learning process that integrates theoretical concepts and implementation.

In short, the impetus for this effort comes from the urgent need for affordable, ongoing, real-time water quality monitoring on a scalable basis. The goals of this deployment are:

1. To develop a real-time water quality monitoring system using Raspberry Pi 3B+.
2. To interface and acquire data from pH, turbidity, and flow sensors using ADC and GPIO.
3. To display sensor values and water usage information on a local I2C LCD.
4. To transmit sensor data to a cloud platform (ThingSpeak) for remote monitoring and visualization.
5. To send automated SMS alerts using Twilio when water quality deviates from safe thresholds.
6. To ensure the system is reliable, easy to deploy, and adaptable for various water monitoring applications.

The rest of the paper is organized as follows: Section 2 thoroughly reviews relevant work and existing systems for water quality monitoring. Section 3 provides the system architecture, i.e., hardware and software components. Section 4 provides a detailed implementation methodology with sensor interfacing, data processing, cloud integration, and alerting mechanisms. Section 5 provides the experimental results, performance analysis, and discussion. Section 6 summarizes the paper with possible future extensions and improvements.

II. LITERATURE SURVEY

Shaikh et al. (2023) [1] have brought an exhaustive review focusing on incorporating Internet of Things (IoT) technologies into water monitoring systems and tackled the issue of water pollution in developing nations like Pakistan. The paper explores to what extent IoT diminishes human interference and boosts accuracy and automation in environmental monitoring. It discusses various IoT-based systems that utilize sensors to detect physical parameters like pH, turbidity, temperature, and total dissolved solids (TDS). The authors critically analyzed the systems based on ARM-based MCUs, ZigBee, and Wi-Fi modules such as ESP8266 and MQTT for data communication; each had low power consumption or real-time transmission but was typically poor where data representation and system integration were involved. They also addressed challenges, including energy efficiency, real-time data analysis, and cloud-based secure communication. The authors emphasize that IoT-based Water Monitoring Systems (WMS) are scalable and low-cost technologies well suited to underserved areas where traditional manual testing is nonviable or unfeasible. The study concludes by raising the potential future combination with cloud computing and machine learning for such systems' improved prediction capacity and decision-making. The present study presents substantial knowledge for designing efficient, accessible, and innovative water quality monitoring infrastructures.

Lakshmikantha et al. (2021) [2] demonstrated an efficient and inexpensive IoT-based intelligent water quality monitoring system that could continuously assess vital parameters such as pH, turbidity, conductivity, temperature, humidity, and CO_2 level. Arduino onboard sensors are utilized to monitor the real-time data over Wi-Fi to a cloud server to be processed and visualized. The prototype was subjected to three different water samples, and the results were compared to thresholds needed to determine portability. One of the system's major strengths is the ability to transmit data to stakeholders for real-time decision-making and application in innovative city solutions. The model also includes an alert system and exhibits integration with cloud computing and deep learning algorithms for water quality prediction. In addition, the paper presents a wide comparative summary of similar work, exhibiting development in deployment through Zigbee, GSM, and solar-powered sensor nodes. The system is unique due to low power requirements, low cost, scalability, and deployment possibility even from a distant region. The authors suggest that future research should investigate incorporating more advanced sensors, expanding coverage by mobile platforms, and employing newer communication protocols to enhance performance. This work significantly contributes to the field by demonstrating a deployable and comprehensive model for real-time, intelligent water monitoring using IoT.

Bhatt and Patoliya (2016) [3] proposed an affordable real-time water quality monitoring system employing the Internet of Things (IoT) and Zigbee communication protocols. Their system uses multiple sensors, including pH, turbidity, conductivity, dissolved oxygen, and temperature, which are fed with significant water quality parameters. The values of the sensors are initially processed through a microcontroller and transmitted through Zigbee to a Raspberry Pi-based core controller. The data is subsequently provided on a cloud platform through browser-based software, enabling remote water quality monitoring anywhere in the world. The system's innovation is utilizing Zigbee for low-power, high-density wireless sensor networking with benefits over traditional Wi-Fi and Bluetooth in scalability and network simplicity. The authors point out the shortcomings of conventional water testing techniques, which are time-consuming, costly, and not applicable to continuous real-time monitoring. Their solution effectively addresses these issues with a low-cost, energy-efficient, multi-node-supporting modular Internet of Things architecture. The system's design includes cloud computing support and remote data access with easy user interface. Even though the paper presents a robust solution, it also mentions potential limitations like dependency on environmental factors affecting Zigbee and the need for reliable power sources. However, the execution demonstrates the feasibility of real-time, remote water quality monitoring and opens the door to further innovation with mobile apps and machine learning-based anomaly detection.

Katole and Bhute (2017) [4] have also criticized the implementation of a real-time water quality monitoring system using the Internet of Things (IoT) as a solution for addressing increasing water pollution and contamination of potable water, especially in rural regions. Their approach uses sensors to measure critical water parameters such as temperature, pH, turbidity, and conductivity. The sensors are connected to an Arduino microcontroller, which interprets and

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ISSN: 2581-9429 Volume 5, Issue 10, May 2025 Impact Factor: 7.67

transmits the data onto the internet using cloud computing facilities. The system must be cost-effective, user-friendly, and accessible anywhere globally through a dedicated IP-based web browser application. One of the most important strengths of this approach is its focus on social impact, demonstrating how these technologies can positively impact the bottom-of-the-pyramid segment, where access to clean water is still a concern. The authors recommend applying sensor cloud platforms to achieve scale and far-distance accessibility. In overcoming problems posed by conventional water test technology — such as delay, expense, and operator faults — research provides a flexible, real-time-based system balancing technological potential with economic need. This document enhances literature because it displays embedded systems, cloud-based technologies, and sensing integration collaboration capable of offering preemptive management for water quality.

Hasan et al. (2024) [5] discussed a comprehensive review of advancement in water quality monitoring through the integration of Machine Learning (ML) and Internet of Things (IoT) technologies. The research identifies the rising need for real-time water monitoring because of increased pollution, population growth, and water scarcity. The authors continue to discuss the drawbacks of traditional water monitoring systems and advocate using IoT-based intelligent systems with wireless sensor networks (WSNs) and real-time data reporting to monitor the environment successfully. They describe how ML algorithms such as Random Forest, SVM, ANN, and deep learning models enhance the predictability of outcomes by identifying complex patterns in big data. The paper categorizes recent literature based on application contexts, including urban, rural, and industrial water bodies, and highlights issues with data quality, model generalization, and system integration. One of the new contributions of this paper is the critical examination of Smart Water Grids (SWG), security issues in IoT deployment, and the synergy between ML and IoT for predictive analytics and early warning systems. Moreover, the paper encapsulates international case studies and experimental demonstrators encompassing sensors, cloud platforms (e.g., ThingSpeak, Ubidots), and mobile applications to automate water quality monitoring. While accepting such limitations as the unavailability of effective data sets and hardware limitations, the paper observes long-term advantages such as lower labor costs, off-season maintenance, and increased scalability. This research is an end-to-end solution to existing water monitoring systems that provides a solid ground for future research in AI-based environmental sustainability. Humnabadkar et al. (2024) [6] presented a full-scale smart water usage and quality monitoring system for home applications. Their design incorporates an ESP32 microcontroller, pH sensor, turbidity sensor, and flow sensor to monitor water usage and quality in real-time. The sensor readings are shown on an LCD and sent to the ThingSpeak IoT platform for remote monitoring and data visualization. The system sounds a buzzer alarm when any parameter goes beyond a set threshold, allowing users to take prompt corrective measures. One of the key features of the system is that it has dual-functionality—tracking not only quality measures (e.g., acidity and clarity) but also quantitative use (e.g., liters used). The readings correctly detect unsafe water conditions and over-consumption patterns, further establishing the usability of such a system in health- and sustainability-conscious homes. The authors illustrate how turbidity identifies contamination and how pH meters monitor acidity levels to maintain potability. The remote monitoring and real-time feedback loop work towards efficient timing in water safety and conservation decisions. The authors further stress integrating IoT technologies such as cloud dashboards and LCD notifications to facilitate responsive and enhanced user experience. This article contributes significantly to the expanding field of smart home automation by introducing an economical and scalable framework for a comprehensive water management system.

Rudramadevi and Sivakumar (2017) [7] created a real-time water quality monitoring system based on the Raspberry Pi 3 microcontroller and integrated it with analog pH, turbidity, and conductivity sensors. Since Raspberry Pi does not support native analog input, the authors used the MCP3008 ADC chip to interface analog-to-digital communication. SPI protocol was used in data acquisition,

allowing the Raspberry Pi to monitor sensor readings constantly. The captured sensor readings were logged, stored in a local file, and dynamically updated on a web-based dashboard. Users could access real-time and historical data remotely using a dedicated IP address. The system also included an LED indicator that turns on when sensor readings exceed the set thresholds, offering instant alerts for water contamination. The system's primary advantages are simplicity and cost, enabling scalable environmental monitoring. Python for automation and SPI for sensor communication help improve system responsiveness and efficiency. The authors further emphasized the system's capability for remote monitoring using IoT modules and cloud connectivity. While the prototype is optimized for elementary water quality parameters, some possible enhancements by the authors for the future are increasing the system to cover nitrate, chloride, and ammonia measurement and automated emails or SMS notifications. This research's practical and modular application contributes towards IoT-enabled water quality evaluation, focusing on accessibility and timely public and environmental health decision-making.

Aparna Ankush et al. (2021) [8] developed a real-time water quality monitoring system using Raspberry Pi as the central controller for monitoring and analyzing essential water parameters. It has pH, temperature, turbidity, conductivity, and dissolved oxygen sensors. Sensor readings are processed and displayed by a customized software interface and transmitted wirelessly to a central control unit via ZigBee communication. The authors emphasize that ZigBee provides low-power and reliable wireless connectivity; thus, the system is appropriate for distributed environments. Their focus is on reducing the cost of water quality determination using real-time monitoring. The system architecture is presented, and evidence of observational data to support the responsiveness and correctness of the system is given. The result proves that it measures actual changes in real-time water quality and provides alerts with the capability to initiate preventive actions. There is also a graphical feature for monitoring values trend and display, which makes it more user-friendly. The study applies to intelligent environmental monitoring, especially in rural and semi-rural regions where drinking water quality is a concern. The work concluded that it could be made even more efficient by implementing machine learning for the prediction of anomalies as well as parameters such as nitrate and ammonia measurement. The current work gives an economical, reliable, and scalable remote real-time monitoring solution for water quality.

Kalpana et al. (2016) [9] suggested an online water quality monitoring system using the Raspberry Pi 3 Model B to automatically measure essential water parameters such as pH, turbidity, and conductivity. The system has corresponding sensors interfaced directly with the Raspberry Pi, and the data is analyzed in real-time with Python and transferred to the cloud with an FTP-based IOT gateway. The cloud server provides dynamic one-to-one IP allocation via a web browser interface for remote viewing. The authors highlight the limitations of the traditional manual sampling method—e.g., time delays, labor costs, and reduced accuracy—and propose a better reliable, cost-saving, and scalable alternative. Users can remotely monitor sensor data anywhere globally in their application, especially for innovative city water management systems. The study also describes hardware components like turbidity sensors, Grove pH sensors, conductivity probes, their specifications, and integration through the GPIO of the Raspberry Pi. Moreover, the system utilizes a GUI developed with Java and HTML to present an intuitive interface for displaying real-time data. The system's flexibility makes easy expansion possible through sensor substitution or Python script revision, allowing future integration with other water parameters like ammonia or nitrate. The authors find that their model offers a cost-efficient and scalable method of water pollution monitoring with broad applications in urban and rural settings.

Khatri et al. (2019) [10] proposed an innovative, real-time drinking water quality monitoring system based on Raspberry Pi 3, multi-sensor array (MSA), and fuzzy logic modeling in a Python environment. The system tracks essential water quality parameters such as pH, electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO), and temperature, as per Central Pollution Control Board (CPCB) norms. The acquired data is treated and analyzed using a Mamdani fuzzy inference system (FIS), allowing for classification in terms of five linguistic labels: "bad," "poor," "satisfactory," "good," and "excellent." The application of fuzzy logic provides the advantage of handling imprecision in sensor measurements and making rule-based decisions. The system features a touchscreen-based GUI, written in Python, to show real-time values and store data for later analysis. A serial port expander was incorporated to facilitate the interfacing of several I2C sensors. Experimentally, the platform had greater than 98% accuracy when calibrated with a commercial benchmark (YSI EXO-1), with negligible relative error (0–2%). This model is self-contained, has a touchscreen interface, and has cloud-compatible integration from existing systems. The setup price is below USD 1000, far below commercial systems (~USD 11,000). This research adds a strong, real-time, low-cost water quality evaluation model appropriate for smart cities and distant water distribution systems.

Umar Farak et al. (2022) [11] presented an integrated IoT-based real-time air and water quality monitoring system using Raspberry Pi as the central processing device. The system can detect major environmental parameters like CO, LPG, Butane, Smoke in the air, and pH values in water, with sensor information displayed through a web interface running on Google Cloud. It employs MQ-series sensors (MQ2, MQ135) for gas sensing and a pH sensor for water acidity measurement. Analog signals from the sensors are converted to digital form by an analog-to-digital converter (ADC) and then forwarded to the Raspberry Pi, which uploads the data to the cloud for real-time monitoring. When the gas concentrations exceed safety thresholds, the system alerts via alarm, making it ideal for accident avoidance and pollution control. The system relies on Ubidots for live visualization so stakeholders can observe environmental conditions remotely. The research focuses on the system's scalability, such that deployment at various sites makes creating a wide-area environmental monitoring network possible. The system includes a simple alert function and provides data-logging capabilities for subsequent analysis. The authors point out its potential for utilization in industrial, urban, and rural applications because it is low-cost, modular, and adaptable. It is essentially a prototype but may also be helpful in smart cities and pollution-prone areas. Combining air and water monitoring on a single IoT platform is a holistic environmental health and safety strategy. Zainurin et al. (2022) [12] systematically reviewed traditional and emerging sensing techniques employed for water quality monitoring. The research compared and assessed methods such as the Internet of Things (IoT), cyber-physical systems (CPS), virtual sensing, and optical methods and their advantages and disadvantages. The authors stressed that the traditional laboratory-based methods are time-consuming, labor-intensive, and chemical reagent dependent, while the modern IoT-based systems are remote, automated, and real-time. This led to the emergence of CPS as a possible solution as it can support embedded sensors, computational algorithms, and actuators, thereby allowing real-time and context-aware decision-making. In addition, the review described some global case studies where machine learning models such as ANN, RF, SVM, and IoT were utilized to predict water parameters such as pH, BOD, DO, and EC with high accuracy. The authors also introduced virtual sensing and ensemble ML models, which have the potential to enhance measurement reliability and minimize the requirement of costly hardware. Besides, optical sensing technologies, namely spectroscopy-based sensors, developed non-invasive, fast biological and chemical impurities sensing. Although there have been advancements, the paper establishes current sensor accuracy, integration complexity, and cost boundaries. However, the research offers a valuable guideline for developing future smart water monitoring systems by integrating physical sensing and intelligent data analytics. It highly recommends transitioning to CPS and soft sensing paradigms to enable sustainable, scalable water quality management.

Ebenezer and Raja (2024) [14] suggested an IoT-enabled innovative water quality monitoring system for improving environmental protection and sustainability. The authors' article is in the context that monitoring of water usage relies predominantly on lab testing and manual sampling, which is time and money-consuming and, at times, ineffective for detecting real-time anomalies. The system under consideration utilizes a hybrid of Wireless Sensor Networks (WSN) and IoT architectures for real-time monitoring of essential parameters like pH, turbidity, dissolved oxygen (DO), and biological oxygen demand (BOD). Sensors are strategically located at various sampling stations and can send pre-analyzed information to the monitoring office through communication modules such as ZigBee or XBee. The authors emphasize the application of open-source boards like Arduino UNO and Raspberry Pi for low-cost deployment while defining the application of cloud integration to access and manage data from distant locations remotely. Some of the recent implementations are discussed in the article, along with key benefits like independence of the system, real-time response, isolation, and scalability.

Besides, they introduce the application of predictive analytics and machine learning to facilitate the sophisticated detection of water quality trends. The system enhances Public health and resource use through real-time learning and facilitates proactive decision-making. The policy is particularly beneficial in managing water pollution issues in urban and rural areas, promoting sustainable water use practices and environmental and public health goals.

Ijaradar and Chatterjee (2018) [15] utilized Raspberry Pi 3 as a controller to showcase a real-time water quality monitoring system for residential communities. With sensors to measure pH, turbidity, temperature, and electric conductivity, such a system does offer the best overall picture. Sensor reading is taken from an Analog-to-Digital Converter (ADS1015) and sent to a cloud-based server via wireless communication to visualize the data and remotely access it. It also allows the graphic and tabular results to be displayed through a web portal and cell phone platforms. Most important among them are its cost and modularity, which enable it to be expanded for use in more expansive environmental monitoring scenarios. Unlike old laboratory-based practices that are manually intensive and require much time, the system offers a real-time response, is automated, and can make alarm sounds for threshold breaches. The authors comment on the advantage of their approach in scenarios involving water contamination potentials in rooftop tanks or society-scale storage systems. Having cloud analytics added via ThingSpeak or similar platforms provides further benefit to the system through historical tracking and decision support for prompt action. The prototype tested on clean and contaminated water shows promising results on accuracy and response. Overall, the study validates the possibility of IoT-based innovative systems providing a safe and sustainable water supply to urban and semi-urban cities.

III. METHODOLOGY

The methodology for developing the water quality monitoring system focuses on integrating hardware and software components to capture, analyze, display, and transmit water parameter data in real-time. This section outlines the step-by-step system design and implementation process, covering sensor interfacing, data acquisition, signal processing, real-time visualization, cloud connectivity, and alert generation. The block diagram of the proposed system is presented in Fig.1.

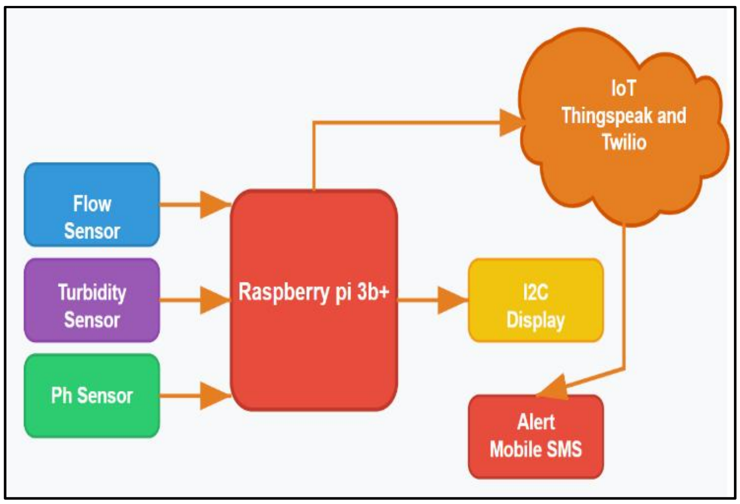


Fig 1. Block Diagram

A. System Overview

The system's core is the Raspberry Pi 3B+, which coordinates input from multiple sensors: a flow sensor, a turbidity sensor, and a pH sensor. These sensors capture the real-time characteristics of water flowing through a pipeline. As the Raspberry Pi does not have in-built analog-to-digital conversion capabilities, an ADS1115 ADC module is used to interface analog sensors. Data collected from the sensors is:

- Processed and analyzed by the Raspberry Pi using Python.
- Displayed locally on a 20x4 I2C LCD screen.
- Transmitted to ThingSpeak, a cloud-based IoT analytics platform.
- Used to trigger SMS alerts through Twilio if thresholds are exceeded.

B. Hardware Methodology

- pH Sensor (ADS1115 - Channel A1): Measures the acidity or alkalinity of the water. The sensor outputs a voltage between 0 – 3.3V, which is read using the ADC and converted to pH using a linear transformation.
- Turbidity Sensor (ADS1115 - Channel A0): Detects water clarity by measuring the intensity of light passing through the sample. Output voltage decreases as turbidity increases.

● Flow Sensor (GPIO18): A digital sensor that outputs pulses proportional to the water flow rate. The number of pulses per unit time is used to compute flow in liters per minute.

Connection Overview:

- ADC (ADS1115) connected via I2C protocol to SDA (GPIO2) and SCL (GPIO3).
- Flow sensor connected to GPIO18 with interrupt-based pulse counting.
- LCD is connected to I2C pins (the same as ADC) for efficient two-wire communication.

C. Software Methodology

The system logic is entirely implemented in Python, leveraging a range of key libraries to facilitate sensor interaction, data display, cloud integration, and alert generation—the RPi.GPIO library configures GPIO pins and captures input pulses from the flow sensor. The adafruit_ads1x15 library enables the Raspberry Pi to read analog voltage values from the pH and turbidity sensors through the ADS1115 analog-to-digital converter. The RPLCD library controls a 20x4 I2C LCD for real-time display of readings. The requests library transmits data to the ThingSpeak cloud platform via HTTP GET requests. In contrast, the Twilio library generates and sends SMS alerts in case of critical water quality violations.

The system operates through a structured flow. The LCDs send a startup message during initialization, and the GPIO and I2C interfaces are configured. The ADS1115 module is initialized to read analog inputs from the turbidity and pH sensors. In the data acquisition phase, the system counts the flow sensor's pulses over a 5-second interval while simultaneously capturing the voltage outputs from the turbidity and pH sensors. The pH value is then approximated using a linear conversion formula: pH = 3.5 × voltage.

Using the pulse count, the system computes the flow rate in liters per minute and total liters used with the formula (pulse_count / 7.5). Then, it estimates the water bill by multiplying the total volume by ₹5 (customizable). These results are displayed on the LCD in three cycles: flow rate with total liters used, turbidity with pH value, and billing amount The system then sends these values to ThingSpeak via a request.get() call, transmitting flow_rate, liters_used, turbidity_voltage, pH, and bill as parameters. An alert mechanism continuously checks the values against defined thresholds. If the turbidity exceeds 2.5V or the pH value falls outside the 6.5 to 8.5 safe range, an SMS is generated using Twilio.Client() and sent to the predefined recipient. The entire process is encapsulated within try-except blocks to handle exceptions related to sensor failure, network connectivity, and cloud communication. In a manual interruption (e.g., via KeyboardInterrupt), the system performs GPIO cleanup. It displays a shutdown message on the LCD, ensuring a safe and user-friendly termination process.

Parameter	Normal Range	Alert Condition
Turbidity	< 2.5 V	Turbidity Voltage > 2.5 V
pH	6.5 – 8.5	pH < 6.5 or pH > 8.5
Flow Rate	Variable	Used for billing, not alert

TABLE I. ALERT CONDITION OF SENSOR VALUES

The proposed methodology integrates hardware and software to create a real-time water quality monitoring system. Its modular and scalable design makes it adaptable to various use cases, including residential, agricultural, and industrial water monitoring. Using open-source tools and affordable hardware makes it accessible and replicable for educational and practical application

IV. RESULT

This section summarizes the experimental verification of the designed real-time water quality monitoring system under three conditions. Each condition was subjected to testing in order to observe the sensor data acquisition behavior and efficacy, cloud transmission, local display, and alert generation. The system observed three critical water parameters: flow rate, pH, and turbidity. The Raspberry Pi 3B+ was the primary controller, and sensor measurements were accessed through the ADS1115 ADC module (for analog sensors) and GPIO (for flow). The data was shown on a 20x4 LCD and streamed to ThingSpeak for remote viewing. Alerts were produced through Twilio when thresholds were breached.

ISSN: 2581-9429
Impact Factor: 7.67

A. Condition 1: When no water flows

In this state, the system was tested when there was no water flow in an idle condition. As expected, the flow sensor indicated a pulse count of zero, which resulted in a calculated flow rate of 0 L/min and total liters used as 0. Therefore, the billing value was still at ₹0. This verified the proper implementation of the flow detection logic. At the same time, pH and turbidity sensors measured stable voltages, which are baseline readings in static water. No alarms were initiated because both values were within the established safe limits (pH: 6.5–8.5, Turbidity Voltage < 2.5V). This test confirmed the accuracy of the system in a no-flow condition and avoided any false alarms.

Fig 2. Results of the no water flows on LCD screen

B. Condition II: When water Flows

When water was passed through the system, the count of flow sensor pulses increased, and the system dynamically calculated the rate of flow in liters per minute (L/min). As time went on with the test running, the volume of water consumption accumulated, and the billing was estimated at ₹5 per liter. The recent values were shown correctly on LCD and displayed accordingly on ThingSpeak. The turbidity sensor reading indicated a minor voltage rise caused by passing particles, and pH readings varied very slightly, but both of them were within the range of acceptability. This situation tested the real-time monitoring feature, real-time billing calculation, and stable integration in the cloud offered by the system. No SMS alerts were also triggered, which confirmed the system's functionality with regular operation under precise water flow.

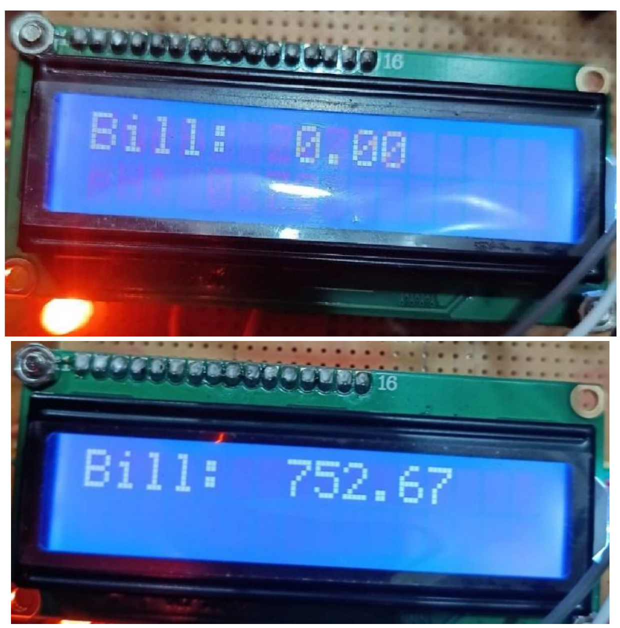
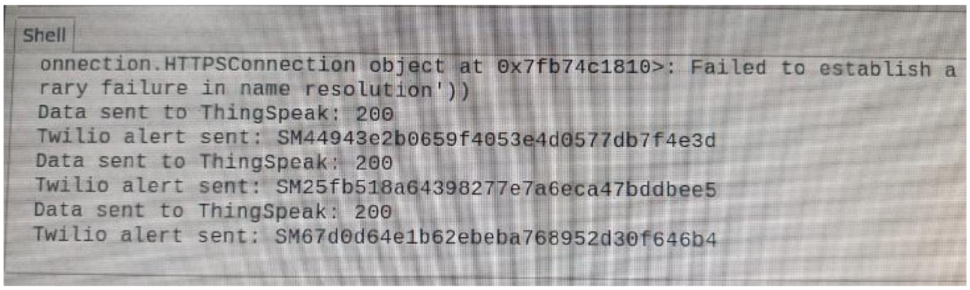


Fig 3. Results of the water flows and bill amount on LCD screen

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 10, May 2025
Impact Factor: 7.67

C. Condition III: When pH and Turbidity values go above a threshold

This condition was meant to check the functioning of the alert system. Simulated impurities were introduced into the water to increase turbidity and move the pH level outside the acceptable limit. As a result, the turbidity voltage exceeded 2.5V, and pH levels dipped below 6.5, triggering the pre-set alert mechanism. The system successfully sent an SMS alert via Twilio to the registered mobile number. The LCD displayed an alert message, and the erroneous readings were noted and plotted on ThingSpeak. This test ensured that the system could sense and respond to hazardous water conditions in real time so that the users could take corrective action.



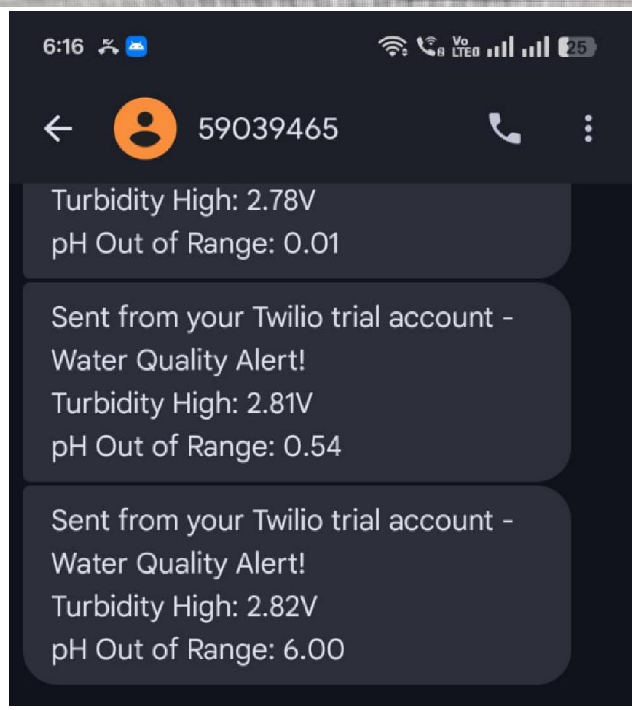


Fig 4. Results of the alert through SMS

The experimental results demonstrate that the proposed IoT-based real-time water quality monitoring system operates effectively under various conditions. In the no-flow scenario, the system correctly recorded zero flow, confirming the accuracy of the pulse-counting logic. During water flow, the system dynamically calculated flow rate, total usage, and billing, with all sensor values remaining within normal limits, indicating stable performance and reliable real-time updates on the LCD and ThingSpeak. The alert mechanism was validated under abnormal water conditions, where elevated turbidity and out-of-range pH levels successfully triggered SMS notifications via Twilio. These outcomes affirm the system's ability to detect and differentiate between normal and hazardous water conditions, perform accurate data logging and visualization, and enhance responsiveness through automated alert generation, making it suitable for practical deployment in imaginative water management scenarios.

V. CONCLUSION AND FUTURE SCOPE

The real-time water quality monitoring system created with Raspberry Pi and IoT technologies was found to be an economical, efficient, and scalable monitoring system for important water parameters such as pH, turbidity, and flow rate. The system easily integrates sensors and processes analog signals through the ADS1115 module. Python-based logic displays real-time values, billing calculations, uploads to ThingSpeak, and sends notifications via Twilio. Experimental confirmation under different conditions confirmed accuracy of sensor readings, timeliness of the alert system, and accuracy of cloud communication. This intelligent monitoring system not only ensures timely detection of water quality variance but also allows for better decision-making for resource management and public health.In the future, there is tremendous scope for development in the system. Additional sensors can be added to sense parameters like Total Dissolved Solids (TDS), Electrical Conductivity (EC), and temperature for further deeper analysis in the future. Machine learning models can be incorporated for predictive maintenance and anomaly detection. Solar power integration will enable it to be utilized in remote or off-grid applications, and a mobile application can provide easy access and control. The open-source and modular design of the system makes it very flexible for many different applications, including agriculture, municipal water utility, and industrial wastewater monitoring, and is therefore contributing to the greater goal of sustainable development and smart city infrastructure.

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