

Research on the Application of Internet of Things Technology in Intelligent Operation and Maintenance of Water Supply Plants in Mountainous Towns

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Received: 31 May 2026 / Accepted: 30 June 2026 / Published online: 2 July 2026

Abstract

Mountainous township water supply plants in southern Zhejiang generally suffer from scattered layout, difficult operation and maintenance, delayed water quality management, high pipe network leakage rate and insufficient digitalization level. Based on the practical operation and maintenance experience of Yuhu Water Supply Plant, this paper explores the whole-process application effect of Internet of Things (IoT) technology in township water supply. By adopting water quality sensing terminals, wireless transmission technology, PLC intelligent control and smart water cloud platform, an intelligent operation and maintenance system adapted to complex mountainous working conditions is constructed. The system realizes real-time monitoring, intelligent regulation and early warning disposal of water intake, water production, water storage and pipe network water supply. The results show that the IoT system significantly improves water quality safety guarantee capability, equipment operation efficiency, pipe network leakage control and energy-saving performance, and effectively solves various drawbacks of traditional manual operation modes. The research can provide practical references for the digital and intelligent upgrading of similar mountainous township water plants. cal foundation for optimizing industrial space policies and planning supply strategies.

Keywords: Internet of Things; Smart Water Affairs; Township Water Supply Plant; Intelligent Operation And Maintenance; Water Quality Management; Pipe Network Leakage Control

1. Introduction

With the continuous advancement of digital rural construction and urban–rural water supply integration, township water supply plants have become important infrastructure carriers for ensuring rural drinking water safety and improving grassroots public service capacity. Compared

with large urban water plants, township water supply plants usually face more complex operating environments, weaker technical support capacity, and more limited operation and maintenance resources. Therefore, promoting intelligent monitoring, automatic control, and refined management in township water supply plants is of great significance for improving water supply safety, reducing operation costs, and enhancing service quality. Existing studies have shown that IoT-based monitoring, intelligent scheduling, NB-IoT communication, PLC automatic control, and data platform integration can effectively support real-time perception, remote regulation, abnormal early warning, and operational decision-making in water supply systems (Pang, 2025; Tian & Wang, 2022; Yang & Wang, 2025; Zhang, 2023). In this context, the intelligent renovation of township water supply plants is not only a technical upgrading process, but also an important practical path for transforming grassroots water supply management from experience-based operation to data-driven governance.

Wencheng County is located in the mountainous area of southern Zhejiang Province, where township water plants are generally characterized by unstable raw water sources, long mountain-laid pipe networks, scattered and remote stations, difficult transportation access, and insufficient operation manpower. These geographical and managerial characteristics make water supply operation more vulnerable to sudden changes in water quality, equipment failure, pressure fluctuation, pipeline leakage, and energy consumption uncertainty. Yuhu Water Supply Plant of Wencheng Water Affairs Co., Ltd. is a typical mountainous township water supply plant. The plant serves 22 administrative villages in Yuhu Town, covering a permanent population of approximately 21,000 people, with a daily water production capacity of 3,500 cubic meters. It is equipped with complete water production facilities, a 47-kilometer mountainous water supply pipe network, and 12 remote booster pumping stations. Before the intelligent renovation, the plant mainly relied on manual inspection, manual regulation, and paper-based records, which made it difficult to achieve timely water quality warning, accurate equipment fault diagnosis, precise leakage control, and scientific energy consumption management. Similar studies have also pointed out that township and village water supply systems urgently need lightweight, low-cost, and practical IoT solutions adapted to dispersed facilities and complex grassroots management conditions (Lei & Cheng, 2024; Li, 2024; Liu, 2026; Yu & Li, 2026).

To address these operational bottlenecks, Yuhu Water Supply Plant launched an IoT-based smart water supply renovation project in 2023. The project introduced IoT perception, intelligent control, and big data analysis into the whole process of raw water intake, water production, disinfection, water quality monitoring, pump station operation, pipe network transmission, leakage control, and user-side metering. Through the deployment of online water quality sensors, flow and pressure monitoring terminals, NB-IoT communication devices, PLC automatic control systems, acoustic leakage detection equipment, and a unified data management platform, the plant gradually realized 24-hour online monitoring, remote control of key equipment, abnormal alarm push, and closed-loop maintenance management. International studies have also demonstrated that low-power wireless networks, autonomous IoT monitoring devices, acoustic sensing systems, and AI-assisted water management platforms can improve the reliability, sustainability, and response efficiency of water distribution systems (García-Martín et al., 2023; Okoli & Kabaso,

2024; Poudel & Mohammadi, 2026; Silva et al., 2025; Slaný et al., 2025). These findings provide technical support and comparative references for the intelligent transformation of small mountainous township water plants.

However, current research on smart water affairs at home and abroad still focuses mainly on large-scale urban water plants, urban distribution networks, and comprehensive smart water platforms. Relatively few studies have examined practical IoT renovation paths for small township water plants in mountainous areas, especially under constraints such as limited investment, dispersed facilities, weak communication coverage, and insufficient professional operation manpower. Based on the author's long-term front-line management experience as the person in charge of Yuhu Water Supply Plant, this paper systematically summarizes the application process, implementation effects, existing problems, and optimization strategies of IoT technology in a grassroots mountainous water supply project. The study aims to provide a practical and replicable reference for the intelligent renovation of township water supply plants, enrich the application cases of IoT technology in rural drinking water management, and support the digital transformation of county-level water enterprises under complex mountainous conditions.

2. Main Problems of Traditional Operation and Maintenance of Mountainous Township Water Plants

The traditional manual operation mode shows poor adaptability to mountainous water supply conditions and restricts the improvement of water service quality. In terms of water quality management, the raw water of mountainous water plants is mainly mountain surface water, which is vulnerable to rainfall, soil erosion and non-point source pollution, leading to frequent water quality fluctuations. Traditional manual sampling conducted only several times a day cannot realize 24-hour continuous monitoring, making it impossible to detect sudden water quality abnormalities in a timely manner. In addition, disinfection and coagulant dosing are completely adjusted by manual experience, resulting in inaccurate dosing volume, excessive or insufficient residual chlorine, and potential drinking water safety risks.

In terms of equipment operation and maintenance, the pumping stations and water supply equipment are widely distributed in remote mountainous areas. Traditional manual inspection is time-consuming and inefficient. The operating status and energy consumption data of water pumps, dosing devices and motors cannot be monitored in real time. Equipment overload, shutdown and agent shortage are often discovered belatedly, which easily causes water supply interruption. Moreover, equipment maintenance mainly relies on post-fault repair without predictive management, resulting in short service life and high energy consumption.

In terms of pipe network management, mountainous water supply pipe networks feature complex terrain, long pipelines and aging sections, with highly concealed hidden leakage and micro-leakage. Traditional manual meter reading and sectional investigation fail to monitor real-time pipe network pressure and flow, leading to delayed leakage detection and long repair cycles. The plant maintains a high water production and sales difference rate, causing serious waste of

water resources and operation costs. Meanwhile, traditional operation leads to fragmented data. Production, water quality, energy consumption and pipe network data are recorded on paper without integrated analysis and intelligent scheduling. Water supply regulation purely depends on manual experience, resulting in unstable water pressure and unreasonable resource allocation during peak water consumption periods.

3. Overall Architecture of IoT Intelligent Operation and Maintenance System for Mountainous Water Plants

In view of the inherent limitations of mountainous water plants, including weak network coverage, limited budget and complex terrain conditions, Yuhu Water Supply Plant has constructed a four-layer IoT intelligent operation and maintenance system, consisting of perception and collection layer, network transmission layer, edge control layer and cloud application layer. Abandoning complicated and high-cost traditional architectures, the system features low investment, strong environmental adaptability and convenient maintenance, which is highly suitable for the intelligent upgrading of grassroots mountainous water supply facilities.

3.1. Perception and Collection Layer

As the basic data acquisition unit of the intelligent system, the perception layer covers the whole key procedures of water production and pipe network water supply. Multi-parameter water quality sensors are deployed at water intakes, sedimentation tanks, clean water tanks and water delivery mains to collect real-time water quality indicators including turbidity, pH value, residual chlorine and dissolved oxygen. Operation monitoring modules are installed on water pumps and dosing equipment to dynamically acquire the operating current, voltage, frequency and real-time status of electromechanical equipment.

The entire water supply pipe network is divided into independent metering zones equipped with NB-IoT flow and pressure monitoring terminals. Liquid level sensors and safety monitoring devices are also deployed to realize comprehensive data collection of water quality changes, electromechanical equipment operation and pipe network operating conditions, covering all key monitoring nodes of the water supply system.

3.2. Network Transmission Layer

A hybrid communication architecture is adopted to adapt to complex mountainous environments. Industrial Ethernet is deployed in centralized plant areas to ensure low-latency data transmission and real-time equipment linkage control. For remote mountain pumping stations and pipe network monitoring points without wired network coverage, low-power NB-IoT wireless transmission technology combined with solar energy storage power supply systems is applied, effectively solving the difficulties of difficult wiring, insufficient power supply and unstable signal transmission in mountainous regions.

Furthermore, the system adopts encrypted data transmission and exclusive equipment authentication mechanisms to avoid data tampering and loss, ensuring the confidentiality, stability and integrity of water supply data during transmission.

3.3. Edge Control Layer

The edge control layer realizes local intelligent linkage control based on PLC controllers, avoiding operational risks caused by network delay of cloud remote control. According to real-time monitoring data of raw water quality, pipe network pressure and water tank liquid level, the system can automatically adjust dosing volume, water pump operating frequency and the number of operating units, achieving precise dosing, constant-pressure water supply and energy-efficient operation.

In addition, the system is embedded with a local fault self-protection function. When abnormal conditions such as equipment overload, excessive water quality indicators and drastic liquid level fluctuations occur, the system automatically triggers emergency responses including equipment shutdown and acousto-optic alarm to eliminate water supply safety hazards in the first place.

3.4. Cloud Application Layer

The cloud application layer is built on a lightweight smart water management platform compatible with both web and mobile terminals. It integrates core functions including real-time monitoring, intelligent early warning, data statistical analysis, full-life-cycle equipment management and automatic report generation. The platform visually displays the entire water production process and pipe network operating status, automatically pushes alarm notifications and generates operation and maintenance work orders once system abnormalities are detected.

The platform automatically summarizes and stores long-term operational data throughout the year, completely replacing the traditional manual paper-based recording mode and realizing comprehensive digitalization, visualization and intelligence upgrading of water supply operation and maintenance management.

4. Implementation Measures of IoT System

To minimize the impact of intelligent renovation on residents' daily water supply, the plant adopts a phased and peak-staggered construction scheme for IoT system upgrading. All construction work including equipment installation, circuit layout, terminal debugging and platform joint commissioning is arranged avoiding morning and evening water consumption peaks, with segmented and short-time night construction adopted. No large-scale or long-term water supply interruption occurred during the whole renovation period, which effectively guaranteed stable domestic water supply for local residents.

4.1. Optimized Equipment Selection Adapted to Mountainous Environments

Considering the harsh climatic and geographical characteristics of mountainous areas such as low temperature, high humidity and off-grid power supply in partial remote areas, all monitoring and control devices adopt industrial-grade equipment with waterproof, dustproof and low-temperature resistance performance. Solar energy storage power supply systems are configured for off-grid monitoring points, and self-cleaning components are installed for all water quality sensors. The optimized equipment selection effectively reduces equipment failure rate and daily

maintenance workload, and greatly improves the long-term operational stability of the system in complex mountainous environments.

4.2. Personnel Training and System Operation Guarantee

In view of the uneven digital operation capabilities of front-line staff, systematic and targeted practical training on intelligent system operation is carried out, covering daily equipment inspection, platform operation, fault diagnosis and disposal, as well as data query and statistical analysis. Simplified visual operation manuals are compiled, and one-on-one targeted guidance is provided for employees with weak digital operation skills. Standardized training ensures that all operation and maintenance personnel can independently complete daily system operation and fault handling, providing solid technical and talent support for the long-term stable and efficient operation of the intelligent system.

5. Analysis of System Application Effects

Since the full operation of the IoT intelligent operation and maintenance system for more than one year, the traditional manual operation mode has been completely transformed, achieving remarkable improvements in water supply safety, operation efficiency, energy conservation and leakage control. In terms of water quality guarantee, the system realizes 24-hour uninterrupted full-process water quality monitoring and intelligent dosing regulation, solving the problems of inaccurate manual dosing and delayed water quality monitoring. The annual qualified rate of finished water quality reaches 100%. All potential water quality abnormalities are disposed of timely, with zero water quality complaints and safety accidents throughout the year (Table 1).

In terms of operation and maintenance management, remote real-time monitoring replaces frequent full-scale manual inspections, greatly reducing human input. The manual inspection cost is reduced by 65%, and the fault detection time is shortened from 24 hours to within 10 minutes. Equipment shutdown and night water supply interruption are completely eliminated. Equipment maintenance is transformed from post-fault repair to predictive maintenance, significantly improving equipment stability and service life.

In terms of energy conservation and leakage control, intelligent variable-frequency regulation of water pumps and precise agent dosing effectively reduce water production energy consumption and chemical consumption. The unit water production power consumption is reduced by 11.5%, and agent consumption is decreased by 8%, saving more than 100,000 RMB in electricity and chemical costs annually. Supported by segmented pipe network monitoring data, multiple hidden mountain leakage points are accurately detected and repaired. The comprehensive pipe network leakage rate is reduced from 13.2% to 7.8%, effectively reducing water resource waste and improving water utilization efficiency.

In terms of digital management, the system automatically generates water quality, energy consumption and operation and maintenance reports, completely replacing manual paper recording. It significantly improves work efficiency, standardizes water supply management

processes, and meets the requirements of industry supervision and enterprise standardized management.

Table 1. Core operational indicator comparison before and after IoT system renovation

Evaluation Indicators	Before Renovation (2022)	After Renovation (2024)	Improvement Effect
Finished water quality compliance rate	97.6%	100%	Completely eliminate water quality non-compliance risks
Pipe network water leakage rate	13.2%	7.8%	Significantly reduce water resource waste
Unit water production power consumption	Baseline value	Reduced by 11.5%	Realize efficient energy-saving operation
Agent consumption for water production	Baseline value	Reduced by 8.0%	Avoid excessive chemical dosing
Manual inspection labor cost	High-frequency full-area manual inspection	Reduced by 65%	Greatly optimize human resource allocation
Average equipment fault discovery time	24 hours	≤10 minutes	Realize ultra-fast fault early warning
Manual paper recording workload	Full manual recording	100% automatic electronic report	Realize standardized digital management

6. Existing Problems and Optimization Directions

Restricted by mountainous geographical conditions, some extremely remote pipe network monitoring points suffer from weak signals and delayed data upload. In addition, the current system only relies on basic flow and pressure data for leakage analysis, resulting in limited identification accuracy of micro-leakage. Meanwhile, data interconnection with the group's general platform has not yet been realized. Targeted optimization and upgrading will be carried out in the future. Signal amplification equipment and long-distance communication terminals will be deployed to solve mountain signal instability. Acoustic leakage detection sensors will be added to optimize the leakage analysis algorithm and further reduce the pipe network water sales difference. The data interface between superior and subordinate platforms will be opened to realize unified data aggregation and global intelligent scheduling, so as to continuously improve the intelligent operation level of the water plant.

7. Conclusion

Taking the intelligent renovation of Yuhu Water Supply Plant as a practical case, this paper explores the application value of IoT technology in mountainous township water supply operation and maintenance. The practice verifies that the IoT operation and maintenance system adapted to mountainous working conditions can effectively solve the core pain points of traditional water plants, including insufficient water quality control capacity, low operation efficiency, high leakage rate, energy waste and non-standard management, realizing comprehensive improvements in water supply safety, operation efficiency, energy conservation and digital management with remarkable input-output benefits.

As a grassroots water management staff, I have fully participated in the scheme design, construction implementation and daily operation of the IoT system, and deeply recognized the enabling effect of IoT technology on the traditional water supply industry. Under the trend of digital water affairs development, township water supply plants should continuously promote intelligent upgrading relying on IoT and big data technologies, improve rural water supply guarantee capacity and refined management level, and provide solid technical support for urban-rural water supply integration and long-term stable rural drinking water safety.

Author Contributions:

Conceptualization, D. Z; methodology, D. Z and Y. D; investigation, D. Z; data collection and analysis, D. Z; writing—original draft preparation, D. Z and Y. D; writing—review and editing, D. Z and Y. D; project administration, D. Z. All authors have read and agreed to the published version of the manuscript.

Funding:

This research received no external funding.

Institutional Review Board Statement:

Not applicable.

Informed Consent Statement:

Not applicable.

Data Availability Statement:

The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflict of Interest:

The authors declare no conflict of interest.

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