World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

IoT-based smart water metering and quality checking system

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World Journal of Advanced Research and Reviews, 2025, 26(03), 1831-1842

Publication history: Received on 09 May 2025; revised on 14 June 2025; accepted on 16 June 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.3.2277

Abstract

Water scarcity is a critical global issue that demands coordinated efforts at all levels to ensure sustainable management and equitable access. A country's water utility relies on a well-functioning distribution system, which includes water sources, treatment plants, reservoirs, pipelines, and consumers. Effective management requires consideration of water availability, quality, quantity, and reliability. As scarcity intensifies, strict regulation and accountability become essential. Various frameworks have been developed to automate different stages of water distribution. Emerging technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), and Information and Communication Technology (ICT), play a key role in monitoring, analyzing, and managing water distribution networks. This study explores the impact of IoT on water distribution by analyzing modern IoT-based designs, monitoring solutions, and control mechanisms. It introduces IoTA4IWNet, an intelligent IoT-driven water network that enables real-time monitoring, automation, and regulation of water distribution. By integrating smart sensors, the system ensures optimal water flow control, minimizes waste, and enhances efficiency. Cloud-based data analytics provide real-time insights into consumption trends, leak detection, and predictive maintenance, allowing proactive decision-making. A data-driven approach enhances infrastructure resilience, reduces operational inefficiencies, and promotes long-term sustainability. IoT-driven automation in water distribution not only improves efficiency but also ensures responsible water usage. This innovative framework supports global water conservation efforts and aligns with sustainability objectives. In conclusion, leveraging IoT, AI, and ICT creates an advanced, automated, and intelligent water distribution system that fosters sustainability, enhances resource efficiency, and addresses the global water crisis effectively.

Keywords: Temperature sensors; Temperature measurement; Water quality; Internet of Things; Cloud computing.

1. Introduction

The combination of human activity and environmental changes is making clean water a valuable resource. Water quality has declined due to unchecked industrial waste dumping, urbanization, and agricultural runoff. Thus, continuous water quality monitoring is essential, particularly for drinking water, to prevent health hazards and preserve public safety. Monitoring vital indicators like pH, turbidity, dissolved oxygen (DO), and biological oxygen demand (BOD) is crucial for assessing water quality and making educated decisions about water treatment and distribution. Despite technological advancements, interoperability problems in modern water control and monitoring systems arise from the lack of standardization in monitoring and controlling devices. This problem affects several aspects of water management, including distribution, consumption, equipment maintenance, and system identification. Distinct monitoring systems with inconsistent procedures lead to inefficiencies in data collection, processing, and reaction mechanisms. This research project aims to educate consumers about the water supply so they may understand water loss, take appropriate action, and contribute to developing an accountable, open, and efficient water distribution system. These innovative techniques enable proactive water conservation and distribution optimization. Conventional methods of monitoring water quality include both laboratory-based analysis and manual sample collecting. However, because they

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are labour-intensive, costly, time-consuming, and do not yield results instantly, these approaches are ineffective in addressing urgent water quality problems. The proposed project aims to overcome these limitations by developing an automated water distribution and flow monitoring system with IoT-enabled sensors. The system incorporates infrared and ultrasonic sensors at strategic locations to efficiently regulate water delivery. These sensors help control the water flow by identifying the presence of users. By responding to demand automatically, smart taps significantly reduce water wastage caused by human negligence. This study suggests a smart water meter reading system based on the Internet of Things (IoT) to monitor and measure water use in gated community blocks and individual apartment complexes. The device accurately captures the amount of water used in each unit and uses preset tariff structures to calculate volumetric pricing. The collected data is then transferred to cloud platforms, which enable real-time monitoring and analysis of consumption patterns. Using IoT technology, users and authorities can detect anomalies such as leaks or excessive use, gain valuable insights into water usage trends, and take proactive measures to enhance water conservation. Ultimately, this strategy promotes equal billing, supports sustainable water management practices, and reduces waste—all of which enhance environmental sustainability and resource efficiency. Focusing on the advancements and challenges to implementing IoT-based solutions, we investigate the role and scope of state-of-the-art monitoring and control systems in water distribution networks in this study. We look at the current status of water distribution networks, providing important background information on their operational efficiency, limitations, and areas that require improvement. Additionally, we look at various IoT architectures for intelligent water management, emphasizing how they impact real-time monitoring, data-driven decision-making, and automated control. We discuss in detail one such framework, the IoT Architecture for Intelligent Water Networks (IoTA4IWNet), highlighting its potential to enhance the efficiency of water distribution networks, detect anomalies, and distribute resources as effectively as feasible. Finding significant technological advancements that can improve sustainability and water conservation is the aim of this study. This article aims to develop a dependable water quality monitoring system that would enable real-time water condition evaluation with the aid of IoT technology. The system continuously monitors turbidity, temperature, pH, and dissolved oxygen levels, among other water quality parameters, using a network of sensors placed carefully throughout water basins and agricultural areas. The sensors' Wi-Fi connectivity allows for seamless data transfer. The collected data is sent to a centralized Cloud database via the MQTT protocol across a TCP/IP network for secure processing, analysis, and storage. Through the use of cloud computing, the system gives stakeholders, farmers, and authorities remote access to real-time water quality data. This enables them to detect contamination, monitor trends, and make informed decisions for effective water management and conservation. A sensor-based, Internet of Things-based solution that serves as an automated water distributor and flow monitoring system is provided by the proposed work. The system has been built with ultrasonic and infrared sensors at key points to control the water distribution. Because the system is fully automated, it provides a solution to the requirement for hygienic practices to prevent disease infection during pandemic scenarios. This project's goal is to create and assess a practical data collection technique that considers energy consumption for Internet of Things-based smart metering applications. The system's components include water flow sensors, an Arduino Uno, and a Wi-Fi-ESP8266. An efficient water meter data collection algorithm (EDCDWM) is employed to reduce the number of packet transmissions. For efficient water management, supply, and monitoring, an Internet of Things-enabled water distribution system is recommended. Due to the expansion of urban residential areas brought on by population increase, water has become a key issue that affects problems with water distribution, interrupted water supply, conservation, and consumption.

2. Literature Review

Automated control, remote access, and real-time monitoring have all been greatly enhanced with the use of IoT technologies in water management. Through cloud-based systems and mobile applications, IoT allows users to monitor water levels, flow rates, and quality metrics. Kumar et al. (2021) To detect water levels in real-time, an ultrasonic sensor was used to develop an Internet of Things-based water level monitoring system. The sensor allowed for remote monitoring and viewing by sending data to a cloud-based application. The system's automated pump control prevented overflow and waste by turning on the pump when water levels were low and turning it off when ideal levels were attained. Additionally, it ensured effective water management and prompt intervention by providing immediate alerts via SMS or smartphone notifications in the event of critically low water levels. Patel et al. (2020) To monitor usage trends and identify leaks in real-time, an Internet of Things-enabled water distribution monitoring system was implemented. The system gave customers comprehensive insights into water usage through the use of smart sensors and cloud-based analytics, assisting in the identification of inefficiencies and unusual consumption. Users were informed of possible leaks via automated warnings, which allowed for prompt action to stop waste. The system improved water conservation efforts by encouraging responsible usage and optimizing delivery. It is a useful solution for homes, businesses, and governments seeking sustainable water distribution because of its data-driven strategy, which guarantees improved resource management. Sharma and Gupta (2019) For real-time water management, an Arduino and Wi-Fi module-based cloud-integrated smart water monitoring system was suggested. The technology sent data to a cloud platform for analysis while continually monitoring water flow. It provided customers with immediate smartphone notifications in the event of abnormal flow conditions, allowing them to act quickly. This proactive strategy assisted in preventing leaks, inefficiencies, and water waste. The system was a dependable solution for intelligent water management in homes, businesses, and agricultural applications since it made use of cloud and IoT technologies to guarantee effective resource usage and remote accessibility. According to this research, IoT-based monitoring greatly improves accessibility and efficiency in water management, minimizing manual intervention and maximizing water use. To avoid overflows and dry runs in storage tanks, water level monitoring is essential. Modern sensor-based technologies offer real-time precision, while traditional float-based monitoring methods are unreliable. Ramesh et al. (2018) To effectively control water levels, a float sensor-based automatic water level controller was created. By automating pump operations according to water levels, the system avoided dry runs and overflow. Its absence of remote access and real-time notifications, however, restricted user control and proactive administration. Monitoring, remote accessibility, and timely notifications could all be enhanced with IoT connectivity. Choudhary et al. (2021) To automate water management, a water level detecting system based on ultrasonic sensors was put into place. A microprocessor received real-time data from the sensor measuring water levels, analysed the data, and adjusted the water pump accordingly. To ensure effective water use, the pump was switched on when the water level fell below a certain threshold and turned off when the ideal level was attained. Ahmed et al. (2022Capacitive level sensors and the Internet of Things were added to the system to increase its accuracy and efficiency. Accurate water level readings were supplied by these sensors, and real-time data transfer to a cloud platform was made possible by IoT connectivity. Through a smartphone app, users could remotely check water levels and get real-time alerts and insights for proactive management. Better automation, less waste, and better use of water resources were all guaranteed by this modification. According to this study, sensor-based water level measurement is far more effective than conventional techniques, and usability is further enhanced by IoT connection. Finding leaks and excessive use requires the detection of irregular water flow. Flow sensors are essential for monitoring water consumption and avoiding needless waste. Mishra and Verma (2019) A flow sensor was used to monitor the input and output water flow in a water leak detecting system. Continuous flow rate measurements were made by the system, which looked for variations that would point to leaks. Users were immediately notified by an alarm that was set off when a large divergence was detected. This proactive strategy ensured effective resource management, minimized damage, and stopped water waste. Singh et al. (2020) To track daily usage in real-time, an Internet of Things-based water consumption tracking system was implemented. The system gave consumers comprehensive daily statistics by gathering and analysing data on water consumption. To reduce waste and encourage conservation, it also sent out alerts for excessive usage. The system's integration of IoT allowed for effective water management and provided insights for improved resource use in cities, businesses, and homes. Khan et al. (2021) To analyse historical water usage and forecast leakage patterns, a smart water meter was created utilizing IoT and AI. The technology reduced water waste by enabling early leak diagnosis through anomaly detection. Predictive analytics and real-time monitoring increased productivity, guaranteeing proactive water management for businesses, governments, and homes. These studies demonstrate that flow sensors and IoT platforms may effectively identify leaks and distribute water more efficiently, improving conservation efforts. To ensure safe consumption and avoid contamination, water quality assessment is essential. To ensure that safety regulations are followed, pH sensors are frequently employed to measure the acidity or alkalinity of water. Gupta et al. (2019) To guarantee water quality, a pH-based water monitoring system was put in place that can identify pH variations in real-time. To allow for prompt intervention, the system continuously monitored pH levels and sent out notifications when readings fell below a safe threshold. This guaranteed safety and assisted in avoiding the use of tainted water. However, remote access and historical data analysis were limited by the system's lack of cloud integration. By enabling data logging, trend analysis, and remote monitoring, IoT and cloud connectivity could improve its functionality. With this enhancement, customers would be able to monitor water quality over time, get notifications from any location, and take more effective preventative action. Jadhav and Sharma (2020) To detect pH levels in real-time, a smart water quality monitoring device with Internet of Things capabilities was created. The technology sent data to a cloud platform while continuously analysing the quality of the water. Users received immediate notifications if anomalous readings were found, allowing for a prompt response. For homes, businesses, and municipal water supplies, this strategy increased monitoring effectiveness, guaranteed proactive management, and improved water safety. Desai et al. (2021) Turbidity and pH sensors were added to the system to improve it and provide a complete water quality monitoring solution. This update made it possible to measure acidity and clarity in real-time, yielding more precise evaluations. To increase resource monitoring, proactive management, and water safety, users received immediate alerts for anomalous values. This study emphasizes how important pH monitoring is to preserving safe water conditions, and how IoT-based solutions are more dependable than traditional techniques because they provide real-time tracking and alarms. To ensure effective water use and lower electricity use, water pump automation is essential. Automatic switching based on user requests and tank levels is made possible by relay-based pump control systems. Kumar and Das (2018) To effectively control water levels, an Arduino-based automatic water pump controller was used. By automating pump operation based on preset thresholds, the device decreased the need for manual intervention. Its absence of remote access capabilities, however, restricted user control and oversight. By facilitating remote operation and real-time status updates, IoT integration may improve functionality. Verma et al. (2020) Through the integration of IoT and mobile control, the system was improved, allowing users to remotely monitor and manage the water pump through a mobile application. Better water management was made possible by real-time data updates, and prompt intervention was guaranteed by rapid notifications. By enabling remote pump activation and deactivation from any location, this update increased convenience, effectiveness, and resource conservation. Raj et al. (2021) By incorporating machine learning algorithms that examined user usage patterns to forecast the best pumping periods, pump automation was further enhanced. The technology effectively modified pump operations to reduce energy usage and water waste by learning from historical data. This anticipatory method avoided needless pumping while guaranteeing water supply when needed. Users profited from less manual intervention due to automated, data-driven decision-making. The updated system improved water resource management for homes and businesses in terms of efficiency, convenience, and sustainability when paired with IoT and mobile control. This study demonstrates that IoT-based automation greatly increases energy efficiency and gives water distribution more control. For Internet of Things-based water monitoring devices to function effectively, a steady power source is essential. Regulation of voltage guarantees the dependable operation of every component. Shah and Nair (2019) The development of a DC-DC step-down converter ensured a steady power supply for sensors and microcontrollers by regulating the voltage from 30V to 12V, 5V, and 3.3V. Effective voltage regulation was supplied by the converter, avoiding variations that would impair system functionality. It was perfect for embedded systems, automation projects, and Internet of Things applications that needed dependable multi-level power distribution because of its small size and great efficiency. Mehta et al. (2021) Pump control algorithms could be optimized to increase energy efficiency, according to a study on power usage in automated systems. Energy waste was decreased through better scheduling and adaptive operation, guaranteeing more economical and sustainable system performance'/"" in a range of automation and Internet of Things applications.

Table 1 Literature Review Table

S.no	Title	Author and year	Merits	Demerits
1.	Smart Water Meter Monitoring System using Internet of Things	Abinaya K et.al (2024)	The system provides real-time water quality and usage data, allowing quick action. It improves water safety by monitoring pH and turbidity, not just flow like regular smart meters. Solenoid valves and IoT-based billing automate water control and payments. IoT and cloud platforms like ThingSpeak enable remote water usage monitoring, reducing manual work. An RFID-based recharge system makes water management easy and convenient for users.	Continuous internet access is required for real-time monitoring, which may be a challenge in remote areas. RFID payments, cloud storage, and IoT sensors increase costs and require technical knowledge. The system monitors pH and turbidity but does not detect contaminants like germs or heavy metals. Sensors need regular recalibration to maintain accuracy, leading to potential maintenance issues. Storing user data on the cloud poses risks of cyberattacks or unauthorized access.
2.	Low-Cost Internet-of-Things Water-Quality Monitoring System for Rural Areas	Razvan Bogdan, Camelia Paliuc, Mihaela Crisan-Vida, Sergiu Nimara, Darius Barmayoun (2023)	The paper introduces a low-cost IoT system with affordable sensors and microcontrollers, ideal for rural areas. It tracks water quality in real-time, measuring pH, turbidity, and TDS through a mobile app. The mobile app makes it easy for non-technical users to access water-quality data. The system's modular design allows customization and the addition of extra sensors. By providing water quality updates, it helps prevent health risks from contaminated water.	The system tracks basic water quality (pH, turbidity, TDS) but misses heavy metals and microbes. Bluetooth-based data transmission has a limited range, making it unsuitable for large areas. Low-cost sensors may be inaccurate and need frequent recalibration for reliability. It lacks AI-powered features like anomaly detection or automatic contamination alerts. The study is based on a small-scale test, limiting its application to wider areas.
3.	Internet of Things (IoT) based Model for Water Management System	Md. Alimul Haque et.al. (2023)	IoT sensors track water quality in real-time, helping prevent contamination. The system automatically stops and redirects contaminated water for filtration. Users get instant water quality alerts through a mobile app for easy access. Affordable components like Arduino make it suitable for homes and industries.	The system monitors pH, temperature, and turbidity but lacks sensors for heavy metals and bacteria. Internet disruptions can affect real-time monitoring and control. Initial setup and maintenance of sensors and IoT components require significant investment.

			Water level monitoring and auto shut-off prevent overflow and water waste.	Low-cost sensors may have accuracy issues, needing frequent recalibration. The study is based on a prototype; real-world challenges need further testing.
4.	System for Water Quality Monitoring and Distribution	D. Nirmala et.al. (2023)	IoT sensors continuously monitor water quality for early contamination detection. Automated distribution adjusts water flow based on quality, optimizing usage. Thermal imaging and acoustic sensors help detect and reduce water leaks. IoT stores and displays real-time data on a mobile app for easy access. The system is useful in homes, schools, hostels, and rural areas for better water management.	The system monitors pH, turbidity, and flow but lacks sensors for heavy metals and bacteria. Microcontrollers and wireless modules consume energy, making continuous use costly. Stable internet is needed for effectiveness, which may be an issue in remote areas. Maintaining IoT devices and sensors requires technical skills, posing challenges for users. Real-world testing is needed to confirm effectiveness in different environments.
5.	Smart Water Management System	Julius Femi Godslove (2022)	The system accurately measures household water use, ensuring fair billing. Real-time monitoring helps consumers reduce wastage and manage water sustainably. IoT smart meters automate billing, reducing manual work and errors. It detects leaks by spotting unusual water flow patterns, preventing water loss. Cloud platforms enable real-time tracking, data storage, and remote access.	The high costs of smart meters and sensors may make them less affordable for some communities. Stable internet is needed for cloud monitoring, which can be a challenge in remote areas. Smart meters require regular maintenance and may have sensor accuracy issues. Cloud storage and IoT communication pose risks of cyber threats and data breaches. Some people may resist switching from traditional billing due to a lack of awareness.
6.	Design of smart water metering, flow Control and quality measurement using IoT communication	Sk Ibrar Ahmed et.al (2022)	The system measures water flow, monitors quality, and controls distribution for efficient use. IoT enables real-time tracking of water consumption and quality through cloud services. Solenoid valves automate water flow control, preventing excess usage and wastage. TDS sensors check water purity, ensuring a safe water supply for consumption.	The system measures TDS and flow but lacks monitoring for bacteria, heavy metals, and chemicals. Stable internet is needed for real-time monitoring, which may be challenging in remote areas. IoT setup requires significant investment and regular sensor maintenance for accuracy.

7.	Smart water meter for automatic meter reading	An Amir et.al (2022)	The system removes the need for manual meter reading, reducing labour costs and errors. Consumers can set water limits, encouraging conservation compared to traditional meters. IoT enables real-time data access via web servers and mobile apps for instant insights. The system ensures accuracy with a minimal measurement error of just 0.03 litres.	Poor internet access can affect the system's functionality in some areas. The smart meter measures water flow but does not monitor water quality. High installation costs and technical complexity come with integrating multiple components. Flow sensors may lose accuracy over time, requiring regular calibration.
8.	IoT-based smart water quality monitoring system	Varsha Lakshmikantha et.al (2022)	The system monitors pH, turbidity, conductivity, and temperature for reliable water assessment. IoT enables continuous monitoring and real-time data access via cloud servers. It is affordable and suitable for both urban and rural areas. Early contamination detection allows quick action to prevent health risks.	The system lacks monitoring for heavy metals and microbial contamination. Stable internet is needed for real-time updates, which may be a challenge in remote areas. Sensors may lose accuracy over time, requiring regular recalibration.
9.	IoT-Based Water Quality Monitoring System for Rural Areas	Ali Hadi Abdulwahid et.al (2020)	The system monitors pH, turbidity, conductivity, and temperature for early contamination detection. IoT and cloud computing allow users to track water quality remotely. It is affordable and suitable for rural areas with budget constraints.	The system lacks sensors for heavy metals, microbial contamination, and toxic chemicals. A stable internet connection is required, which may not always be available in remote areas. Sensors need regular recalibration and maintenance to ensure accurate readings.
10.	Intelligent Water Distribution and Management System using the Internet of Things	Mr. M. Srihari (2018)	IoT-based control valves and flow sensors ensure equal water distribution and minimize wastage. Flow sensors detect leaks at different pipeline points, preventing unnecessary water loss. A pH sensor monitors water quality in real-time, ensuring safe consumption. Authorities can manage water distribution remotely using cloud-based IoT platforms, reducing.	The system requires a stable internet connection, which may not be available in remote areas. It only measures pH and lacks monitoring for other key water quality parameters. The use of IoT and cloud infrastructure increases costs and requires regular maintenance.

3. Comparative result analysis and discussion

3.1. Efficiency

The efficiency of an **IoT-based water metering and quality-checking system** refers to how effectively smart sensors and real-time data are used to monitor and manage water consumption and quality. An efficient system simplifies water management by ensuring accurate measurement, detecting leaks, preventing excessive usage, optimizing distribution, and reducing operational costs.

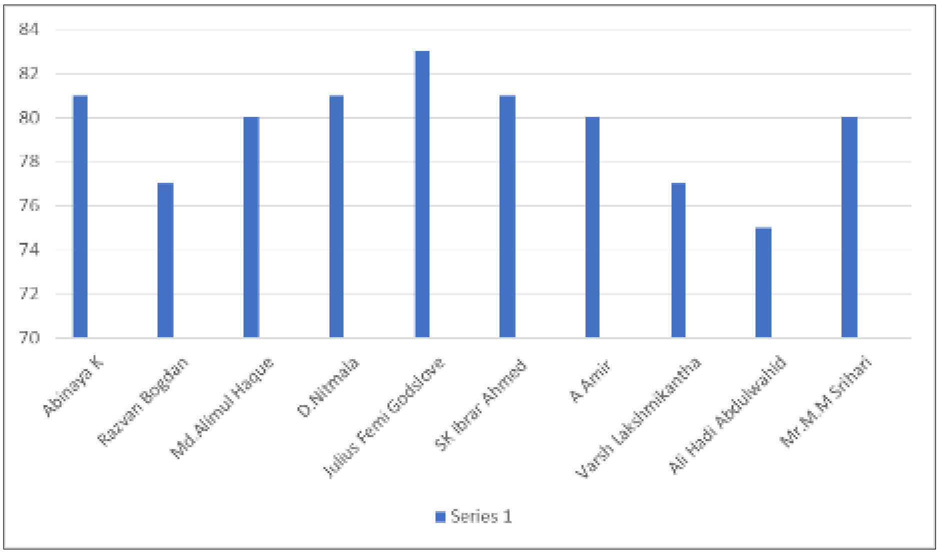

Figure 1 Comparison of system wise Efficiency Analysis

3.2. Efficiency of water metering system

The efficiency of a water metering system is determined by its accuracy in measuring water consumption, real-time monitoring capabilities, and ability to prevent water wastage. An efficient system ensures precise billing, detects leaks early, optimizes water usage, reduces manual intervention, and enhances overall resource management. Factors such as sensor accuracy, data transmission reliability, and ease of integration with IoT and cloud platforms influence its effectiveness.

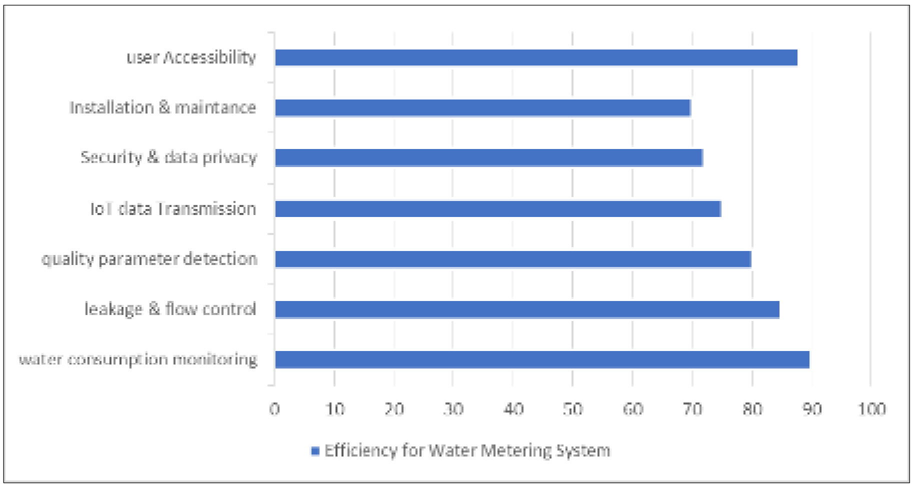

Figure 2 Efficiency for water metering system

4. Conclusion

Efficient water management is a growing necessity in both residential and industrial settings. Traditional water monitoring methods often lead to unnecessary wastage, inadequate water supply, and a lack of real-time awareness. The IoT-based Water Tank Monitoring System developed in this project provides an advanced, automated, and user-friendly solution to address these challenges. This system successfully integrates Arduino Uno, flow sensors, level sensors, pH sensors, relays, an LCD, a buzzer, and IoT technology to provide a real-time, automated, and remote-controlled water monitoring system. The level sensor ensures that water levels are constantly monitored, preventing overflow and dry-run scenarios. The flow sensor detects abnormal water consumption, helping identify leaks and unnecessary wastage. The pH sensor ensures that the water quality remains safe for consumption. The relay-based automated pump control optimizes water usage by activating or deactivating the pump based on predefined thresholds. This eliminates manual intervention and reduces electricity consumption. Additionally, IoT integration allows users to monitor water levels, flow rates, and pH levels remotely through a mobile application. Instant alerts notify users of any low water levels, excessive consumption, or unsafe water quality, allowing timely action to prevent damage or wastage. A major highlight of this system is its power-efficient design, incorporating a stable power supply that converts 30V to 12V, 5V, and 3.5V, ensuring uninterrupted operation of all components. The implementation of a buzzer alert system further enhances safety by promptly warning users about critical water-related issues. By automating water distribution, enhancing water conservation, and ensuring real-time monitoring with IoT, this system significantly improves traditional water management practices. It enables cost savings, efficient water utilization, and proactive leakage detection, making it an ideal solution for smart homes, industries, and commercial applications.

4.1. Future scope

The project provides a strong foundation for further advancements in water management technology. Future enhancements may include:

- Multi-Tank Support – Expanding the system to monitor and control multiple tanks simultaneously.
- Advanced Water Quality Monitoring – Integrating turbidity, TDS, and temperature sensors for more comprehensive water analysis.
- AI-Based Water Consumption Prediction – Using machine learning algorithms to analyze usage patterns and optimize water distribution.
- Smart Home Integration – Connect with voice assistants like Google Assistant or Amazon Alexa for seamless control.
- Battery Backup System – Implementing a backup power supply to ensure system operation during power outages.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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