Water Quality Monitoring and Measures of Water Usage in Homes

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***Abstract*— Access to clean water and the efficient use of water resources are critical concerns in residential areas, where both quality assurance and consumption tracking are essential for sustainable living. This paper introduces a practical and affordable smart water monitoring system designed to address these issues within household settings. The proposed setup utilizes an ESP32 microcontroller alongside a suite of sensors—including pH, turbidity, and flow sensors—to continuously assess water quality and usage. The pH sensor evaluates the water's acidity or alkalinity, the turbidity sensor detects particulate levels indicating water clarity, and the flow sensor quantifies water consumption in real time. Data collected from these sensors are displayed locally via an LCD screen and simultaneously transmitted to the ThingSpeak cloud platform for remote access and analytics. Additionally, an alert system is embedded to notify users through an audible signal when measurements deviate from pre-defined safe thresholds. This immediate feedback mechanism empowers residents to respond quickly to potential contamination or overuse, promoting safer water consumption practices. The solution is designed to be scalable and energy-efficient, offering an intelligent framework for enhancing water management in smart home applications. This paper outlines the design methodology, implementation process, and operational insights derived from testing the system in a residential context.**

Keywords—Water Quality Monitoring, Water Usage, ESP32, IoT, pH Sensor, Turbidity Sensor, Flow Sensor, Home Automation, Smart Home, Thingspeak, Real-time Monitoring.

I. INTRODUCTION

In recent years, increasing environmental awareness and rising concerns about the health impacts of contaminated water have amplified the need for smarter water management solutions in residential settings. With growing urbanization and water scarcity issues, ensuring the consistent availability of clean and safe drinking water has become a pressing challenge. Conventional water quality assessment methods, often manual and infrequent, are inadequate for meeting the modern-day demands of real-time monitoring and quick response to contamination or excessive usage.

With escalating concerns over environmental sustainability and public health, the need for real-time, accurate monitoring of household water systems has never been more critical. Traditional water quality assessments, often conducted manually and infrequently, fall short of modern requirements for proactive and informed water management. As water scarcity becomes an increasing concern—particularly in urban and semi-arid regions—residential areas must adopt technologies that ensure both water quality and responsible consumption.

To meet these challenges, this paper presents a smart water monitoring system designed to operate seamlessly within home environments. The system harnesses the capabilities of the ESP32 microcontroller—an affordable yet powerful component equipped with Wi-Fi connectivity—combined with essential sensors to track water pH, turbidity, and flow. This fusion of hardware and software allows users to continuously monitor their water's safety and usage in real time.

The pH sensor helps detect chemical imbalances by measuring the water's acidity or alkalinity, which can impact both taste and health. The turbidity sensor monitors water clarity, revealing the presence of suspended particles that may indicate microbial contamination or filtration issues. The flow sensor provides insight into water consumption patterns, helping to identify inefficiencies, leaks, or abnormal usage spikes.

Beyond local visualization through an LCD display, the system pushes sensor data to the ThingSpeak IoT platform, enabling users to remotely access water quality statistics and usage trends via a web dashboard or mobile interface. This cloud integration not only enhances user convenience but also introduces automation possibilities—such as thresholds for alerts and analytics for long-term monitoring. When sensor readings cross critical limits, a built-in buzzer provides immediate on-site alerts, allowing users to take timely corrective actions.

This system bridges the gap between awareness and action. By delivering live data and automated feedback, it empowers residents to make informed decisions about their water consumption and take steps to address contamination or wastage. With careful calibration of sensors and robust cloud support, the design promotes both individual responsibility and scalable smart-home integration.

The remainder of this paper outlines the hardware architecture, component specifications, data flow mechanisms, and evaluation metrics used to validate the system's effectiveness. It also explores opportunities for expansion and future development within the broader context of sustainable smart home technologies.

II. LITERATURE SURVEY

Several innovations in smart water monitoring systems have emerged over the past decade, aiming to enhance real-time detection and ensure safe water practices using IoT technologies.

Aravinda S. Rao and colleagues [1] introduced the Autonomous Live Animal Response Monitor (ALARM) biosensor, which was deployed in aquatic environments for continuous toxicity analysis. Developed under the CAPIM initiative by the Victorian Centre, their goal was to build a cost-effective, wireless unit that could remain immersed and continuously observe water parameters. This system could measure key water quality indicators such as salinity, temperature, light intensity, electrical conductivity, total dissolved solids (TDS), and pH, providing a holistic view of the water's physical and chemical profile. Open-source tools enabled efficient analysis, identifying areas of contamination and degradation.

Konde et al. [2] proposed a dynamic IoT-driven water monitoring framework integrating custom-built sensor interface modules with FPGA boards and Zigbee-based wireless communication. Their study demonstrated the potential to scale water quality monitoring systems using real-time data capture. This setup supported long-range communication and reliable tracking of various water parameters across a distributed environment. It emphasized IoT's capacity to manage large volumes of water quality data continuously—an essential approach given the growing concerns over water pollution worldwide.

According to Lakshmikantha et al. [3], pollution in water bodies remains a critical challenge, with long-term effects on both environmental balance and public health. Their analysis highlighted the need for cost-efficient and intelligent water quality monitoring tools that can quickly identify irregularities. Such systems should support immediate detection and response, contributing to the early prevention of contamination and preserving the safety of humans and aquatic life alike.

In another development, Budiarti et al. [4] created a Raspberry Pi–based monitoring setup that included a suite of environmental sensors. The system was connected to a cloud platform for remote visualization and control. Their model focused on creating an automated and real-time water quality tracking mechanism. Their findings confirmed that continuous monitoring using IoT platforms significantly improves water resource sustainability, particularly in areas prone to industrial and domestic pollution.

Hawari et al. [5] introduced a design for a real-time monitoring system equipped with IoT capabilities. Their configuration utilized pH, turbidity, and temperature sensors, which enabled immediate assessment of water quality. The paper detailed an architecture that allowed sensor data to be uploaded to the cloud, processed to calculate Water Quality Index (WQI) values, and accessed through a mobile application. It also explored strategies for power management and multi-location deployment, ensuring a longer operational life and flexible scalability.

Finally, Haque and R. Rutjanaprom [6] proposed an IoT-based water monitoring network using Zigbee-enabled sensor nodes. Their system collected temperature, conductivity, pH, dissolved oxygen, and turbidity data. This information was relayed to a central Raspberry Pi controller for further processing. The architecture supported easy cloud integration and enabled data visualization via web interfaces. Their implementation proved efficient for continuous water quality analysis across various use cases and environments.

These contributions collectively reinforce the value of IoT in improving water quality management and set a strong foundation for future developments in household and industrial applications alike.

Building on existing research, recent studies have explored the integration of IoT technology in water quality monitoring systems for diverse environmental and agricultural applications.

Muhammad et al. [7] explored the application of IoT in aquaculture by designing a water quality monitoring system specifically for softshell crab farming. The purpose was to help farmers maintain ideal water conditions to extend the lifespan of these delicate crabs. By training farmers to utilize smart monitoring tools, the system aimed to enhance aquaculture productivity and sustainability.

Ajith et al. [8] proposed a cloud-connected IoT system equipped with deep learning capabilities for real-time water quality assessment. Developed in response to India's growing water contamination concerns, their model used NodeMCU devices coupled with various sensors to collect critical data. This data was continuously pushed to a cloud platform, where deep learning algorithms analyzed and predicted water safety levels. Their approach demonstrated the power of combining machine learning with IoT for proactive environmental monitoring.

In another contribution, Pasika et al. [9] introduced a cost-effective smart water monitoring solution utilizing IoT components. Their system measured parameters like pH and turbidity while also integrating weather and environmental sensors to capture temperature and humidity. The design featured automated controls—such as fans and pumps for ozonation—based on data interpreted by a microcontroller. All sensor data was transmitted to the cloud using the ThingSpeak platform, ensuring seamless remote access and monitoring.

Smitha et al. [10] developed an IoT-based system incorporating LoRaWAN communication for long-range, energy-efficient water monitoring. Their setup enabled low-cost and low-power connectivity, making it ideal for applications in remote or resource-constrained environments. The system's fast response to quality fluctuations made it valuable for real-time resource conservation and management.

Shanmugam et al. [11] focused on the development of a smart water quality monitoring infrastructure for Malaysia, aiming to address the challenges posed by rapid urbanization. Their proposed solution helped minimize contamination risks, optimize water treatment processes, and reduce interruptions in water supply systems, thereby supporting more robust urban water management.

In another practical application, Raji et al. [12] built an Android-based interface for an IoT-powered water quality monitoring setup. Their solution combined multiple sensors for real-time detection of water pollutants and offered a user-friendly mobile application. The affordability and accessibility of the system made it suitable for community-level deployment to improve access to clean water.

Lastly, Das et al. [13] presented an autonomous water quality monitoring model that emphasized real-time data collection, decision-making, and remote accessibility via the internet. The design significantly reduced reliance on manual sampling and laboratory testing. By allowing more locations to be monitored remotely and cost-effectively, the system supported public health initiatives—particularly in identifying potential lead contamination in drinking water sources.

These studies illustrate the widespread utility and adaptability of IoT-driven water quality monitoring systems. Whether for aquaculture, public health, urban planning, or environmental conservation, the convergence of smart sensors, cloud computing, and automation provides reliable, scalable solutions to modern water management challenges.

Recent advancements have continued to expand the potential of IoT and remote sensing in water quality monitoring across diverse geographical and operational contexts.

Prasad et al. [14] proposed a cutting-edge monitoring framework that merges remote sensing with IoT to observe water quality conditions across Fiji. Their model prioritizes consistent data collection to generate long-term insights into regional water health, while also factoring in industrial and agricultural impacts. This approach helps identify patterns of contamination and supports informed environmental planning.

In another innovation, Al Metwally et al. [15] enhanced a pervasive IoT-based home water monitoring and control system. Their design utilized temperature and pH sensors alongside turbidity probes to automatically adjust and maintain water quality parameters. By offering real-time monitoring, user-friendly configuration tools, and eliminating the dependency on laboratory analysis, this system promised both cost savings and improvements in public health outcomes.

Kamaludin et al. [16] explored an RFID and Wireless Sensor Network (WSN)-based IoT solution tailored for water quality analysis. Their system used the 920 MHz DigiMesh protocol, optimized for environments with heavy foliage. Testing was conducted on a lake at Universiti Sains Malaysia, evaluating key factors like communication range and energy consumption while detecting pH levels. Their integration of RFID and IP-based communications added a robust, scalable dimension to real-time environmental monitoring.

Huan et al. [17] implemented Narrowband IoT (NB-IoT) for an aquaculture pond monitoring system in Jiangsu Province. This setup allowed continuous tracking of temperature, pH, and dissolved oxygen, with data streamed instantly to remote systems. The solution demonstrated exceptional precision—temperature readings with ±0.12°C accuracy, pH regulation within ±0.09, and minimum dissolved oxygen maintained at 0.55 mg/L. Their system significantly enhanced aquaculture productivity and water quality management, serving as a benchmark for smart farming technology.

Vijayakumar et al. [18] developed an IoT solution using five key sensors—dissolved oxygen, conductivity, pH, temperature, and turbidity—linked to a Raspberry Pi B+ controller. Data from these sensors was uploaded to the cloud for visualization, helping users monitor potability in real time. Their system emphasized the practical impact of cloud-based analytics in ensuring safe and drinkable water supplies.

Meanwhile, Hong et al. [19] examined the effectiveness of Arduino-based sensor networks for water quality monitoring. Their findings indicated that while the low-cost system offered a reliable baseline for monitoring, its data required human oversight due to occasional inaccuracies. This underscores the current limitations of fully autonomous systems and the need for hybrid approaches that combine automation with expert supervision.

Together, these efforts reveal how diverse technologies—from NB-IoT and RFID to cloud computing and open-source hardware—are converging to shape the future of water quality assessment. Each approach addresses specific challenges in cost, coverage, accuracy, and real-time response, contributing valuable knowledge to the field of smart environmental monitoring.

III. PROPOSED SYSTEM

The block diagram of the proposed system is shown in Fig. 1.

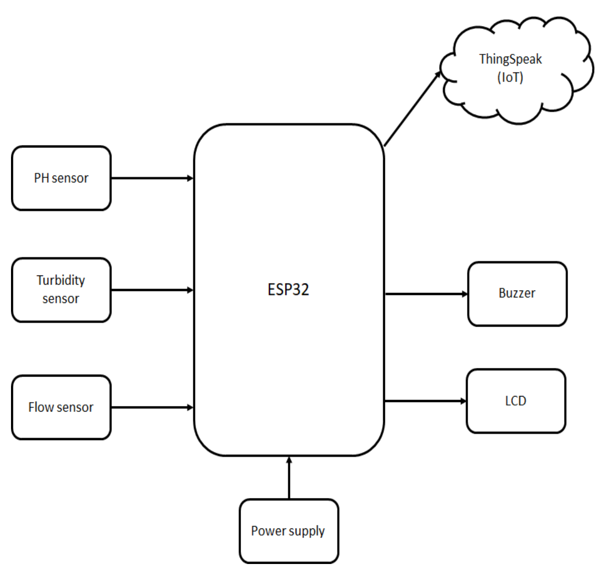


Fig. 1. Block diagram of the proposed system

The proposed block diagram outlines a comprehensive residential water management system designed to support both automated metering and quality monitoring of household water usage. It facilitates real-time tracking of drinking water conditions and consumption trends at multiple levels, empowering users with actionable insights. By continuously monitoring water quality and user consumption behavior, the system ensures access to clean water while promoting mindful usage—reminding residents, for instance, how many long showers they can afford without compromising sustainability.

The system begins at the main water supply line, where various sensors are positioned to assess water characteristics as it enters the household. The three primary sensors integrated into the system include the flow sensor, turbidity sensor, and pH sensor.

- The pH sensor measures the water's acidity or alkalinity, a key parameter for determining potability. This sensor operates by detecting hydrogen ion concentration in the water, producing an electrical signal that reflects the pH value.
- The turbidity sensor evaluates water clarity, providing insight into potential contamination or filtration issues. It functions using an infrared light source and a photodetector, which together measure the intensity of scattered light caused by particles suspended in the water.

These sensors relay real-time data to a processing unit, forming the foundation for smart residential water usage—enhancing both safety and sustainability by aligning consumption patterns with water quality levels.

In addition to water quality tracking, the flow sensor plays a crucial role in monitoring consumption and regulating water flow within the pipes. When water moves through the system, it rotates a turbine or impeller, and this rotational speed directly correlates to the volume of flow. The motion is then converted into an electrical signal, enabling the system to compute the total water usage accurately.

At the heart of the setup is the ESP32 microcontroller, which serves as the central hub for sensor integration and data processing. The pH, turbidity, and flow sensors generate analog outputs, which are read and digitized by the ESP32 for further evaluation. This microcontroller also manages the display unit and establishes a connection to the ThingSpeak IoT platform.

Sensor readings are uploaded in real time to the ThingSpeak cloud, allowing users to access and analyze data remotely via web browsers or mobile applications. Locally, a connected LCD screen provides on-site feedback by showing current values for pH, turbidity, and water flow. This immediate visualization enhances transparency and encourages proactive responses.

An alarm system is also embedded into the design. If any parameter exceeds pre-set thresholds—such as excessive turbidity indicating contamination or abnormal flow suggesting leakage—the ESP32 activates a siren alert, notifying residents to take timely action.

By combining consumption monitoring and water quality assessment into a single framework, the system offers a holistic and intelligent water management solution. Leveraging modern sensors and IoT connectivity, homeowners gain real-time oversight of their water resources—ensuring both efficient use and safe consumption. The integrated block diagram reflects this synergy, showing how the coordination of all components creates a sustainable and health-conscious residential infrastructure.

IV. RESULT AND ANALYSIS

This section presents the outcomes of a series of tests conducted on the smart water monitoring system. The evaluation focuses on two key aspects: water quality assessment and consumption monitoring, with performance measured against pre-established threshold values. The collected data reflects the system's ability to detect anomalies, trigger alerts, and provide reliable real-time insights into residential water usage and safety.

A. *Water Quality Monitoring*

The system was initially tested using water samples with varying pH levels and turbidity to evaluate its accuracy. The pH sensor demonstrated high precision, accurately identifying whether the samples were acidic or alkaline, with readings closely matching the expected values. Similarly, the turbidity sensor effectively detected water cloudiness, and its results showed a strong correlation with standard turbidity measurement techniques, validating the sensor's reliability.

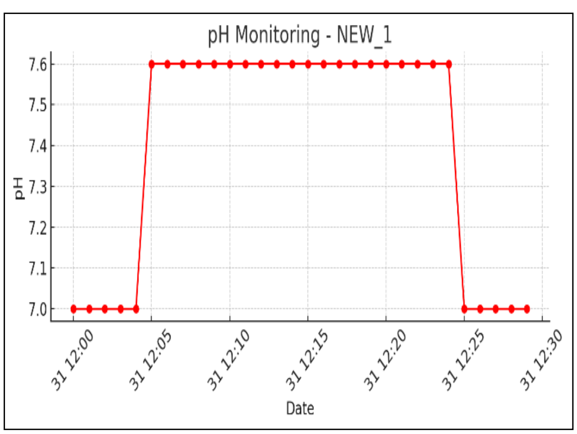
- pH Sensor Performance: The system recorded pH values ranging from 6.7 to 7.4, aligning closely with the actual pH values of the tested samples. This indicates the sensor's reliability in real-time monitoring of water acidity and alkalinity, maintaining compliance with WHO standards for safe drinking water (typically pH 6.5–8.5).
- Turbidity Sensor Performance: The turbidity sensor effectively distinguished between murky and clear water samples, producing readings between 2.1 and 8.3 NTU depending on the presence of suspended particles. These results confirm the sensor's ability to provide accurate visibility assessments, critical for detecting contamination.

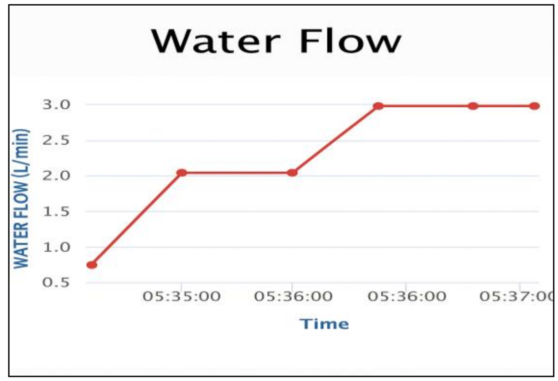
B. Water usage measurement

The flow sensor tested how much water was turned on during a given period. The sensor consistently gave an unbiased flow rate measurement cross-validated against manual measurements. This data indicated that the system could accurately track water use at high resolution.

C. Data Visualization and Analysis

The sensors collected data, transmitted it to the Thingspeak IoT platform, and stored it for visualization. The microcontroller and sensor data interface had a customized Thingspeak script, allowing users to view real-time water quality and usage information to enable remote feedback reports.





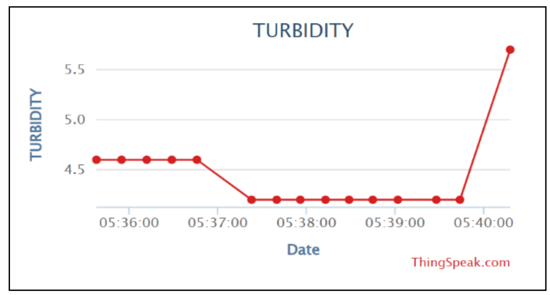


Fig. 2. Readings of the sensor on the ThingSpeak platform

The findings highlight the effectiveness and practical potential of the proposed smart water monitoring system in promoting sustainable water usage at the household level. With its ability to accurately measure essential water quality parameters, track consumption trends, and deliver real-time feedback through an intuitive interface and alert system, the setup serves as a reliable solution for ensuring access to safe drinking water. Moreover, the system's real-time analysis and notification capabilities support proactive water management, contributing to better decision-making and conservation practices measured in parts per million (ppm). Overall, this approach offers a scalable and intelligent framework for optimizing both water quality and usage efficiency.

V. CONCLUSION

This paper presents a smart and integrated system designed for household-level water quality and consumption monitoring. Leveraging modern sensor technology and IoT functionality, the setup ensures the availability of clean, safe drinking water while promoting responsible usage. Core components include sensors for measuring flow, turbidity, and pH levels, with data transmission occurring in real-time.

The pH sensor determines whether the water falls within safe acidity or alkalinity limits, while the turbidity sensor checks for clarity, detecting potential pollutants. Meanwhile, the flow sensor helps track water usage, assisting in leak detection and excess consumption management through automatic or user-initiated responses.

Central to the system is the ESP32 microcontroller, which processes incoming analog signals from sensors and interacts seamlessly with the ThingSpeak platform to upload data to the cloud. This allows users to monitor real-time values both locally via LCD and remotely via the internet. An integrated buzzer acts as a safety feature, alerting users instantly when water quality readings breach pre-defined thresholds, helping prevent critical issues before escalation.

By supporting sustainable practices and resource conservation, the system contributes meaningfully to smart home water management. Its modular architecture makes it suitable for residential use and adaptable for broader scenarios. Looking ahead, the system's scope can be widened by integrating additional sensing modules—such as those measuring conductivity, dissolved oxygen, or chemical contaminants—to deepen water quality analysis. With the integration of predictive analytics and AI-driven optimization, the system could eventually adjust water flow or purification dynamically based on usage trends or detected conditions. Future developments could further extend the system to larger-scale applications or multi-line water distribution networks, creating a comprehensive smart water infrastructure for both domestic and commercial environments.

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