International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Review Article)

Survey on Smart Water Management System

Geetha N *, Midharshana S, Rahul Kanth S, Rooshitha Jemimah R and Swetha S.

Department of Information Technology,Coimbatore Institute of Technology, Coimbatore, India.

International Journal of Science and Research Archive, 2025, 17(01), 314-318

Publication history: Received on 21 August 2025; revised on 03October 2025; accepted on 06 October 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.17.1.2720

Abstract

Water scarcity has emerged as one of the most pressing global issues, with over 2 billion people currently lacking access to safe drinking water. By 2050, water demand is expected to rise by 20–30%, posing severe challenges for governments, industries, and communities worldwide. Traditional water management practices are reactive, labor-intensive, and inefficient, resulting in wastage, energy overuse, and inadequate monitoring of water quality. To overcome these issues, Smart Water Management Systems (SWMS) have emerged as an IoT-driven solution, integrating real-time sensors, wireless communication, cloud platforms, and analytics . These systems enable continuous monitoring, automatic pump control, leakage detection, and quality assessment. This paper presents a comprehensive survey of SWMS, covering their layered architecture, major research contributions, and global implementations. Case studies from the United States, Singapore, and India demonstrate the effectiveness of IoT-based frameworks in reducing wastage and improving efficiency . The paper also discusses future directions including Artificial Intelligence (AI), Machine Learning (ML), blockchain integration, and digital twins . Findings suggest that SWMS can play a critical role in achieving the United Nations Sustainable Development Goal 6 (Clean Water and Sanitation).

Keywords: Smart Water Management; IoT; Water Quality; Leak Detection; Cloud Computing; Sustainability

1. Introduction to smart water management

Water is an essential natural resource, vital for drinking, agriculture, sanitation, and industrial processes. However, climate change, rapid urbanization, and inefficient management have led to severe stress on global water resources [1]. According to the World Health Organization, one in three people worldwide does not have access to safe drinking water [2].

Urban regions face increasing challenges—Cape Town's "Day Zero" crisis in 2018 nearly depleted municipal reservoirs, while Indian cities like Chennai and Bengaluru struggle with groundwater depletion and erratic distribution [1]. Traditional systems, which rely on manual monitoring of tanks, delayed detection of leaks, and irregular quality checks, are insufficient for today's demands [3].

Estimates suggest that up to 40% of distributed water in developing countries is classified as Non-Revenue Water (NRW), meaning it is lost through leaks, theft, or inefficiency [1]. Such wastage also raises operational costs and energy consumption, especially in pumping systems [3].

Smart Water Management Systems (SWMS) represent a paradigm shift. These IoT-enabled solutions employ sensors, microcontrollers, wireless modules, and cloud platforms to automate monitoring and decision-making [4], [5]. They are capable of preventing overflow, detecting underground leaks, monitoring quality, and optimizing energy use through intelligent pump scheduling [3].

*Corresponding author: Geetha N

By bridging technology with sustainability, SWMS are being adopted in domestic households, agriculture, industries, and smart cities [7], [8], marking a step toward climate resilience and long-term resource efficiency [1].

2. Literature survey

Research into IoT-enabled water management has gained momentum worldwide. Several significant studies and projects are outlined below:

2.1. Smart Water Distribution Systems

A 2020 study in *IEEE Access* described the use of flow meters, TDS sensors, and depth sensors for ensuring fair distribution in municipal networks. Cloud integration was employed to provide analytics, billing, and usage reporting, which enhanced consumer transparency. In Barcelona, pilot projects demonstrated improved supply efficiency and reduced losses through smart distribution monitoring [3].

2.2. Smart Tank Management

An *IJERT 2021* paper proposed using ultrasonic sensors (HC-SR04) and laser sensors (VL53L0X) integrated with NodeMCU/Arduino to automate household and small-scale water pumps. The system connected to cloud dashboards like Adafruit IO for real-time monitoring and manual overrides. This framework successfully minimized tank overflows, reduced manual intervention, and improved water usage efficiency at the domestic level [4].

2.3. Smart Water Watch (SWMT)

A *Springer 2022* framework introduced a five-layer IoT-based smart water monitoring system using Arduino Uno R3, ESP32 Wi-Fi modules, ultrasonic sensors, and turbidity meters. MQTT was used for lightweight data transmission, while MongoDB and HiveMQ handled cloud-based data storage and processing. The study reported measurable outcomes, including an 18% reduction in water wastage and a 12% improvement in energy savings, proving the benefits of IoT-enabled water management [5].

2.4. IBM Smarter Water Project (Dubuque, USA)

IBM collaborated with the city of Dubuque, USA, to deploy smart meters and analytics dashboards as part of the Smarter Water Project. The findings showed that households reduced water consumption by nearly 15% after becoming aware of their usage patterns. This project highlighted the importance of consumer awareness and behavioral change in conservation strategies [6].

2.5. Singapore Smart Water Grid

Singapore's Public Utilities Board (PUB) implemented a nationwide smart water grid by deploying advanced pressure, flow, and leak-detection sensors. AI-driven analytics forecasted demand, optimized distribution schedules, and improved overall efficiency. This large-scale initiative positioned Singapore as a global leader in sustainable water management and demonstrated how strong governance and technology integration can achieve resilience in water supply [7].

2.6. Indian Smart Cities Mission

Under India's Smart Cities Mission, cities like Pune and Bengaluru piloted IoT-based water management networks. These projects included real-time leak detection, automated billing, and optimized pumping schedules. Although these pilots showed promising results, scaling them across India remains a challenge due to high implementation costs, infrastructure constraints, and varied urban conditions [8].

2.7. Comparative Insights:

Domestic systems, such as smart tanks, are generally low-cost, easy to implement, and well-suited for households, though they often have limited scalability [4]. In contrast, urban smart grids, such as Singapore's PUB initiative, require higher investment but enable wide-scale optimization supported by strong policy frameworks [7]. Industrial and agricultural systems offer potentially transformative benefits but demand robust connectivity and significant upfront investments to ensure effective deployment and long-term efficiency [5], [8].

3. Process explanation

The functioning of SWMS can be explained through a five-layer architecture:

3.1. Perception Layer (Sensing)

This is the foundation of SWMS where physical parameters are captured through sensors. Ultrasonic sensors such as HC-SR04 are widely used to monitor tank water levels, while laser sensors like VL53L0X provide more precise measurements for enhanced accuracy. Flow sensors are employed to track household or industrial water consumption patterns, whereas TDS and turbidity sensors measure water quality to ensure compliance with safety standards. Temperature sensors help assess environmental impacts on water resources. These sensors interface with microcontrollers such as Arduino, ESP32, and Raspberry Pi, which digitize and preprocess the data before transmission [4], [5].

3.2. Network Layer (Transmission)

Once data is collected, it needs to be reliably transmitted. Communication technologies such as Wi-Fi, Zigbee, LoRaWAN, and NB-IoT are widely adopted for this purpose. Wi-Fi is best suited for household and small-scale systems due to its convenience, while LoRaWAN and NB-IoT are optimized for city-wide or rural deployments, offering long-range connectivity with low power consumption. The MQTT protocol is frequently employed as it provides lightweight, efficient, and reliable data transfer across devices and cloud servers [9], [10].

3.3. Middleware Layer (Processing & Storage)

At this layer, data is processed, stored, and analyzed. Cloud platforms such as Adafruit IO, AWS IoT Core, MongoDB, and HiveMQ serve as the backbone for handling real-time data streams. These systems detect anomalies such as leaks or pipe bursts, enabling predictive maintenance and reduced wastage. They also perform demand forecasting by analyzing historical usage patterns, while simultaneously optimizing pump and valve operations to enhance energy efficiency. Security measures such as encryption and authentication are enforced at this stage to protect the integrity of the system and prevent unauthorized access [9], [10].

3.4. Application Layer (User Interaction)

This is the layer where end-users interact with the system. Mobile applications and cloud dashboards enable real-time monitoring of tank levels, consumption reports, and water quality updates. Alerts for overflow, leakage, or low supply can be sent to users instantly. The interface also provides features such as pump automation/manual control, billing information, and advanced analytics. By integrating interactive dashboards, users are empowered to make informed decisions about their water usage [3].

3.5. Business Layer (Decision & Optimization)

At the highest level, decision-makers such as policymakers, urban planners, and municipal authorities leverage insights generated by SWMS. These include predicting peak water demand, managing Non-Revenue Water (NRW), planning rainwater harvesting, and integrating sustainability practices into urban infrastructure. The data-driven insights derived at this stage directly influence governance strategies, resource allocation, and sustainable city planning [1].

3.6. Future goals

The next generation of Smart Water Management Systems will be shaped by advanced technologies and greater user involvement. Artificial Intelligence (AI) and Machine Learning (ML) will be used for anomaly detection through neural networks, demand forecasting using time-series analysis, and reinforcement learning for optimal pump scheduling [11].

Digital twins—virtual replicas of water distribution networks—will be adopted for simulation, optimization, and predictive maintenance, as already piloted in Singapore's PUB initiative [7]. Blockchain technology will provide transparent and secure billing mechanisms, enabling fraud prevention and trust in water transactions [12].

Furthermore, Natural Language Processing (NLP) and speech-based interfaces will allow users to control pumps and valves through voice commands, improving accessibility. Gamified dashboards and real-time conservation alerts will encourage behavioral change, motivating consumers to adopt sustainable water usage practices [3].

4. Conclusion

Smart Water Management Systems (SWMS) represent a transformative approach to addressing water scarcity, wastage, and declining water quality. By integrating IoT sensors, wireless networks, cloud-based analytics, and Artificial Intelligence, these systems enable real-time monitoring, efficient distribution, predictive optimization, and enhanced user control.

Global case studies highlight their potential: the IBM Smarter Water Project in Dubuque demonstrated a 15% reduction in household water usage through consumer awareness; Singapore's PUB showcased large-scale efficiency through AI-driven analytics; and India's Smart Cities Mission explored real-time leak detection and optimized pumping in urban environments.

Despite these advancements, challenges remain in terms of affordability, interoperability between devices, and ensuring cybersecurity in IoT deployments. However, with continued innovation, SWMS are poised to play a central role in advancing the United Nations Sustainable Development Goal 6 (Clean Water and Sanitation), driving climate resilience and enabling the development of resource-efficient smart cities.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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