# Research on the Application of Internet of Things Technology in Water Operation and Management of Mountainous Counties——A Case Study of Wencheng Water Affairs

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**Abstract**

Water supply in mountainous counties of southern Zhejiang is featured by scattered water sources, complex pipe network terrain, difficult operation and maintenance, and weak leakage control. The traditional manual operation and maintenance mode suffers from low efficiency, high cost and delayed safety management, which cannot meet the requirements of modern water operation management. Based on the operational practice of Wenzhou Public Utilities Development Group Wencheng Water Co., Ltd., this paper constructs a four-level smart water framework of “perception layer-transmission layer-platform layer-application layer” by adopting the Internet of Things (IoT) engineering technology system. Low-power IoT, edge computing and big data analysis technologies are deeply integrated into core businesses including water quality monitoring, pipe network leakage control, pump station energy consumption management and intelligent meter reading. In view of the shortcomings of mountainous water affairs such as weak communication conditions, difficult equipment operation and maintenance, and data islands, this paper proposes a lightweight and low-cost implementation optimization scheme. The practical results show that the application of IoT technology effectively reduces pipe network leakage rate and operational maintenance costs, realizes active early warning of water supply safety and digital upgrading of operation management, and significantly improves the refined operation level of water affairs in mountainous counties, which can provide a reference for the digital transformation of water affairs in similar mountainous areas.

**Keywords:** Internet of Things; Smart Water Affairs; Mountainous Water Supply; Leakage Control; Water Operation Management

## 1. Introduction

Wencheng County is located in the mountainous region of southern Zhejiang Province, where hills and mountains dominate the natural terrain. In this geographical context, water sources, village-level reservoirs, booster pump stations, and terminal water supply facilities are widely dispersed, while transmission and distribution pipelines are often laid along mountainous terrain, resulting in long pipeline routes, complex operating conditions, and high management difficulty. Wencheng Water Affairs is responsible for the operation and management of centralized urban and rural water supply across the county. Its operation department undertakes key tasks such as pipeline network operation and maintenance, water quality supervision, non-revenue water control, energy consumption management, and metering management. Compared with urban centralized water supply systems, mountainous county-level water supply systems face more prominent constraints, including scattered facilities, difficult site access, unstable communication environments, and insufficient power supply conditions. These characteristics make the traditional operation mode increasingly unable to meet the requirements of safe, efficient, and refined water supply management.

For a long time, water supply operation in mountainous areas has relied heavily on manual inspection, on-site sampling, and household meter reading. However, due to inconvenient transportation, scattered monitoring points, and limited inspection frequency in remote mountainous villages, problems such as water quality risks, hidden pipeline leakage, abnormal pressure fluctuation, equipment failure, and inaccurate metering are often discovered with delay. This not only causes water resource waste and increases labor and maintenance costs, but also weakens the emergency response capacity and service quality of water enterprises. With the development of the Internet of Things, NB-IoT, LoRa low-power communication, smart metering, real-time monitoring, and big data analysis technologies, smart water affairs has gradually become an important direction for the digital transformation of the water industry. Existing studies have shown that IoT-based systems can support real-time water quality monitoring, pressure and flow monitoring, leakage identification, smart metering, and intelligent water distribution management, thereby improving the operational efficiency and sustainability of water supply systems (Das & Jain, 2017; García-Martín et al., 2023; Kumar, 2025; Maroli & Narwane, 2020). In China, the publication of the Specification for Communication Protocol of Internet of Things for Smart Water Affairs also provides a technical basis for the standardized development of smart water IoT systems (GB/T 38637-2020, 2020).

Although smart water affairs has attracted increasing attention at home and abroad, existing research and applications are still mainly concentrated in urban centralized water supply and drainage systems. International studies have explored IoT-based smart water distribution networks, low-power wireless communication, real-time water quality monitoring, and Industry 4.0 technologies in urban water systems, providing useful technical references for intelligent monitoring and system optimization (García-Martín et al., 2023; Marchezan, 2026; Verma et al., 2025). Domestic research has also discussed NB-IoT-based pipeline monitoring, smart water construction in small and medium-sized cities, and the application challenges of smart water technologies in municipal water supply and drainage systems (Fu, 2023; Li, 2025; Yang, 2025).

However, mountainous county-level water supply systems differ significantly from urban systems in terms of spatial distribution, communication coverage, energy supply, maintenance capacity, and investment scale. Existing high-cost, full-coverage, and heavy-platform solutions are often difficult to apply directly to small-scale and scattered water supply scenarios in mountainous counties. Research on lightweight IoT deployment, low-cost sensing, low-power communication, and practical operation optimization for decentralized rural and mountainous water supply remains insufficient (Zhang, 2026).

Based on the operational practice of Wencheng Water Affairs, this study focuses on the application and optimization of IoT technology in mountainous county water supply scenarios. Theoretically, it responds to the research gap in existing smart water studies, which tend to emphasize urban centralized pipe networks while paying insufficient attention to decentralized and lightweight IoT applications in mountainous areas. It enriches the case-based research on county-level smart water affairs and expands the understanding of IoT engineering applications under complex terrain and dispersed facility conditions. Practically, the construction of an IoT-based smart water system can help improve leakage control, strengthen water quality supervision, reduce operation and maintenance costs, optimize energy and metering management, and enhance the safety guarantee capacity of water supply services. By examining the practical experience of Wencheng, this paper aims to provide a replicable and adaptable path for the digital upgrading of water enterprises in mountainous counties, especially in regions with similar geographical and operational conditions in southwestern Zhejiang.

## 2. Core Pain Points of Traditional Water Operation in Mountainous Areas

### 2.1. Inadequate Full-Coverage Monitoring and Passive Water Safety Management

The small water sources, village-level reservoirs and booster pump stations in Wencheng County are widely scattered in remote mountainous areas. In the traditional mode, key parameters such as water quality, water level and pipe network pressure are collected manually on a regular basis with low monitoring frequency and long intervals. The operation status of the water supply system cannot be grasped in real time, and hidden dangers such as water source pollution, pipe network leakage and reservoir overflow cannot be detected timely, resulting in prominent potential risks to water supply safety.

### 2.2. Severe Pipe Network Leakage and Difficult Production-Sales Difference Control

Affected by geological settlement, pipe aging and terrain fluctuation, hidden leakage of mountainous pipe networks occurs frequently. In addition, the pipe network covers a wide range with extremely low efficiency of manual patrol inspection. Tiny hidden leakage cannot be eliminated for a long time, leading to a high production-sales difference rate, massive invalid water resource loss and reduced corporate profit margins, which has become the core difficulty of water operation management.

### 2.3. High Manual Operation Cost and Lack of Data Support for Decision-Making

Traditional operation modes rely on a large number of manual work including inspection, meter reading, water quality sampling and pump station duty, with high labor investment and low efficiency. Remote pump stations have no 24-hour on-duty personnel, and water supply load adjustment and equipment scheduling rely entirely on managers' experience without real-time data support. The dynamic optimization of pump energy consumption and dosage cannot be realized, resulting in high production and operation costs.

### 2.4. Isolated Business Systems and Serious Data Islands

Before the transformation, independent systems including factory automatic control, pipe network account and business charging adopted inconsistent communication protocols with no data interconnection and sharing. The Operation Department needed to manually summarize data across multiple systems for production-sales difference accounting, cost analysis and report statistics, which was time-consuming and error-prone, making integrated digital operation management impossible.

## 3. Design of IoT System Architecture for Mountainous Water Affairs

Combined with the characteristics of mountainous water supply in Wencheng, the company builds a smart water IoT system adapted to low-power, long-distance and weak-signal scenarios, adopting the industry-standard four-level architecture of perception layer, transmission layer, platform layer and application layer, which balances construction cost and operation practicability.

### 3.1. Perception Layer: Deployment of Full-Coverage Data Collection Terminals

As the core data source of the system, the perception layer deploys differentiated IoT terminals for various water supply scenarios. Water quality, liquid level and flow sensors with solar power supply are arranged at water sources to adapt to mountainous sites without municipal power supply. Energy consumption and equipment operation monitoring terminals are installed in water plants and booster pump stations to realize remote regulation of water pumps and electric valves. Pressure, flow and acoustic leakage monitoring devices are deployed at key pipe network nodes to realize DMA partition metering. Integrated monitoring equipment is installed in village-level reservoirs to monitor water level and water quality in real time. NB-IoT smart water meters are gradually popularized across the region to realize automatic collection of user water consumption data. All terminals adopt national standard communication protocols to ensure equipment compatibility.

### 3.2. Transmission Layer: Multi-Mode Hybrid Networking Transmission

To solve signal blind spots caused by mountain and forest occlusion, a hybrid networking mode of LoRa and NB-IoT is adopted. LoRa base stations provide low-power and long-distance signal coverage for remote mountainous sites with weak network conditions and no municipal power supply. NB-IoT narrowband IoT is applied in urban and township core areas to ensure stable data transmission. Optical fiber transmission is adopted for core stations, and edge gateways realize local data cleaning, caching and compressed transmission, avoiding data loss caused by mountainous network fluctuations and building a stable cloud-edge collaborative transmission system.

### 3.3. Platform Layer: Big Data Smart Water Platform

As the core hub of the system, the platform layer undertakes data access, governance, storage and intelligent analysis. It converges multi-source data such as water quality, pipe network, energy consumption and water metering through unified data interfaces, automatically cleans and calibrates abnormal data, and realizes standardized data management. The platform is equipped with AI algorithms for leakage identification, water quality early warning and energy consumption optimization, which can automatically judge equipment operation status and water supply risks. It also integrates equipment management functions to monitor terminal online status and faults in real time, providing data support for operational management.

### 3.4. Application Layer: Professional Business Modules for Water Operation

Based on the core work of the Operation Department, multi-dimensional business application modules are built, including water quality traceability, pipe network leakage control, pump station energy consumption scheduling, smart meter reading and revenue management, equipment operation and maintenance management, and operational data analysis. It realizes full-process visual and intelligent management of water supply, meeting the daily needs of operation and maintenance, cost control, data analysis and emergency disposal.

## 4. Core Application of IoT Technology in Water Operation

### 4.1. Full-Process Intelligent Water Quality Monitoring to Ensure Water Supply Safety

IoT sensors build a 24-hour online monitoring system covering the whole chain of “water source-water plant-reservoir-user terminal”, collecting core water quality indicators such as turbidity, pH value and residual chlorine in real time. The system will trigger pop-up window and SMS dual early warnings when data is abnormal, enabling managers to quickly locate hidden danger points and remotely adjust equipment operating parameters. The traditional 24-hour manual disposal time is shortened to 15 minutes. Meanwhile, the system can automatically optimize the dosing process of water plants according to fluctuations in raw water quality to stabilize finished water quality. All data is automatically archived, greatly reducing manual ledger work and ensuring 100% qualified water quality in the whole region.

### 4.2. Precise Pipe Network Leakage Control Based on Partition Metering and Intelligent Sensing

Based on the IoT DMA partition metering system, flow monitoring terminals are deployed at the inlet and outlet of township pipe networks to compare regional inflow and outflow data in real time. Combined with pipeline acoustic sensing equipment, underground hidden leakage points can be accurately located. The AI algorithm automatically calculates the regional leakage rate and generates maintenance work orders for closed-loop management, completely changing the traditional blind manual inspection mode. After the transformation, the comprehensive pipe network leakage rate of the company has been significantly reduced, effectively reducing invalid water resource loss, cutting water production and operation costs, and achieving the assessment goals of production-sales difference control.

As shown in Table 1, the application of IoT partition metering and acoustic leakage detection technology has achieved quantitative and remarkable improvement in water supply management efficiency, leakage control and emergency response capability, forming a replicable intelligent leakage governance model for mountainous water supply.

**Table 1. Improvement Effects of IoT-Based Intelligent Leakage Control in Mountainous Water Supply Pipe Networks**

| Indicator | Before IoT Transformation | After IoT Transformation | Optimization Effect |
|---|---|---|---|
| Comprehensive Pipe Network Leakage Rate | 16.8% | 12.6% | Reduced by 4.2% |
| Manual Pipe Inspection Workload | Full manual patrol coverage | Partial intelligent inspection | Reduced by 65% |
| Water Quality Abnormal Response Time | 24 hours | 15 minutes | 99% time reduction |
| Annual Invalid Water Loss | High continuous loss | 180,000 tons saved annually | Great water resource conservation |

### 4.3. Intelligent Pump Station Scheduling to Reduce Production Energy Consumption

After the intelligent IoT transformation of mountain booster pump stations, the system can automatically adjust the pump frequency and operating conditions according to real-time pipe network pressure and water load data, realizing peak-load shifting and energy-saving operation. The equipment load is reduced during low water consumption periods and pressure is stabilized in advance during peak periods, replacing the traditional manual duty and experience-based scheduling mode. It not only stabilizes pipe network water supply pressure, but also greatly reduces pump station power consumption, and cancels night duty in remote stations, saving a lot of labor and energy costs.

### 4.4 Full Coverage of Smart Water Meters for Efficient Revenue Management

The fully popularized NB-IoT smart water meters support automatic remote meter reading and data uploading, realizing automatic water fee accounting and completely eliminating manual household meter reading work. The built-in water consumption anomaly identification model can accurately identify water theft, private pipeline connection and abnormal water use, reducing water fee loss. Meanwhile, remote valve closing and arrears management functions effectively improve water fee recovery efficiency and the refinement level of revenue management.

### 4.5. Digital Data Analysis to Support Scientific Operational Decision-Making

The IoT data platform breaks cross-system data barriers, automatically summarizes core operational indicators such as production-sales difference, energy consumption, water quality and operation cost, and generates visual dashboard and monthly operational reports. Relying on real-time and historical data, the Operation Department can accurately locate areas with high energy consumption and high leakage, formulate targeted schemes for pipe network transformation, equipment renewal and cost control, and promote the transformation of water operation from empirical decision-making to data-driven scientific decision-making.

## 5. Construction Difficulties and Optimization Countermeasures

### 5.1. Core Construction Difficulties

Firstly, the mountainous area has complex communication conditions with weak signals in remote sites due to mountain and forest occlusion, and the power supply stability of equipment without municipal power is insufficient. Secondly, scattered mountainous monitoring points lead to high one-time investment in full-scale IoT transformation with a long capital return cycle. Thirdly, equipment from multiple manufacturers has inconsistent protocols, resulting in difficult data docking; in addition, professional IoT operation and maintenance personnel are scarce in mountainous areas, leading to low efficiency of equipment fault disposal. Fourthly, the humid and variable mountainous environment easily causes sensor data drift, resulting in data distortion and judgment deviation.

### 5.2. Optimization Countermeasures

In view of the above difficulties, the company adopts a lightweight phased transformation scheme, prioritizing the upgrading of core pipe networks and key water source points, and gradually promoting full-scale transformation. Special financial subsidies are applied to alleviate capital pressure. LoRa base station signal compensation and photovoltaic energy storage power supply are adopted to solve mountainous signal and power supply problems. Unified equipment access protocols and technical standards are formulated to avoid data docking barriers. An internal part-time operation and maintenance team is established, with regular professional training jointly conducted by manufacturers to build a grid-based operation and maintenance mechanism. Meanwhile, a data security protection system is built through data encryption, authority grading and regular equipment calibration to ensure the authenticity, safety and effectiveness of IoT data.

## 6. Application Effects, Prospects and Conclusion

The implementation of the IoT-based smart water system has brought comprehensive and remarkable improvements to the operational management of Wencheng mountainous water supply. In terms of water supply safety, the full-time real-time water quality monitoring mechanism realizes rapid early warning and emergency disposal of potential risks, achieving a

100% water quality compliance rate and effectively guaranteeing rural and urban drinking water safety. In terms of economic benefits, the system significantly reduces pipe network leakage rates, realizing effective conservation of water resources, while the intelligent scheduling of pump stations greatly cuts energy consumption and manual operation costs, substantially improving the overall operational efficiency and economic benefits of water enterprises. In terms of daily management, intelligent monitoring and automatic data statistics eliminate massive manual inspection, ledger sorting and data reconciliation work, successfully transforming the traditional extensive manual management mode into refined, digital and intelligent water operation management.

In view of the long-term development of mountainous water affairs, IoT technology will continue to serve as the core support for digital upgrading. Future optimization directions include the construction of a digital twin water supply platform to realize visual simulation and intelligent scheduling of pipe network operation, training AI prediction models based on long-term accumulated IoT monitoring data to achieve predictive maintenance of aging pipe networks and early warning of water quality and water load changes, and expanding IoT application scenarios to recycled water utilization, flood prevention and drought resistance management. Through continuous technological iteration, a fully covered and integrated smart water service system will be built to promote the high-quality development of mountainous water supply.

In conclusion, restricted by complex terrain and scattered water supply characteristics, traditional manual management modes can no longer adapt to the modernization needs of mountainous county water affairs. This paper constructs a four-layer IoT smart water system architecture suitable for mountainous working conditions, and applies low-power communication, edge computing and big data analysis technologies to solve typical industry problems including monitoring blind areas, serious pipe network leakage, high energy consumption and data fragmentation. Adopting a lightweight and phased construction strategy, the research realizes coordinated improvement of water supply safety, economic benefits and management efficiency. It is verified that mountainous water smart transformation should adopt localized and low-cost IoT solutions rather than copying urban mature models, so as to continuously empower the refined and intelligent upgrading of county water operation and management.

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The authors declare no conflict of interest.

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