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An IoT-Enabled System for Water Conservation, Quality Detection, and Leakage Control System

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ABSTRACT: This study addresses the growing challenges in water management arising from population growth, urbanization, and inefficient utilization of water resources. Traditional monitoring systems largely rely on manual supervision and periodic inspections, which often fail to identify leakages and water quality degradation at an early stage, resulting in significant water wastage and potential health risks. The project proposes an IoT-enabled water conservation system emphasizing real-time leakage detection and basic water quality monitoring. The system integrates flow sensors to detect leakage through inlet and outlet flow comparison, along with total dissolved solids (TDS) and turbidity sensors for assessing water quality parameters. Collected data is displayed locally and transmitted to a cloud platform for remote access, while automatic motor control is implemented to minimize water wastage during abnormal conditions. Wi-Fi communication is employed to support real time data transmission and mobile application access. Although alternative technologies such as ZigBee and Sigfox offer low-power and long-range communication, they were not adopted due to increased system cost, network complexity, and limited real-time data support. The proposed system aims to deliver a low-cost, reliable, and efficient solution tailored for small-scale residential and institutional applications. This study guides IoT practitioners in integrating automation and sustainability in water management.

KEYWORDS: Internet of Things (IoT), water management, leakage detection, water quality monitoring, flow sensors, turbidity sensor, total dissolved solids (TDS), Wi-Fi communication, cloud monitoring, automatic motor control.

I. INTRODUCTION

Water scarcity and deterioration of water quality have emerged as critical global challenges due to rapid population growth, urbanization, industrial expansion, climate variability, and inefficient water management practices. According to recent studies, a significant proportion of freshwater resources is lost annually due to unnoticed leakages in distribution pipelines, storage systems, and domestic plumbing networks [1], [2]. In parallel, the degradation of water quality caused by environmental pollution, industrial effluents, agricultural runoff, and aging infrastructure poses serious risks to public health, agricultural productivity, and industrial operations [3], [4]. These interconnected challenges demand innovative, scalable, and intelligent water management solutions capable of ensuring both water conservation and safety. Traditional water monitoring and management methods rely heavily on manual inspection, periodic meter readings, and laboratory-based water quality testing [5]. While such approaches have been historically effective for limited-scale monitoring, they are inherently time- consuming, labour-intensive, and unsuitable for continuous or real-time assessment [6]. Manual inspections often fail to detect hidden leakages occurring underground or within building infrastructure, leading to prolonged water loss and increased operational costs [7]. Similarly, laboratory-based water quality analysis introduces delays between sampling and result availability, during which contaminated water may continue to be supplied for domestic or institutional use [3], [8]. These limitations underscore the need for automated, real- time, and remotely accessible water monitoring systems. Recent advancements in Internet of Things (IoT) technologies have significantly transformed the landscape of water resource management by enabling continuous data acquisition, real-time monitoring, and automated system control [1], [6], [9]. IoT-based systems integrate a network of sensors, communication modules, embedded controllers, and cloud platforms to collect, process, and transmit water related data from distributed sources to centralized monitoring interfaces [10], [11]. This paradigm allows early detection of abnormal conditions such as leakages, pressure drops, and water quality deviations, thereby reducing water wastage, minimizing response time, and decreasing dependency on human supervision [12], [13]. The adoption of IoT in water systems aligns with the broader objectives of smart cities, sustainable development, and digital infrastructure transformation [8], [14]. Several studies have demonstrated the effectiveness of IoT-based solutions for water monitoring and conservation. Mathubala et al. [1] proposed an IoT-based water monitoring and conservation system that integrates flow sensors and communication modules to track water usage and detect abnormal consumption patterns. Manwatkar et al. [3] developed an IoT-based water quality monitoring system that continuously measures parameters such as pH, turbidity, and temperature, enabling early identification of contamination events.

Similarly, Sharanya et al. [5] designed an IoT- based system that combines water quality and leakage monitoring with machine learning algorithms to improve detection accuracy and system responsiveness. These works collectively highlight the growing role of IoT in enabling intelligent water infrastructure. Despite these advancements, existing systems often focus on either leakage detection or water quality monitoring as independent functions, rather than providing a unified solution that integrates both aspects into a single platform [3], [5], [9]. Furthermore, many proposed systems employ complex architectures, advanced machine learning models, or proprietary hardware, which can increase system cost, computational complexity, and deployment difficulty, particularly in small-scale residential or institutional settings [7], [10]. In addition, several solutions prioritize large- scale urban water networks or industrial applications, leaving a gap in the availability of affordable and easily deployable systems for households, schools, hostels, clinics, and small commercial establishments [14], [18]. Another critical design consideration in IoT-based water monitoring systems is the choice of communication technology. Various wireless communication protocols, including ZigBee, Sigfox, LoRaWAN, NB-IoT, and Wi- Fi, have been explored in the literature for transmitting sensor data to cloud platforms [6], [15], [18]. ZigBee is widely used in low-power sensor networks and supports mesh topology, making it suitable for large-scale distributed deployments [6], [15].

Sigfox and LoRaWAN offer long-range communication with ultra-low power consumption, making them appropriate for remote or rural monitoring scenarios [6], [15]. However, these technologies often involve additional infrastructure costs, subscription models, limited data throughput, and latency constraints that can restrict real-time data transmission and system responsiveness [6], [18]. Wi-Fi-based communication, on the other hand, provides high data rates, low latency, and widespread infrastructure availability, particularly in urban and institutional environments [1], [5], [14]. Several researchers have adopted Wi-Fi in IoT water monitoring systems to enable real-time data transmission, mobile application access, and seamless integration with cloud platforms [1], [5], [10]. Although Wi-Fi consumes relatively more power than low-power wide-area network (LPWAN) technologies, its advantages in terms of simplicity, accessibility, and real-time performance make it a suitable choice for small-scale residential and institutional applications where power availability is not a major constraint [14], [18]. Consequently, the selection of Wi-Fi as the primary communication technology aligns with the objectives of system affordability, ease of deployment, and real-time monitoring. In parallel with communication technologies, advancements in sensor technologies have significantly enhanced the accuracy, reliability, and affordability of water monitoring systems.

Flow sensors are widely used for measuring water flow rates and detecting anomalies indicative of leakages or abnormal consumption [1], [2], [9]. Turbidity sensors and total dissolved solids (TDS) sensors are commonly employed for assessing water clarity and dissolved impurity levels, which serve as key indicators of water quality [3], [5], [13]. The integration of these sensors into IoT platforms enables continuous monitoring of both quantitative and qualitative aspects of water usage, thereby supporting informed decision-making and timely intervention [12], [14]. Machine learning and data-driven analytics have further enhanced the capabilities of IoT based water monitoring systems by enabling predictive maintenance, anomaly detection, and pattern recognition [5], [9], [10], [13]. Ebisi et al. [9] explored machine learning schemes for leak detection in IoT-enabled water transmission systems, demonstrating improved detection accuracy compared to rule-based methods. Islam et al. [10] presented an intelligent IoT and ML-based water leakage detection system that employs advanced data analytics and automated alert mechanisms to enhance system efficiency and reliability. Essamlali et al. [7] reviewed advances in machine learning and IoT for water quality monitoring, emphasizing the role of cloud-based analytics, edge computing, and intelligent sensor networks in supporting real-time decision-making. While these approaches offer enhanced performance, they also introduce additional computational complexity and system overhead, which may not be necessary for small-scale deployments requiring basic leakage and quality monitoring. In addition to sensor and analytics advancements, modern engineering tools such as cloud computing, edge computing, mobile applications, supervisory control and data acquisition (SCADA) systems, and cybersecurity frameworks have become integral components of contemporary water management systems [6], [11], [15].

Dwarakanath et al. [11] proposed a smart IoT-based water treatment system integrated with SCADA, illustrating the role of industrial automation, real-time control systems, and centralized monitoring in large-scale water infrastructure. Sushma et al. [8] developed a unified metering system for water and energy monitoring in smart cities, utilizing interoperable IoT platforms, cloud data storage, and real-time dashboards to support multi-utility management. Elayudhan et al. [15] provided a comparative technological review of IoT-enabled water distribution systems, identifying the growing adoption of cloud computing, big data analytics, cybersecurity frameworks, and energy-efficient communication protocols as key enablers of modern water management solutions.

These studies collectively demonstrate the convergence of IoT, information technology, and automation in shaping next- generation water infrastructure. However, the increasing complexity of modern water management systems also raises concerns regarding cost, scalability, system maintenance, and user accessibility [15], [18]. High-end sensors, proprietary communication modules, cloud service subscriptions, and advanced analytics platforms can significantly increase system deployment and operational costs, thereby limiting accessibility for economically constrained users or institutions [7], [18]. Moreover, complex system architectures may require specialized technical expertise for installation, configuration, and maintenance, which may not be readily available in all deployment contexts [15].

These challenges highlight the need for simplified, cost effective, and user-friendly IoT-based water management systems that can deliver essential monitoring and control functionalities without excessive complexity or financial burden.

II. LITERATURE REVIEW

Water quality monitoring has gained significant importance due to increasing pollution and the growing demand for safe drinking water. Traditional monitoring methods rely on manual sampling and laboratory analysis, which are time-consuming, costly, and unsuitable for real-time applications. To overcome these limitations, recent research has focused on Internet of Things (IoT)-based water monitoring systems, which enable continuous and automated data collection.
IoT-based systems integrate sensors, microcontrollers, and communication modules to monitor key water quality parameters such as turbidity, Total Dissolved Solids (TDS), pH, and temperature.

These systems provide real-time monitoring and remote access to data through cloud platforms or mobile applications, improving efficiency and decision-making. Among these parameters, turbidity is widely used to detect suspended particles and contamination, while TDS helps assess the concentration of dissolved minerals and overall water purity.
Several studies highlight the advantages of using multiple sensors together, as it improves the accuracy and reliability of water quality assessment. Multi-parameter systems allow a more comprehensive evaluation compared to single-parameter approaches. Additionally, IoT-based solutions have been applied in smart water management, particularly for detecting leakage and monitoring water consumption. Flow sensors are commonly used to analyze water movement and identify abnormal patterns that indicate leaks or wastage.

Recent advancements also include the integration of data analytics and machine learning techniques to enhance prediction accuracy and system intelligence. However, existing systems often face challenges such as high implementation cost, limited scalability, and lack of user-friendly interfaces. Many solutions focus only on monitoring and do not provide automated control mechanisms.

The proposed system addresses these limitations by combining real-time water quality monitoring (TDS and turbidity), flow-based leakage detection, automated motor control, and IoT-based remote access. This integrated approach ensures efficient water management, improves user accessibility, and supports sustainable utilization of water resources.

III. RESEARCH METHODOLOGY

The proposed system represents an IoT-enabled smart water management framework designed to monitor water quality, detect leakage, regulate water flow, and provide real-time alerts to users. The system integrates multiple environmental sensors with a microcontroller-based processing unit and an IoT communication module to ensure continuous data acquisition, intelligent decision- making, and remote accessibility. By combining sensing, processing, actuation, and communication layers, the system offers a reliable, automated, and scalable solution for domestic, industrial, and municipal water management applications. At the core of the system lies the ATmega328 microcontroller, which acts as the central control and processing unit. All sensors, output devices, and communication modules are interfaced with this controller, enabling synchronized operation and real-time system response. The flowchart illustrates the sequential and parallel interactions among the system components, starting from power supply distribution and sensor data acquisition to data processing, output display, cloud transmission, and actuation through relay control. The power supply unit provides stable and regulated electrical power to all components of the system, including the microcontroller, sensors, IoT module, LCD display, and relay circuitry.

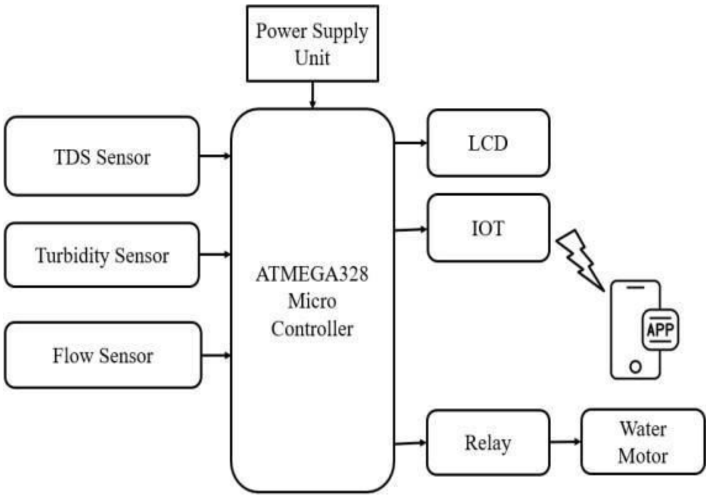
A reliable power source is essential for maintaining uninterrupted system operation, especially in continuous monitoring applications. The power supply ensures that voltage fluctuations do not affect sensor accuracy or microcontroller performance. In practical deployments, this unit may include voltage regulators, filtering circuits, and battery backup to enhance system reliability and resilience during power interruptions. The system integrates three primary sensors: the Total Dissolved Solids (TDS) sensor, the turbidity sensor, and the flow sensor. Each sensor performs a distinct function, collectively providing a comprehensive assessment of water quality and usage patterns. The TDS sensor measures the concentration of dissolved salts and minerals in water, which is a critical indicator of water purity and suitability for consumption. High TDS values often indicate contamination or excessive mineral content, making the water unsuitable for drinking or industrial use. The turbidity sensor measures the cloudiness or haziness of water caused by suspended particles such as silt, microorganisms, or organic matter. Elevated turbidity levels can signal pollution, microbial growth, or pipeline contamination.

The flow sensor measures the rate and volume of water flowing through the system, enabling accurate monitoring of water consumption, detection of abnormal flow patterns, and identification of potential leakage or unauthorized usage. All sensor outputs are transmitted as analog or digital signals to the ATmega328 microcontroller. The microcontroller continuously samples these signals using its built-in analog-to-digital converter (ADC) and digital input pins, converting raw sensor data into meaningful physical parameters such as parts per million (ppm) for TDS, Nephelometric Turbidity Units (NTU) for turbidity, and liters per minute (LPM) for flow rate. The ATmega328 microcontroller serves as the system's intelligence hub, processing sensor data, executing decision algorithms, and controlling system outputs. Once the sensor data is acquired, the microcontroller applies calibration equations and threshold-based logic to interpret water quality and flow conditions. Predefined safety thresholds for TDS and turbidity are used to determine whether the water is safe, marginal, or unsafe for use. Similarly, flow rate data is analyzed to identify normal consumption patterns or abnormal fluctuations indicative of leakage, pipe bursts, or unauthorized water usage. Based on this analysis, the microcontroller generates control signals to update the LCD display, transmit data to the IoT module, and activate or deactivate the relay controlling the water motor. The decision-making process is designed to operate in real time, ensuring rapid response to changes in water quality or flow conditions.

This automated logic reduces human intervention, improves system reliability, and enhances overall operational efficiency. The LCD display provides a local visual interface for users, enabling real-time observation of water quality parameters and system status. Key information such as TDS level, turbidity value, flow rate, motor status, and alert messages is displayed continuously. This feature is particularly useful in on-site installations where immediate access to system data is required, such as residential buildings, water treatment facilities, and industrial plants. By presenting sensor readings in a clear and user-friendly format, the LCD display enhances system transparency and usability. It allows operators to verify system performance, identify abnormal conditions, and take manual corrective actions if necessary. The display also serves as a fallback information channel in situations where network connectivity is unavailable or unreliable.

The IoT module enables wireless communication between the microcontroller and remote cloud platforms or mobile applications. Sensor data, system status updates, and alert notifications are transmitted over the internet, allowing users to monitor water quality and system performance from any location. This remote accessibility significantly enhances system convenience, scalability, and responsiveness. The mobile application interface provides a user-friendly dashboard that displays real-time and historical data, including TDS levels, turbidity trends, water consumption patterns, and motor operation status. In addition, the application can generate alerts when sensor values exceed safe thresholds or when abnormal flow patterns are detected. These alerts enable users to take timely corrective actions, such as shutting off the water supply, initiating maintenance, or switching to alternative water sources. Furthermore, the IoT interface supports bidirectional communication, allowing users to remotely control system components, such as turning the water motor on or off. This capability enhances system automation and enables intelligent water resource management, particularly in large-scale or geographically dispersed installations.

Fig.1. Block Diagram of Proposed System



The Fig.1. is the system architecture which incorporates local data display and cloud-based remote monitoring, enabling users to access real-time water usage and quality information through mobile applications or web interfaces [1], [5], [10]. Automatic motor control is implemented to prevent water wastage during abnormal conditions such as excessive flow, leakage detection, or poor water quality, thereby enhancing system autonomy and conservation effectiveness [14], [17].

This closed-loop control mechanism aligns with the objectives of intelligent water management by enabling automated response to detected anomalies without requiring continuous human intervention [11], [15]. In selecting the communication technology, the proposed system adopts Wi-Fi-based IoT communication to support real-time data transmission, cloud connectivity, and mobile application access while maintaining system simplicity and affordability [1], [5], [14]. Although alternative technologies such as ZigBee and Sigfox offer advantages in terms of low power consumption and long-range communication, they were not adopted due to increased system cost, network complexity, infrastructure requirements, and limitations in real-time data throughput [6], [15], [18]. The choice of Wi-Fi aligns with the deployment context of small-scale residential and institutional environments, where existing Wi-Fi infrastructure is typically available and power constraints are minimal. Furthermore, the proposed system emphasizes modularity and scalability, allowing additional sensors or control modules to be integrated in future enhancements without significant redesign [6], [15]. This design approach supports gradual system expansion and adaptation to evolving monitoring requirements, thereby extending system lifespan and return on investment [8], [18]. By leveraging widely available hardware components, open-source platforms, and standard communication protocols, the system also promotes interoperability, ease of maintenance, and long-term sustainability [15], [18]. The contributions of this work are positioned within the broader context of IoT-based water management research while addressing specific gaps related to system integration, affordability, and practical deployment.

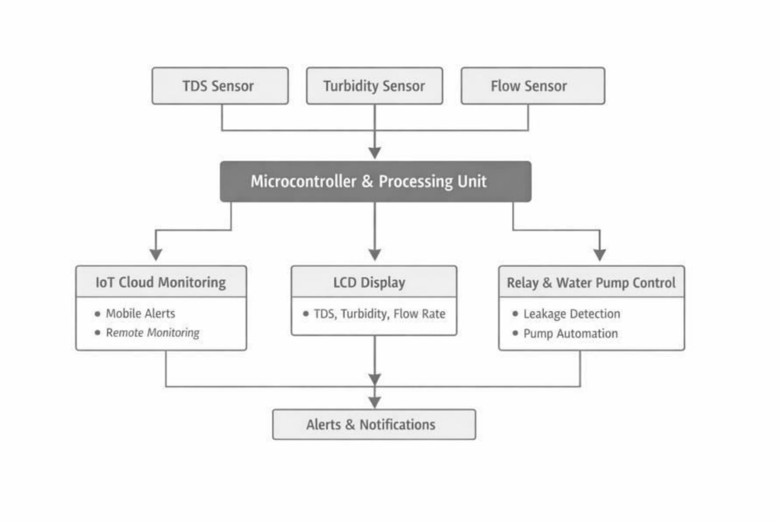


FIG: 2 System model of IoT-Based Water Quality Monitoring and Control System

The Fig.2. illustrates the overall architecture of the IoT-based water monitoring system. It includes TDS, turbidity, and flow sensors that collect real-time water data and send it to the microcontroller for processing. The processed data is displayed on an LCD and transmitted to an IoT platform for remote monitoring and alerts. Additionally, the system controls a relay-based water pump for leakage detection and automated operation, ensuring efficient water management. Whereas many existing systems focus on either leakage detection or water quality monitoring as standalone functions, the present work integrates both functionalities into a unified, low-cost platform suitable for real-world applications [3], [5], [9]. Moreover, by prioritizing real time monitoring, automated control, and user accessibility, the system aligns with the emerging paradigm of intelligent, autonomous, and user-centric water management solutions [6], [11], [15]. The remainder of this paper is organized as follows: Section II reviews related work on IoT-based water monitoring, leakage detection, and water quality assessment. Section III describes the proposed system architecture, hardware components, and communication framework. Section IV presents the system implementation and operational workflow. Section V discusses experimental results and performance evaluation. Finally, Section VI concludes the paper and outlines directions for future research.

The design of IoT-based Water Management Systems has gained significant attention in recent years due to the growing need for efficient water conservation, leakage detection, and quality monitoring. Modern water systems rely not only on traditional sensing technologies but also on the integration of IoT devices, machine learning algorithms, and intelligent data processing platforms. A robust design framework ensures that these systems are reliable, scalable, energy-efficient, and capable of providing real-time insights for operational decision- making. Several studies have analyzed the key design requirements necessary for the successful implementation of IoT-enabled water management solutions. Alshami et al. [6] conducted a comprehensive review of IoT innovations in water and wastewater management, identifying critical design considerations. Among these, sensor accuracy stands out as a foundational requirement because inaccurate measurements can lead to false alarms or missed detections, ultimately reducing system reliability. Interoperability is equally important, particularly in heterogeneous IoT environments, where multiple types of sensors, communication modules, and actuators must interact seamlessly. Energy efficiency is essential for the long-term operation of wireless sensor nodes, especially in remote or distributed installations where frequent maintenance is impractical. Furthermore, the study emphasized data security, which is crucial for protecting sensitive water consumption and infrastructure data from cyber threats. Finally, real-time communication reliability ensures timely detection of leakages or water quality anomalies, enabling swift corrective actions. Sushma et al. [8] extended the discussion on design requirements by proposing a unified metering system for smart cities, where water and energy resources are monitored concurrently. Their work underscores the need for architectural flexibility to support multi-utility monitoring, ensuring that data from various sources can be integrated, analyzed, and visualized efficiently.

Fault tolerance is highlighted as a critical feature, allowing the system to continue functioning under hardware failures or network disruptions. The study further emphasizes the importance of interoperability between different utility systems, which facilitates centralized monitoring and coordinated management of resources, thereby improving operational efficiency in smart city environments. Dwarakanath et al. [11] focused on industrial and institutional applications by integrating IoT devices with supervisory control and data acquisition (SCADA) systems. Their analysis identifies real-time control as a core requirement, allowing automated interventions in response to sensor readings, such as shutting off a water pump during leak detection. They also highlight system redundancy as essential to prevent downtime, particularly in critical infrastructure settings where water supply interruptions can have severe consequences. Operational reliability is reinforced through continuous monitoring, centralized decision-making, and secure data communication, which ensures that industrial- scale water management systems maintain consistent performance. Boujelben et al. [12] addressed the integration of lightweight deep learning models for leak detection in IoT water networks. They emphasized low- latency data processing at edge devices to reduce the response time between anomaly detection and system action.

Their study also stresses computational efficiency, particularly in resource-constrained environments, where edge nodes must process real-time data without relying on cloud infrastructure alone. Additionally, the authors highlight adaptive system behavior, which allows the system to respond dynamically to changing operational conditions, such as fluctuating water pressures or varying environmental factors, thereby increasing overall system resilience. Jan et al. [14] examined smart water tank systems, highlighting functional requirements such as automated decision-making and real-time alert generation. These features enable immediate corrective actions, such as switching motors ON/OFF or notifying operators about abnormal water levels or leakages. System robustness is emphasized to ensure continuous operation even under variable conditions, including sensor faults, power fluctuations, or communication disruptions. The study demonstrates that integrating automated control mechanisms with reliable sensor networks significantly enhances water management efficiency. Elayudhan et al. [15] provided a comparative technological review of IoT-enabled water distribution systems, identifying additional critical design requirements including scalability, fault tolerance, energy optimization, and secure data communication. Their study discusses the trade-offs between centralized and distributed architectures, highlighting that while centralized systems offer easier data management, distributed models enhance scalability and resilience.

The authors also stress the importance of selecting appropriate communication protocols based on deployment context, balancing factors such as network range, power consumption, and real-time data requirements. Singh and Ahmed [18] conducted a systematic review of smart water management systems, revealing recurring operational challenges such as optimal sensor placement, ensuring data reliability, maintaining communication stability, and planning for system maintenance. Their findings highlight the necessity of a holistic approach, where design considerations extend beyond hardware and software to include long-term usability, adaptability to changing water demands, and cost-effectiveness. They further emphasize the need for user-friendly interfaces that facilitate easy monitoring and management by non-technical personnel, which is critical for adoption in residential and small-scale industrial settings. Collectively, these studies underscore that designing IoT- based water management systems requires careful attention to multiple interdependent factors. Effective systems must be modular, allowing incremental upgrades and sensor integration; scalable, capable of adapting to both small scale and large-scale networks; secure, to protect sensitive operational data; and energy-efficient, to support long-term deployments. Real-time monitoring, automated control, and interoperability between heterogeneous devices are equally important for practical deployment. By addressing these design requirements, modern IoT-enabled water systems can achieve high levels of reliability, efficiency, and sustainability, ultimately contributing to water conservation, leak prevention, and improved water quality management.

ANALYSIS OF DESIGN REQUIREMENTS:

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MODERN ENGINEERING AND IT TOOL USED:

The proposed IoT-Enabled Water Conservation, Quality Detection, and Leakage Control System is designed to provide a smart, automated, and efficient solution for continuous monitoring of water quality and usage, while minimizing wastage through real-time detection and control mechanisms. The system integrates multiple sensors with a microcontroller-based processing unit and IoT communication modules to track critical parameters such as total dissolved solids (TDS), turbidity, and flow rate. By analyzing this data in real time, the system can identify contamination, leakage, or abnormal water consumption patterns and automatically initiate corrective actions, ensuring safe and efficient utilization of water resources across residential, industrial, and municipal environments.

At the core of the system lies the ATmega328 microcontroller, which functions as the central processing and control unit. It interfaces with all sensing, communication, and actuation components, enabling synchronized operation across the system. The microcontroller continuously acquires data from the connected sensors, performs signal conditioning and analog-to-digital conversion, and processes the data using embedded algorithms. The processed data is then transmitted to an IoT cloud platform for remote visualization and system supervision. This centralized processing architecture ensures reliable real-time performance, reduces system complexity, and enhances overall operational efficiency.To facilitate mobile-based monitoring and interaction, the system utilizes the Arduinodroid application as an additional user interface. Arduinodroid is an Android-based application that enables wireless communication between the ATmega328 microcontroller and a smartphone via the IoT communication module. Through this application, users can view real-time sensor readings such as TDS level, turbidity, and flow rate directly on their mobile device. The app provides a simpleand intuitive interface for observing system status, receiving alerts, and verifying operational conditions without the need for complex hardware interfaces. This mobile integration enhances user convenience, supports on-the-go monitoring, and improves system accessibility, especially in residential and small-scale industrial deployments.

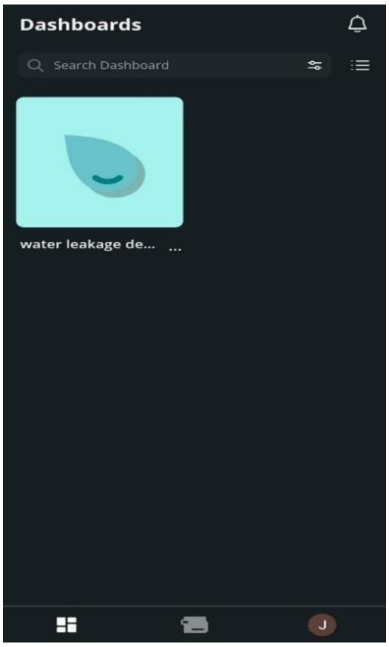

Fig.3. Project Dashboard Interface in ArduinoDroid Application

The Fig.3. illustrates the dashboard screen of the ArduinoDroid application, where the project titled “water leakage detection” is displayed. The interface includes a search bar for navigating dashboards and a visual tile representing the project, enabling users to access and monitor system data conveniently through a mobile device.A key feature of the system is its automated leakage detection and control mechanism. The flow sensor continuously monitors water movement through the pipeline, and the microcontroller analyzes this data to detect irregular flow patterns. Conditions such as continuous flow without expected consumption, sudden drops in flow, or abnormal spikes can indicate leakage, pipe bursts, or unauthorized usage. When such anomalies are detected, the system automatically triggers corrective action by controlling the water motor through a relay driver circuit. The relay acts as an electrically isolated switching device, allowing the low-power microcontroller to control the high-power motor safely and efficiently. By automatically turning the motor on or off based on predefined conditions, the system prevents water wastage, reduces the risk of flooding, and enhances operational safety.

The system also includes alert mechanisms that notify users of critical conditions through the IoT application. When TDS or turbidity levels exceed safe thresholds, or when leakage is detected, the system immediately sends notifications to the user’s mobile device or web dashboard. These alerts enable timely intervention, allowing users to take appropriate corrective measures such as inspecting pipelines, adjusting water sources, or performing maintenance. This real-time alerting capability significantly improves user awareness, system responsiveness, and overall water management effectiveness.From a software perspective, the system is programmed to operate using a structured and efficient algorithmic flow. Upon startup, the microcontroller initializes all peripherals, communication interfaces, and sensor modules. It then periodically collects sensor readings at defined intervals and performs signal conditioning to remove noise and improve accuracy. The acquired data is compared against predefined threshold values stored in the microcontroller's memory. Based on this comparison, the system executes decision-making logic to determine whether the water quality and flow conditions are within acceptable limits. If abnormal conditions are detected, appropriate control actions and alert notifications are generated. This closed-loop control approach ensures real-time responsiveness and autonomous operation.

Real-time data logging is implemented to store sensor readings in the cloud database. This historical data can be analyzed to identify long-term trends, consumption patterns, system performance metrics, and potential areas for optimization. Such data-driven insights support informed decision-making, predictive maintenance, and efficient water resource planning. The use of serial communication protocols ensures reliable and accurate data exchange between the ATmega328 microcontroller and the IoT module, minimizing transmission errors and latency.The system architecture is designed to be modular, allowing individual components such as sensors, controllers, communication modules, and actuators to be replaced, upgraded, or expanded independently. This modularity enhances system maintainability, flexibility, and scalability. For instance, additional sensors such as pH, temperature, or pressure sensors can be integrated to extend the system's functionality. Similarly, advanced data analytics or machine learning algorithms can be implemented at the cloud level to improve anomaly detection, predictive analysis, and automated decision- making. This adaptability makes the system suitable for both small-scale residential applications and large-scale industrial or municipal water management systems.

Energy efficiency is another key consideration in the system design. The components are selected and configured to consume minimal power while maintaining continuous monitoring and communication. Low-power sensors, efficient microcontroller operation, and optimized communication protocols contribute to reduced energy consumption, making the system suitable for long-term deployment and environmentally responsible operation. This efficient power utilization also supports the integration of renewable energy sources, such as solar panels, in remote or off-grid installations.

The mechanical design of the system ensures practical and reliable deployment in real-world environments. Sensors are strategically placed within the water pipeline to obtain accurate and representative measurements. The electronic components are housed in protective enclosures to shield them from moisture, dust, temperature variations, and physical damage. Proper insulation, grounding, and cable management are implemented to ensure electrical safety and long-term durability. This robust physical design enhances system reliability and ensures consistent performance under diverse environmental conditions.

Overall, the proposed IoT-enabled water conservation and quality detection system successfully integrates sensing technology, microcontroller-based automation, and cloud-based IoT connectivity to deliver a comprehensive, intelligent, and user-friendly solution. The combination of real-time monitoring, automated leakage control, remote accessibility, and data-driven decision-making ensures efficient water usage, reduces human intervention, and enhances system reliability. By addressing critical challenges such as water wastage, contamination, and inefficient monitoring, the system provides a practical and scalable framework for modern water management. Its modular design, energy efficiency, and adaptability make it suitable for widespread adoption across residential, industrial, and municipal sectors, offering a long-term solution for sustainable and intelligent water resource management.

IV. RESULTS AND DISCUSSION

The IoT-Enabled Water Conservation, Quality Detection, and Leakage Control System was successfully designed, implemented, and evaluated under controlled test conditions. The system continuously monitored critical water parameters, including flow rate, Total Dissolved Solids (TDS), and turbidity, enabling real-time assessment of both water usage and water quality. Flow sensors placed at the inlet and outlet points provided continuous data, and leakage conditions were effectively detected by comparing the measured flow rates. When abnormal flow patterns were identified, the system automatically deactivated the water motor through a relay mechanism, demonstrating reliable and timely leakage control.

FIG: 4 Experimental Setup of the IoT-Based Water Conservation, Quality Detection and Leakage Control System

The Fig.4. shows the complete experimental setup integrating sensors, microcontroller, water pump, and piping system. It demonstrates how water flow, quality parameters (TDS and turbidity), and leakage are monitored and controlled in real time. The setup highlights the coordination between hardware components and IoT module for efficient water management.The water quality monitoring module accurately measured TDS and turbidity levels, and these readings were displayed locally on an LCD screen, ensuring immediate on-site visibility. Simultaneously, sensor data was transmitted to the IoT cloud platform, where real-time updates and alerts were observed through a mobile application. This dual-display mechanism enhanced system usability by supporting both local and remote monitoring. The cloud dashboard successfully reflected real-time variations in water quality and flow, confirming the reliability of data transmission and system responsiveness. Overall, the experimental results validate the system's capability to reduce water wastage, improve monitoring efficiency, and provide timely alerts with minimal human intervention. From a performance perspective, the leakage detection mechanism proved effective even under varying flow conditions. The threshold-based comparison of inlet and outlet flow rates enabled rapid identification of abnormal water loss without requiring complex data processing or machine learning algorithms.

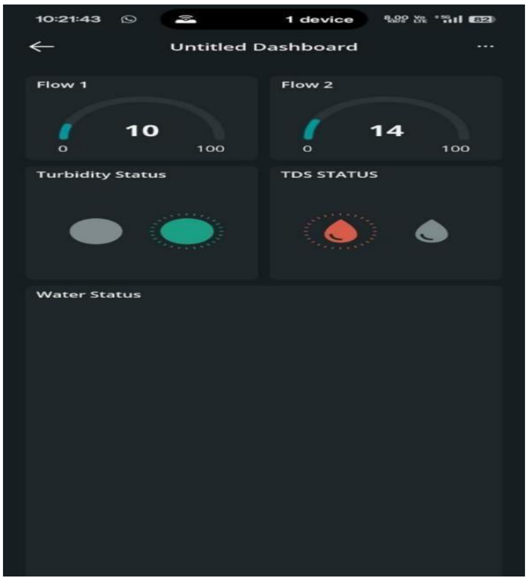

Fig.5. Mobile IoT Dashboard Interface for Real-Time Water Quality and Flow Monitoring

This approach significantly reduces computational overhead and makes the system suitable for low-resource environments. The automated motor control feature further enhances system autonomy by eliminating the need for manual intervention during leakage events, thereby preventing prolonged water loss and potential infrastructure damage. The Fig.5. shows a mobile-based dashboard interface used to monitor real-time water parameters such as TDS, turbidity, and flow rate. It provides users with easy access to live data and system status through a user-friendly visual interface. This enables remote monitoring, quick analysis, and efficient management of the water system. The water quality monitoring component, while limited to basic parameters such as TDS and turbidity, successfully functioned as an early-warning mechanism. Although these parameters alone do not provide comprehensive laboratory-grade water analysis, they are sufficient to indicate potential contamination, sediment intrusion, or water source deterioration.

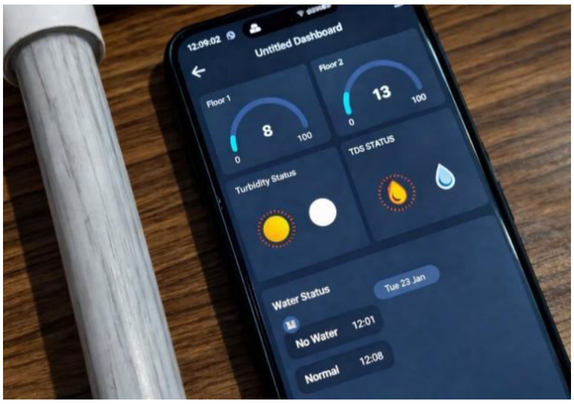

Fig.6. Readings in Dashboard Interface

The Fig.6. displays the mobile dashboard showing real-time readings of water parameters. It also indicates water availability status with time updates, providing a clear and interactive interface for monitoring system performance remotely. The system therefore serves as a preliminary screening tool that enables users to take timely corrective action or seek further testing when abnormal values are detected. The results demonstrate that the proposed system provides a practical and cost-effective solution for small- scale water management applications, including residential buildings, hostels, schools, and small commercial facilities.

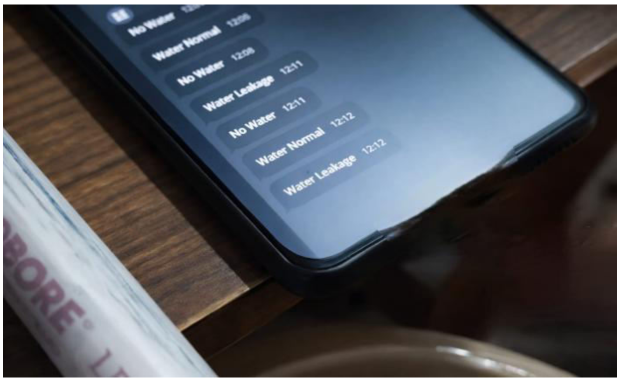

Fig.7. Water Status Alerts Display in Dashboard Interface

The Fig.7. shows the mobile dashboard presenting time-stamped water status updates, including conditions such as “No Water,” “Water Normal,” and “Water Leakage.” It highlights the system’s ability to log and display real-time alerts, enabling users to track changes in water flow and quickly identify leakage or supply issues for effective monitoring and control. The integration of IoT connectivity enables real- time visualization, historical data tracking, and remote supervision—capabilities that are absent in conventional manual water management systems. Additionally, the use of affordable sensors, Wi-Fi communication, and open- source platforms significantly reduces system cost and deployment complexity, making it accessible to a broader user base.Despite its successful performance, certain limitations were observed during testing. Sensor accuracy was found to vary slightly due to environmental conditions, calibration drift, and sensor aging. Furthermore, the system relies on fixed threshold values for leakage detection and water quality assessment, which may not adapt optimally to dynamic operating conditions or varying water usage patterns. These limitations can be addressed in future enhancements by incorporating adaptive threshold mechanisms, improved sensor calibration techniques, and intelligent decision-making algorithms based on machine learning or data analytics.

V. CONCLUSION

This project successfully demonstrates the design and implementation of an IoT-based water leakage detection and quality monitoring system that addresses critical challenges in water conservation and management. The system effectively monitored inlet and outlet water flow to detect leakage conditions and continuously measured essential water quality parameters such as Total Dissolved Solids (TDS) and turbidity in real time. By integrating automatic motor control using a relay mechanism, the system was able to prevent unnecessary water wastage during abnormal operating conditions. Furthermore, IoT connectivity enabled remote monitoring through a cloud- based platform, providing users with real-time access to water usage and quality information via a mobile application. The experimental results confirm that the proposed system offers a reliable, low-cost, and practical solution for small-scale applications such as residential buildings, hostels, educational institutions, and small commercial facilities. The use of affordable sensors, Wi-Fi-based communication, and simple embedded controllers ensures ease of deployment and maintenance while maintaining acceptable system performance.Although advanced communication technologies such as ZigBee and Sigfox were studied during the design phase, they were not implemented due to increased system cost, network complexity, and limited support for high-frequency real- time data transmission. In contrast, Wi-Fi communication was found to be more suitable for the project requirements, offering seamless integration, widespread availability, and continuous cloud connectivity. The system currently operates using threshold-based logic and monitors a limited set of water quality parameters. While this approach does not provide laboratory-grade analysis, it serves as an effective early-warning mechanism that enables timely identification of leakage conditions and water quality degradation. The design prioritizes simplicity, affordability, and reliability, making it suitable for real-world deployment where cost and ease of use are critical factors. The system’s modular architecture also allows for future expansion without major redesign. Despite its successful performance, certain limitations were observed. Sensor accuracy may vary due to environmental conditions, calibration drift, and hardware aging. Additionally, fixed threshold values may not optimally adapt to changing usage patterns or dynamic water supply conditions. These limitations highlight opportunities for future enhancement and optimization. Future work may focus on integrating additional water quality sensors, such as pH, temperature, dissolved oxygen, and conductivity, to provide a more comprehensive assessment of water safety. Advanced data analysis techniques, including machine learning and predictive modeling, can be incorporated to improve leakage detection accuracy, reduce false alarms, and enable predictive maintenance.

The adoption of adaptive threshold mechanisms and anomaly detection algorithms would further enhance system intelligence and reliability. For large-scale and geographically distributed deployments, alternative communication technologies such as LoRaWAN, NB-IoT, ZigBee, or Sigfox may be explored to support long-range communication, low power consumption, and improved network scalability. Integration with smart city platforms, utility management systems, and centralized dashboards could also enable coordinated water resource management at the community or municipal level. In conclusion, the proposed IoT-based water leakage detection and quality monitoring system represents a balanced and effective approach to modern water management, combining functionality, affordability, and practicality. The system demonstrates strong potential to support sustainable water usage, reduce wastage, and enhance operational efficiency, while providing a foundation for future advancements in intelligent and scalable water management solutions.

VI. FUTURE WORK

1. Sensor accuracy may vary due to environmental factors such as temperature and water conditions.
2. Calibration drift over time can affect the reliability of sensor readings.
3. Sensor aging may lead to gradual degradation in performance.
4. The system relies on fixed threshold values, limiting adaptability to changing conditions.
5. Leakage detection may not be fully accurate under highly dynamic or irregular flow patterns.
6. The system lacks advanced intelligence, as it does not use machine learning or data-driven decision-making.
7. Future improvements can include adaptive thresholds, better calibration methods, and intelligent algorithms for enhanced accuracy and performance.

REFERENCES

[1] R. S. Mathubala, M. Manasha, N. V. Nishitha, J. Thiyaa Varsini, and M. S. Vaishnavi, "IoT based water monitoring and conservation system", International Journal of Advanced Research in Science, Communication and Technology (IJARSCT) International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal Volume 5, Issue 3, March 2025.

[2] S. J, P. A. S. K, V. X. S, O. R. M. R, M. M and S. K, "Water Leakage Detection and Recognition System," 2025 3rd International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT), Bengaluru, India, 2025, pp. 1020-1028, doi: 10.1109/IDCIOT64235.2025.10915052.

[3] R. Manwatkar, N. Chamate, and P. Malame, "IoT based water quality monitoring system," International Journal of Advanced Research in Science, Communication and Technology (IJARSCT) International journal for research Volume 13, Issue 2, 2025 DOI Link: https://doi.org/10.22214/ijraset. 2025.66030 .

[4] Bhoge, Rohit & Holey, Janhavi & Rajput, Vidhan & Rathod, Shardul & Raut, Yash & Nandankar, Praful. (2024). Leveraging IoT for Detecting Power and Water Theft in Urban Environments: A Comprehensive Review. 9. 60-68. E. Farah and I. Shahrour, "Use of data-driven methods for water leak detection and consumption monitoring in a university campus," 2024.

[5] U. G. Sharanya, K. M. Birabbi, B. H. Sahana, D. M. Kumar, N. Sharmila and S. Mallikarjunaswamy, "Design and Implementation of IoT-based Water Quality and Leakage Monitoring System for Urban Water Systems Using Machine Learning Algorithms," 2024 Second International Conference on Networks, Multimedia and Information Technology (NMITCON), Bengaluru, India, 2024, pp. 1-5, doi: 10.1109/NMITCON62075.2024.10698922..

[6] Alshami, Ahmad & Saleh, Eslam & Elsayed, Moustafa & Eltoukhy, Abdelrahman & Zayed, Tarek. (2024). IoT Innovations in Sustainable Water and Wastewater Management and Water Quality Monitoring: A Comprehensive Review of Advancements, Implications, and Future Directions. IEEE Access. PP. 1-1. 10.1109/ACCESS.2024.3392573.

[7] Essamlali I, Nhaila H, El Khaili M. Advances in machine learning and IoT for water quality monitoring: A comprehensive review. Heliyon. 2024 Mar 13;10(6):e27920. doi: 10.1016/j.heliyon.2024.e27920. PMID: 38533055; PMCID: PMC10963334.

[8] Sushma, N. & H N, Suresh & Jayaramu, Mohana & Srinivasu, Parvathaneni Naga & Bhoi, Akash Kumar & Barsocchi, Paolo. (2023). A Unified Metering System Deployed for Water and Energy Monitoring in Smart City. IEEE Access. PP. 1-1. 10.1109/ACCESS.2023.3299825.

[9] F. Ebisi, I. P. Nikolakakos, J. V. Karunamurthi, A. N. Ahmed Binahmed Alnuaimi, E. Al Buraimi and S. Alblooshi, "Machine Learning Schemes for Leak Detection in IoT-enabled Water Transmission System," 2023 International Conference on IT Innovation and Knowledge Discovery (ITIKD), Manama, Bahrain, 2023, pp. 1-7, doi: 10.1109/ITIKD56332.2023.10100175.

[10] Islam, M. R., Azam, S., Shanmugam, B., & Mathur, D. (2023). An Intelligent IoT and ML-Based Water Leakage Detection System. IEEE Access, 11, 123625-123649. https://doi.org/10.1109/ACCESS.2023.3329467B.

[11] Dwarakanath, P. Kalpana Devi, A. Ranjith Kumar, A. S. M. Metwally, G. A. Ashraf, B. L. Thaminen, and others, "Smart IoT- based water treatment with a supervisory control and data acquisition (SCADA) system process," 2023.

[12] C.Nagarajan and M.Madheswaran - 'Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques'- Taylor &Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011. DOI: 10.1080/15325008.2010.541746

[13] C.Nagarajan and M.Madheswaran - 'Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter' - Journal of Electrical Engineering, Vol.63 (6), pp.365-372, Dec.2012. DOI: 10.2478/v10187-012-0054-2

[14] C.Nagarajan and M.Madheswaran - 'Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis'- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011. DOI 10.1007/s00202-011-0203-9

[15] S.Tamilselvi, R.Prakash, C.Nagarajan,"Solar System Integrated Smart Grid Utilizing Hybrid Coot-Genetic Algorithm Optimized ANN Controller" Iranian Journal Of Science And Technology-Transactions Of Electrical Engineering, DOI10.1007/s40998-025-00917-z,2025

[16] S.Tamilselvi, R.Prakash, C.Nagarajan," Adaptive sliding mode control of multilevel grid-connected inverters using reinforcement learning for enhanced LVRT performance" Electric Power Systems Research 253 (2026) 112428, doi.org/10.1016/j.epsr.2025.112428

[17] S.Thirunavukkarasu, C. Nagarajan, 2024, "Performance Investigation on OCF and SCF study in BLDC machine using FTANN Controller," Journal of Electrical Engineering And Technology, Volume 20, pages 2675–2688, (2025),

doi.org/10.1007/s42835-024-02126-w

[18] C. Nagarajan, M.Madheswaran and D.Ramasubramanian- 'Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model'- Acta Electrotechnica et Informatica Journal , Vol.13 (2), pp.18-31,April-June.2013, DOI: 10.2478/aeei-2013-0025.

[19] C.Nagarajan and M.Madheswaran - 'DSP Based Fuzzy Controller for Series Parallel Resonant converter'- Springer, Frontiers of Electrical and Electronic Engineering, Vol. 7(4), pp. 438-446, Dec.12. DOI 10.1007/s11460-012-0212-0.

[20] C.Nagarajan and M.Madheswaran - 'Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis'- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.

[21] C.Nagarajan and M.Madheswaran, "Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation" has been presented in ICTES'08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007

[22] Suganthi Mullainathan, Ramesh Natarajan, "An SPSS and CNN modelling based quality assessment using ceramic materials and membrane filtration techniques", Revista Materia (Rio J.) Vol. 30, 2025, DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0721

[23] M Suganthi, N Ramesh, "Treatment of water using natural zeolite as membrane filter", Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022

[24] Boujelben, M., Benmessaoud, Z., Abid, M., & Elleuchi, M. (2023). An efficient system for water leak detection and localization based on IoT and lightweight deep learning. Internet of Things, 24, 100995. https://doi.org/10.1016/j.iot.2023. 100995.

[25] T. Tejaswi, C. Manoj, P. Venkata Daivakeshwar Naidu, T. Santhosh, P. Venkata Sai Akhil and V. Ganesan, "Nexus of Water Quality prediction by ANN," 2022 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES), Chennai, India, 2022, pp. 1-5, doi: 10.1109/ICSES55317.2022.9914054.

[26] . Jan, Farmanullah & Min Allah, Nasro & Saeed, Saqib & Iqbal, Sardar & Ahmed, Rashad. (2022). IoT-Based Solutions to Monitor Water Level, Leakage, and Motor Control for Smart Water Tanks. Water. 14. 309 10.3390/w14030309.

[27] elayudhan, N. K., Pradeep, P., Rao, S. N., Devidas, A. R. and Ramesh, M. V. (2022) 'IoT-enabled water distribution systems a comparative technological review', IEEE Access, (31 pp). doi: 10.1109/ACCESS.2022.3208142.

[28] Islam, Gazi & Hossain, Md & Faruk, Md & Nur, Fernaz & Hasan, Nayeem & Khan, Md. Khalid & Tumpa, Zerin. (2022). IoT-Based Intelligent Gas Leakage Detection and Fire Protection System. International Journal of Interactive Mobile Technologies (iJIM).
16. 49-70. 10.3991/ijim.v16i21.30311.

[29] P Shri Tharanyaa, Abin Satheesan, R Saravanakumar and D Sharmila,"IoT Based Water flow Monitoring, Theft Avoidance and Alert system for Water Supply", J P Shri Tharanyaa et al 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1084 012122 DOI 10.1088/1757- 899X/1084/1/012122,(2021).

[30] Singh, M., & Ahmed, S. (2020). IoT based smart water management systems: A systematic review. Materials Today: Proceedings, 46, 5211-5218.
https://doi.org/10.1016/j.matpr.2020.08.588S. P. Khabusi and R. Jindal, "Pressure dependent piped water theft detection with IoT- based remote billing and location alert,".

[31] Ayamga, Michael & Nakpih, Callistus. (2024). An IoT-Based Water Leakage Detection and Localization System. Asian Journal of Research in Computer Science. 17. 1-14. 10.9734/AJRCOS/2024/v17i3421.

[32] Kiran, A., Rubini, P., & Kumar, S. S. (2025). Comprehensive review of privacy, utility and fairness offered by synthetic data. IEEE Access.

[33] Padmapriya, V. M., Thenmozhi, K., Hemalatha, M., Thanikaiselvan, V., Lakshmi, C., Chidambaram, N., & Rengarajan, A. (2025). Secured IIoT against trust deficit-A flexi cryptic approach. Multimedia Tools and Applications, 84(9), 5625-5652.

[34] Pandi Prabha, S., & Rengarajan, A. (2025, February). Decentralized Resource Allocation Model Using Multi-agent Reinforcement Learning for Cloud Environment. In International Conference on Universal Threats in Expert Applications and Solutions (pp. 71-82). Singapore: Springer Nature Singapore.

[35] Anbazhagan, K. (2024). Trustworthy and Adaptive AI Systems for Enterprise Analytics Cybersecurity and Decision Optimization Using API-First and Cloud-Native Architectures. International Journal of Technology, Management and Humanities, 10(03), 65-74.

[36] Gopinathan, V. R. (2025). AI-Powered Kubernetes Orchestration for Complex Cloud-Native Workloads. International Journal of Research Publications in Engineering, Technology and Management (IJRPETM), 8(6), 13215-13225.