IoT-Based Water Tank Quality and Level Monitoring System for Smart Water Management

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Abstract- ***Water scarcity and inefficient water management are growing concerns worldwide. With rapid urbanization and rising populations, the need to monitor, conserve, and intelligently manage water resources has never been more urgent. This paper presents a comprehensive literature review of Internet of Things (IoT)-based smart water tank monitoring and control systems, drawing on five recent peer-reviewed studies published between 2022 and 2025. The reviewed works explore a range of approaches — from real-time sensor dashboards and MQTT-based smart city architectures to IoT-GSM hybrid devices and ESP32-powered cloud monitoring solutions. Through systematic analysis, this review identifies critical research gaps including the absence of predictive analytics, limitations in network scalability, high operational costs, lack of full motor automation, and restricted applicability to complex multi-reservoir systems. Based on these identified gaps, this paper formulates five research questions and corresponding objectives, proposing directions for future work that integrate Machine Learning, hybrid communication protocols, and automated actuation into next-generation water management systems. The findings underscore the need for smarter, more scalable, and economically viable IoT solutions to address global water challenges.***

Keywords- Internet of Things (IoT), Smart Water Tank Monitoring, MQTT Protocol, Real-Time Sensing, Water Quality Detection, Water Level Control, Predictive Analytics, Edge Computing, ESP32, Home Automation.

I. INTRODUCTION

1.1 Background of the Study

Water is one of the most precious natural resources on Earth, yet its management remains largely reactive and inefficient. In urban environments, overhead water tanks are the primary means of local water storage for residential, commercial, and industrial users. Traditional tank management relies heavily on manual observation — a person physically checks the water level and switches the motor pump on or off accordingly. This approach is not only labor-intensive but also highly prone to human error, leading to two of the most wasteful outcomes: tank overflow and water shortage.

The Internet of Things (IoT) has emerged as a transformative technology capable of bringing intelligence to everyday infrastructure. By embedding sensors and microcontrollers into water tanks and connecting them to the internet, it becomes possible to monitor water levels, detect quality changes, identify leaks, and automate pump control — all in real time, from anywhere in the world. The literature reviewed in this paper reflects the rapid growth of IoT-enabled water management solutions over the past few years, each addressing a different dimension of this complex problem.

1.2 Problem Statement

Despite notable advances, the field still faces significant challenges. Many proposed systems focus on one aspect of water management — such as level monitoring or quality detection — while neglecting others like predictive planning or cost-effective communication. Moreover, most solutions are designed for small-scale or single-household deployments, making them difficult to scale to urban or industrial settings. According to the WHO, approximately 2.1 billion people lack access to safe drinking water, while agencies such as WASA have reported that millions of liters of treated water are lost daily due to poor infrastructure and inefficient management. These figures highlight an urgent need

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for intelligent, integrated, and affordable water management systems.

1.3 Motivation

The motivation for this review stems from the recognition that while individual IoT-based water management solutions exist, there is a lack of synthesized understanding of their collective strengths, weaknesses, and unexplored areas. By analyzing five key studies in this space, this paper aims to provide researchers and practitioners with a clear roadmap of what has been accomplished and where the most impactful future work lies. The convergence of affordable sensors, cloud platforms, and communication protocols like MQTT and GSM makes this an ideal time to push these systems to the next level.

1.4 Objectives of the Study

- To review and synthesize existing IoT-based water tank monitoring and control systems from recent literature.
- To perform a comparative analysis of methodologies, datasets, findings, and limitations across selected studies.
- To identify critical research gaps that hinder the development of more effective and scalable solutions.
- To formulate research questions and objectives that guide future investigation in this domain.
- To propose directions for future work, including the integration of Machine Learning and hybrid communication architectures.

1.5 Contributions of the Paper

- A structured and critically analyzed review of five recent IoT water management studies (2022–2025).
- Identification of five distinct research gaps with supporting evidence from the literature.
- Formulation of five research questions and corresponding measurable objectives.
- A synthesized problem statement grounded in real-world water management challenges.
- A foundation for future research in predictive, scalable, and cost-efficient IoT water systems.

1.6 Organization of the Paper

The remainder of this paper is organized as follows. Section 2 presents a thematic literature review with a comparative analysis table. Section 3 identifies and discusses the key research gaps uncovered through the review. Section 4 outlines the research questions derived from those gaps. Section 5 details the research objectives mapped to each question. Section 6 presents problem statements contextualized within different domains. Section 7 discusses proposed research directions. Section 8 covers applications and use cases. Section 9 concludes the paper with a summary of contributions and future outlook.

II. RELATED WORK / LITERATURE REVIEW (CORE SECTION)

2.1 Thematic Classification of Literature

A. Alert-Based Monitoring (Float Sensor + Wi-Fi + SMS)

Lokhande et al. (2023) [1] presented an Intelligent IoT-Based Alert Messaging System using the ESP8266 microcontroller paired with water float sensors, a water quality sensor (pH), and a water flow sensor. The system monitored water levels at four thresholds (25%, 50%, 75%, 100%) and transmitted alerts via the Twilio SMS API to end users. A web dashboard built with PhpMyAdmin/MySQL backend stored sensor readings. The relay module controlled a motor pump automatically when the tank was empty, and the system sent timely alerts to prevent overflow. The architecture demonstrated simplicity and cost-effectiveness suitable for residential deployment. However, the system lacked predictive analytics and relied on float switches, which may suffer mechanical wear.

B. MQTT-Based Layered Architecture (Edge-Fog-Cloud)

Ancy Jenifer et al. (2022) [6] proposed an IoT-Based Smart Water Tank Supply Management System using the MQTT publish-subscribe protocol. Their three-layer architecture comprised an Edge layer (sensors + NodeMCU controllers), a Fog layer (Raspberry Pi / Municipal Office Server running Mosquitto MQTT broker with Node-RED), and a Cloud layer (IBM Cloud). The tanks were equipped with HC-SR04 ultrasonic sensors, PH sensors, YF-S201 flow sensors, and DS18B20 temperature sensors. MQTT topic hierarchy allowed role-based notification (motor operators received level alerts, municipal leaders received all area data). The system stored data in JSON format and visualized results in a web dashboard. This approach excelled in scalability and filtered notification, but lacked local SMS/GSM backup for connectivity failures.

C. IoT-GSM Multifunctional Control (Leakage + Quality + Level)

Chowdhury et al. (2022) [7] developed an IoT-GSM Based Controlling and Monitoring System targeting water wastage, leakage, and pollution prevention. The system used an ESP32 DevkitC V1 microcontroller, a turbidity sensor (SKU-sen0189) for water quality, an HC-SR04 ultrasonic sensor for water level, and a YFS-201 flow sensor with solenoid valves for leakage detection and supply control. The Blynk cloud platform provided the cross-platform mobile application interface for remote monitoring. A GSM module sent SMS and email alerts. The system supported both automatic and manual motor control modes and costed approximately $77 USD in prototype form. A key limitation was reliance on single turbidity sensor to assess quality, which may lack accuracy for complex contamination scenarios.

D. Real-Time ESP32 Monitoring with ThingSpeak (TDS + DHT11 + Ultrasonic)

Patro et al. (2025) [8] proposed a Smart IoT-Based Real-Time Monitoring System using an ESP32 microcontroller with four sensors: an HC-SR04 ultrasonic sensor for distance/level measurement, a DHT11 for temperature and humidity, a water level sensor, and a TDS V1.0 sensor for measuring dissolved solids (water quality). Data was continuously transmitted to ThingSpeak cloud, visualized in interactive charts. A buzzer alerted users when the tank reached full capacity. The system was scalable from domestic to industrial use. Limitations included the absence of SMS/notification for water quality anomalies and no automated pump control logic.

E. Multi-Tank NodeMCU System with Predictive Pump Control (Blynk + MQTT)

Zhumadillayeva et al. (2025) [9] presented a Smart Water Level Monitoring and Control System integrating three NodeMCU ESP8266 microcontrollers (one host + two clients), HC-SR04 ultrasonic sensors, relay modules, submersible pumps, and solenoid valves, coordinated through the Blynk IoT platform using MQTT. The system implemented a mathematical control model based on time-of-flight calculations for water level estimation and threshold-based pump activation logic. Experimental validation with ~10,245 data instances demonstrated 1.6-second latency, 1.5% measurement error, 32% reduction in pump operation time compared to manual methods, and 92% user satisfaction in a survey of 25 participants. The multi-tank architecture was a novel contribution, though the study identified ongoing gaps in AI/ML integration and renewable energy support.

F. Cloud-Based Water Tank Management (Raspberry Pi + ThingSpeak)

Chandra Sekhar et al. (2023) [2] presented a cloud-based water tank management system using a Raspberry Pi as the central controller connected to ultrasonic sensors, pressure sensors, float switches, and capacitive sensors. Sensor data was transmitted over Wi-Fi to the ThingSpeak cloud platform for real-time storage, analysis, and visualization. The system enabled remote monitoring through web and mobile interfaces, and implemented automated control actions — activating pumps and adjusting valves — when water levels crossed defined thresholds. ThingSpeak's MATLAB integration allowed deeper data analytics and anomaly detection. Load and scalability tests confirmed the system's capacity to handle multiple water storage facilities. However, the study did not incorporate water quality sensing, limiting its utility in scenarios where contamination is a concern.

G. Smart Water Management with Arduino Mega and GSM (Urban IoT)

Alam et al. (2021) [3] developed an efficient smart water management system based on IoT technology aimed at resolving water distribution challenges in urban Bangladesh. The system employed an Arduino Mega microcontroller with an ultrasonic sensor for water level monitoring and a GSM module for remote communication. A relay switch automatically activated or deactivated an induction motor pump based on sensor readings: if the water level fell below 20 cm the relay switched ON, and above 40 cm it switched OFF. Sensor data was uploaded to the Ubidots cloud platform and displayed via a web interface. A mobile app provided graphical real-time water level status. The total prototype cost was approximately $38 USD. While the system achieved automated pump control and SMS/email alerting, it was limited to a single ultrasonic sensor and did not address water quality parameters.

H. IoT-Based Water Quality Monitoring and Filtering (Arduino + pH/Turbidity)

Haque et al. (2023) [4] proposed an IoT-based model for real-time water quality monitoring and filtering applicable to residential colonies and apartment buildings. Their system integrated pH sensors, temperature sensors, turbidity sensors, an ultrasonic water level sensor, a water flow sensor, a solenoid valve, and a water filter unit, all coordinated by an Arduino UNO controller connected to a cloud-based web application. The algorithm checked tank fullness via the ultrasonic sensor, then assessed water quality: if water quality was good the supply valve opened; if poor, the pipeline valve closed and water was redirected to the filter unit. ANOVA analysis of pH readings before and after filtering validated the model's effectiveness in bringing water within the safe pH range of 6.5–8.5. A key limitation was that the existing system only warned users of poor quality without preventing water outflow, a gap the proposed model addressed through automated valve control.

I. Ultrasonic + Arduino Blynk System with Buzzer Alerts (Automated Pump Control)

Yap and Ali (2025) [5] designed a Smart Water Management System (SWMS) that combined an Arduino Uno microcontroller, an ultrasonic sensor for water level measurement, a relay module for pump control, an I2C LCD display, and an ESP-01 Wi-Fi module for IoT connectivity via the Blynk platform. The system activated the pump when the water level reached 13 cm or higher and deactivated it when it fell to 10 cm or lower. A buzzer provided audible alerts for abnormal conditions. Experimental validation across five trials recorded an average measurement error of only ±0.13 cm, confirming high sensor accuracy. Remote control through the Blynk app was tested successfully in all trials. The study acknowledged its prototype-scale limitation and noted that real-world container vibrations could influence sensor readings, suggesting future enhancements in AI-driven predictive analytics and broader sensor calibration.

J. Smart Water Management for Rural and Urban Infrastructure (NodeMCU + ML)

Joshika et al. (2025) [10] presented an IoT-based Smart Water Management System targeting both rural and urban water distribution. The system used a NodeMCU microcontroller receiving inputs from an ultrasonic sensor for water level and a flow sensor for leak detection. A driver circuit controlled motor pumps and valves, with sensor data uploaded to the cloud and displayed on a Java-based animated graphical user interface that provided real-time tank level visualization. Machine learning algorithms were integrated for anomaly detection and future water demand prediction. Results showed the system saved approximately 30% of water resources compared to manual methods, and successfully prevented overflow and leakage conditions. The study highlighted the potential of combining IoT with predictive analytics but noted that the prototype had not yet been validated at a large-scale urban deployment.

K. Sustainable IoT System for Water Leakage and Temperature Detection

Warimani et al. (2025) [11] developed a sustainable IoT-based system focused on water leakage detection and temperature monitoring using an Arduino Uno microcontroller, two YFS201 flow sensors positioned at the supply pipeline origin and destination, and a temperature sensor. A NodeMCU Wi-Fi module transmitted data to a cloud server and user web portal. Leakage was detected by comparing the flow rate difference between the two sensors: if the discrepancy exceeded a threshold, the pump was automatically shut off and a buzzer and LED indicator alerted the user. Dry-run conditions were also detected when no flow was registered within 10 seconds of pump activation. Prototype testing across three types of water (cold, hot, normal) validated the temperature sensing capability. The study established the viability of the dual-sensor leakage detection method while noting that scaling to larger pipeline networks would require hardware upgrades.

L. Water Management and Control for Smart Cities (IoT + AI + Blynk)

Kumar et al. (2022) [12] proposed a Smart Water Management and Control System for smart cities and rural areas, integrating Arduino with NodeMCU (ESP8266), ultrasonic sensors, water flow sensors, a float switch, and solenoid valves controlled via a relay circuit. The Blynk cloud platform and ThingSpeak were used for real-time monitoring and data visualization. The system automatically refilled tanks when water levels dropped below a set threshold and terminated supply when full. Water flow rates were calculated using the formula (flow frequency × 60 / 7.5) to compute liters per hour. The proposed architecture targeted smart city water distribution applications by implementing sensors in each tank across a city to provide municipal authorities with real-time water level and consumption data. The implementation cost was approximately $30 per water tank.

2.2 Comparative Analysis of Existing Methods

Author(s)	Year	Microcontroller	Sensors Used	Communication	Cloud/UI Platform	Key Limitation
Vaibhav K Lokhande	2021	ESP8266 (NodeMCU)	Float, pH, Flow sensors	Wi-Fi	PhpMyAdmin + Twilio SMS	Float sensor wear; no AI
Ancy Jenifer J	2022	NodeMCU + Raspberry Pi	HC-SR04, pH, YF-S201, DS18B20	MQTT / Wi-Fi / GSM	IBM Cloud + Node-RED	No local GSM backup
Abdullah Al Shahid Chowdhury	2022	ESP32 DevkitC V1	HC-SR04, Turbidity, YFS-201	Wi-Fi + GSM	Blynk + SMS/Email	Single quality sensor; no AI
Kiran Kumar Patro	2025	ESP32	HC-SR04, DHT11, TDS V1.0, Water Level Sensor	Wi-Fi	ThingSpeak	No auto pump control or quality alerts
Ainur Zhumadillayeva	2025	NodeMCU ESP8266 x3	HC-SR04 (x3), Relay Module	Wi-Fi + MQTT	Blynk IoT Platform	No ML; no quality monitoring

Fig 2.2 Comparative Analysis of Existing Methods

2.3 Critical Review

Strengths of Existing Methods:

- All five systems demonstrate real-time responsiveness and remote accessibility, validating the fundamental feasibility of IoT-based water management.
- The Zhumadillayeva et al. study achieves the most rigorous quantitative validation with 10,245+ data points, 1.6s latency, 1.5% error margin, and 32% pump efficiency improvement.
- The MQTT-layered architecture by Ancy Jenifer et al. provides the most scalable design, suitable for city-level water management.
- Chowdhury et al. present the most complete feature set among the five, addressing water level, quality, and leakage in a single device.

Weaknesses:

- No single study integrates all critical parameters: level + quality (pH, TDS, turbidity) + temperature + leakage + predictive analytics in one unified system.
- Most studies use small-scale prototypes with limited external validation.
- Patro et al. do not implement automated pump control despite robust sensing.
- Security considerations (data encryption, user authentication) are absent from most architectures.
- Float sensors used by Lokhande et al. are prone to mechanical failure and lack precision compared to ultrasonic sensors.

2.4 Identified Research Gaps

- Multi-Tank Integration: Most studies focus on a single tank; coordinated control across multiple tanks and reservoirs remains largely unaddressed.
- Predictive Analytics: None of the five systems incorporate AI/ML models for consumption forecasting or anomaly prediction.
- Comprehensive Quality Monitoring: Few systems combine level monitoring with multi-parameter quality sensing (pH, TDS, turbidity, temperature).
- Security and Privacy: Secure data transmission, cloud authentication, and user access controls are largely absent.
- Energy Harvesting: No study integrates renewable energy (e.g., solar power) for self-sustaining off-grid operation.

III. PROPOSED METHODOLOGY (DESIGN SECTION)

3.1 System Overview

The proposed integrated system consolidates the best elements from all five reviewed studies into a unified, multi-layer IoT framework. The system targets residential and commercial buildings with one or more overhead water tanks and an underground

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reservoir, providing automated management with end-to-end monitoring.

3.2 Workflow Diagram

- Input → Sensor Layer → Microcontroller Processing → Communication Layer → Cloud & Analytics → Output/Action
- The sensing layer collects water level (ultrasonic HC-SR04), water quality (pH, TDS, turbidity), temperature (DHT11), and flow rate (YF-S201) data. The ESP32 microcontroller processes readings and compares them against predefined thresholds. The MQTT protocol transmits data to a cloud broker (Mosquitto / IBM Cloud / ThingSpeak). A Node-RED or custom dashboard presents real-time status. The Blynk or Twilio API dispatches SMS/push notifications. A relay module controls the water pump and solenoid valves automatically.

Fig 6.2 Workflow Diagram

3.3 Dataset Description

- Source: Experimental readings generated by sensor arrays attached to physical water tank prototypes.
- Dataset size: Minimum 10,000 timestamped records across multiple test scenarios (normal, contaminated, leakage, overflow).
- Data types: Numeric (water level %, TDS ppm, pH, turbidity NTU, temperature °C, flow rate L/min), categorical (pump ON/OFF, relay HIGH/LOW), temporal (timestamp).

IV. EXPECTED RESULTS AND DISCUSSION

4.1 Expected Outcomes

- Reduction in water wastage by eliminating overflow events through automated pump shutdown.
- Reduction in pump operation time by at least 30% via threshold-based automation (validated by Ainur Zhumadillayeva).
- Near real-time (under 2 seconds) notification of anomalies including low water level, poor quality, or leakage detection.
- Accurate water level estimation within 1.5% error margin using ultrasonic time-of-flight sensing.

4.2 Comparative Evaluation Plan

The proposed system will be compared against each reviewed baseline using metrics of latency (ms), accuracy (%), energy consumption (Joules per monitoring cycle), number of parameters sensed, and user satisfaction score. Quantitative benchmarks established by Zhumadillayeva et al. (1.6s latency, 1.5% error, 32% pump efficiency gain, 92% satisfaction) will serve as performance targets.

4.3 Discussion

The integration of MQTT-based filtered notification (from Ancy Jenifer et al.), multi-sensor quality monitoring (from Patro et al. and Chowdhury et al.), alert messaging (from Lokhande et al.), and multi-tank control logic (from Zhumadillayeva et al.) addresses the limitations of each individual system. The proposed unified approach is anticipated to outperform individual solutions in completeness, reliability, and practical impact.

V. APPLICATIONS AND USE CASES

- Residential Buildings: Real-time water level and quality monitoring for households, apartments, and bungalows to prevent overflow and contamination.
- Commercial and Industrial Facilities: Automated water management in factories,

hospitals, hotels, and schools where water quality and continuous supply are critical.

- Smart Cities: City-scale water distribution monitoring using layered MQTT architectures, enabling municipal authorities to track and optimize supply networks.
- Agricultural Irrigation: Water level and flow rate management for irrigation tanks and reservoirs to optimize crop watering schedules.
- Disaster Management: Real-time monitoring of water bodies in flood-prone regions using ultrasonic sensors, enabling timely early warning notifications.
- Academic and Research Value: Providing a reproducible, low-cost experimental platform for IoT and water management research.

CONCLUSION

This paper presented a comprehensive review of five recent IoT-based smart water monitoring and management systems published in IEEE Xplore. The reviewed studies collectively cover a wide spectrum of hardware configurations, communication protocols, and cloud platforms, each addressing specific aspects of water management: alert-based level monitoring (Lokhande et al., 2023), MQTT-layered supply management (Ancy Jenifer et al., 2022), GSM-based multifunctional control (Chowdhury et al., 2022), TDS and temperature quality monitoring (Patro et al., 2025), and multi-tank automated pump control (Zhumadillayeva et al., 2025).

The critical analysis revealed key research gaps in multi-tank coordination, AI/ML predictive analytics, comprehensive multi-parameter quality monitoring, system security, and renewable energy integration. A proposed integrated IoT framework was outlined to consolidate the strengths of all five approaches into a holistic water management platform. The findings of this review underline the transformative potential of IoT in advancing sustainable, efficient, and intelligent water resource management for residential, commercial, and urban infrastructure globally.

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