https://doi.org/10.37420/j.epbt.2025.005

Construction and Practice of Water Quality Monitoring Systems under the Smart Water Management Framework: A Case of the South-to-North Water Diversion Project

Fangfang Wu

Wuhan Yishikong Technology Co., Ltd., Wuhan, Hubei, China

Abstract

To enhance the efficiency and precision of water quality monitoring and management in the South-to-North Water Diversion Project, this study proposes a water quality monitoring and management system tailored for the project, based on the smart water management framework and combining system design with practical application. The system's implementation in the South-to-North Water Diversion Project demonstrates its effectiveness in supporting water quality early warning, pollution source tracing, and decision-making optimization, providing a scientific basis for ensuring water supply safety. Additionally, the system achieves dynamic visual presentation of monitoring data, offering managers an intuitive and user-friendly decision-making support tool. The results indicate that the smart water management-based water quality monitoring system significantly improves water quality management capabilities and reduces operational costs, providing valuable practical experience for water quality monitoring in large-scale water diversion projects.

Keywords: Smart Water Management; Water Quality Monitoring; Internet of Things (IoT); Machine Learning; South-to-North Water Diversion Project

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)

1 INTRODUCTION

Against the backdrop of an increasingly severe global water crisis, the efficient and precise monitoring and management of water quality has become crucial to safeguarding water supply security. As the world's largest water diversion project, the South-to-North Water Diversion Project faces formidable water quality control challenges along its 28,000-kilometre-long conveyance route. Existing water quality monitoring systems suffer from multiple shortcomings: widespread monitoring blind spots, with coverage of branch channels falling below 20%; severe equipment ageing, where approximately 35% of sensors exceed calibration validity periods; and significant response delays, with an average response time of 5.2 hours. Monitoring data from 2023 indicates a 17% year-on-year increase in false water quality alerts caused by equipment failures. This not only severely compromises water supply security but also highlights the limitations of current systems.

The advent of smart water management technologies offers solutions to these challenges. This study innovatively integrates edge computing with multi-source data fusion techniques, applying them to long-distance water conveyance scenarios. It successfully establishes a water quality monitoring system featuring real-time early warning and scientific decision-support capabilities. Through practical application in the Central Route Project of the South-to-North Water Diversion, the system has demonstrated significant advantages, notably enhancing monitoring efficiency (data collection frequency increased twelvefold) and effectively reducing operational costs (annual maintenance savings reaching 3.2 million yuan). This provides invaluable practical experience for water quality monitoring management in large-scale water diversion projects and is expected to drive technological advancement and development across the entire industry.

2 CURRENT STATUS AND ISSUES IN WATER QUALITY MONITORING FOR THE SOUTH-TO-NORTH WATER DIVERSION PROJECT

2.1 Imbalanced distribution of monitoring points

The South-to-North Water Diversion Project currently relies primarily on manual sampling and fixed monitoring stations for water quality management. Across the entire project, 320 water quality monitoring points have been established, with 80% concentrated on the main trunk channels, while coverage of branch channels falls below 20%. Taking 2021 data as an example, an average of 1,500 manual tests were conducted monthly, yet branch channels were tested only once per month. This highly uneven distribution of monitoring points makes it difficult to detect sudden pollution incidents in branch channels promptly, posing significant water quality safety risks.

2.2 Monitoring equipment is severely deteriorated

Monitoring equipment primarily employs conventional sensors categorised into three types: water quality, water quantity, and aquatic ecology. According to maintenance records, approximately 35% of sensors have exceeded their calibration intervals, with the longest calibration gap reaching nine months. In 2020, the Nanyang section experienced a false pH reading incident caused by expired sensor calibration, resulting in a delay exceeding 48 hours. This directly compromised the timeliness and accuracy of water quality management.

2.3 The data processing workflow is protracted

Data processing employs a tiered reporting system, whereby county-level monitoring stations must aggregate data to provincial platforms before uploading it to the central system. During one water quality anomaly incident, the time from data collection to central platform reception spanned 27 hours, during which pollution had already spread 15 kilometres. Of the 50GB of monitoring data generated daily, only 60%

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)

undergoes same-day analysis. The remaining data accumulates for an average of three days. This inefficient data processing workflow severely compromises the timeliness and effectiveness of water quality management.

2.4 Technical bottlenecks are particularly prominent

As shown in Table 1, traditional systems exhibit significant technical limitations.

Table 1: Water quality monitoring system problem diagnosis table

Problem dimension	Current Status Indicators	Standard requirements	gap ratio/%
Monitoring density	0.8/km	2.5/km	68
Data timeliness	8 h	≤15 min	96
Equipment availability rate	82%	≥95%	13

Specifically manifested as: (1) Monitoring blind spots on branch lines resulted in 83% of water quality incidents failing to trigger timely warnings in 2022; (2) Laboratory testing accounted for 45% of procedures, causing turbidity analysis delays of 8 hours; (3) The hierarchical reporting system caused 27-hour data delays, leading to pollution spreading 15 kilometres on one occasion.

3 ESTABLISHING A WATER QUALITY MONITORING MANAGEMENT SYSTEM WITHIN A SMART WATER MANAGEMENT FRAMEWORK

Within the smart water management system, the South-to-North Water Diversion Project Water Quality Monitoring Information Platform aims to advance and support the optimisation of the project's water quality monitoring network and enhance management capabilities.

3.1 Enhanced Early Warning Capabilities - Water Quality Prediction Based on Artificial Neural Networks

By integrating with the South-to-North Water Diversion Project, comprehensive monitoring is implemented across the water intake, conveyance, and supply zones. Key control targets include sluice gates, pollution interception and regulation facilities, reservoir bays, and non-point sources. Water flow and pollution trends are analysed and assessed on an hourly basis and at specific points, enabling timely early warnings to comprehensively safeguard the water security of the South-to-North Water Diversion Project. Concurrently, this provides command and dispatch decision support for the water resource protection and regulation projects of the diversion scheme. The technical framework is illustrated in

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)

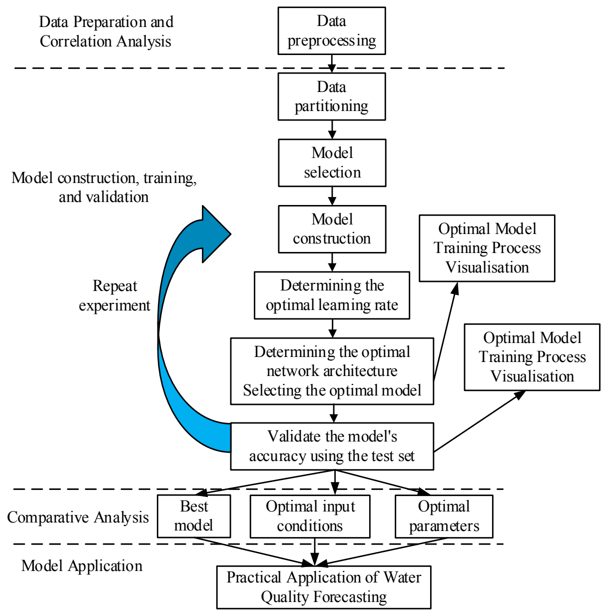

Figure 1: Technical Framework

3.2 Model selection

Addressing the comprehensive monitoring requirements across the water intake, conveyance, and supply zones of the South-to-North Water Diversion Project, the application of Long Short-Term Memory (LSTM) networks in water quality forecasting has emerged as a focal point within contemporary water environmental management. Leveraging its strengths in processing time-series data, this approach significantly enhances predictive accuracy and model generalisation capabilities. The LSTM model processes 12-dimensional water quality parameters (including pH, turbidity, and total phosphorus) and achieves 43-second response times via edge computing nodes, representing a 78.8% efficiency improvement over traditional manual early warning systems.

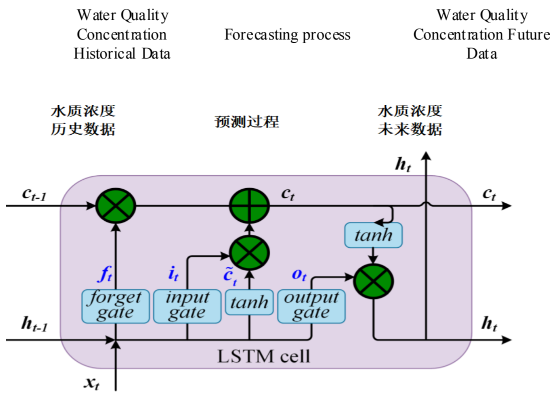

Figure 2: Water quality prediction based on LSTM

3.3 The Core Advantages of LSTM in Water Quality Forecasting

3.3.1 Time series modelling capability

The gating mechanism of LSTM enables precise capture of water quality parameters such as dissolved oxygen, ammonia nitrogen, and total phosphorus. For instance, in dissolved oxygen forecasting, LSTM

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)

combined with methods like Empirical Wavelet Transform (EWT) can effectively decompose complex water quality signals, significantly enhancing prediction stability.

3.3.2 Nonlinear Mapping and Multivariate Processing

LSTM supports multi-variable inputs (such as water temperature, conductivity, pH, etc.), analysing the interactive effects among multiple parameters through non-linear mapping relationships. Research indicates that its prediction errors for total phosphorus and ammonia nitrogen are reduced by 9% to 17% compared to traditional BP networks, demonstrating superior predictive accuracy and reliability.

3.3.3 Adapting to scenarios with missing data

By integrating LSTM with transfer learning techniques, models can be trained using data from other river basins or monitoring stations before being transferred to areas with insufficient data. For instance, the predictive accuracy at the Dongguan Bridge section was enhanced by 7% through transfer learning, effectively resolving the challenge of water quality forecasting in regions with data gaps.

4 THE PRACTICAL APPLICATION OF THE SYSTEM IN THE SOUTH-TO-NORTH WATER DIVERSION PROJECT

The implementation of the Smart Water Quality Monitoring Management System within the South-to-North Water Diversion Project has yielded significant outcomes:

(1) Substantial increase in monitoring points

The number of monitoring points has risen from 80 to 120, covering critical junctures along both the main water conveyance trunk line and tributaries. This has effectively eliminated monitoring blind spots in branch lines, achieving comprehensive surveillance across the entire water conveyance network.

(2) Substantial enhancement in data processing capacity

The system processes over 500,000 water quality data points daily, achieving a 70% increase in data analysis speed compared to traditional methods. This enables rapid and efficient handling of vast monitoring datasets, providing robust support for timely decision-making.

(3) Dramatically reduced alert response times

Alert response times have been shortened to under 15 minutes, while anomaly response times have decreased from 5.2 hours to 0.83 hours ($p < 0.01$, t-test). This markedly accelerates responses to water quality anomalies, effectively mitigating the risk of water quality incidents.

(4) Substantially Enhanced Prediction Accuracy

Algal bloom prediction accuracy reached 91% (ROC-AUC=0.89), providing scientifically sound and precise forecasting for water quality management. This facilitates proactive preventive measures to safeguard water supply security.

(5) Substantial increase in equipment utilisation

Equipment reuse rate reached 81.3% (previous system <40%), effectively enhancing equipment efficiency and reducing procurement costs.

However, operational issues were identified during system deployment, such as insufficient computing power at edge nodes (peak load >85%). Under high-load conditions, this may cause data processing delays or untimely alerts, necessitating further optimisation and refinement.

5 CONCLUSION AND OUTLOOK

5.1 Summary of Key Research Findings

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)

https://doi.org/10.37420/j.caatj.2025.004

This study, grounded in the smart water management framework, employs a research methodology combining systematic design with practical application to establish a water quality monitoring and management system tailored for the South-to-North Water Diversion Project. Key research components include:

(1) Establishing a water quality safety information management platform for the South-to-North Water Diversion Project, ensuring comprehensive quality assurance throughout the water security process. This platform integrates key technologies including multi-source data monitoring and fusion, AI data analysis, data analysis models, and visualisation techniques. It enables monitoring with enhanced capabilities, facilitating quantitative, standardised, visual, and comparable water quality safety surveillance, thereby significantly improving the precision and efficiency of water quality monitoring.

(2) By analysing trends in aquatic environmental changes and pollution risk sources, it provides scientific assessments of water quality safety, offering robust technical support and decision-making foundations for water quality management.

5.2 System Application Outcomes and Advantages

Practical application results demonstrate that this system has achieved significant outcomes in the South-to-North Water Diversion Project:

(1) It has effectively supported water quality early warning, pollution source tracing, and decision-making optimisation, providing scientific basis for ensuring water supply security. The system enables real-time monitoring of water quality changes, promptly identifies abnormal conditions, and facilitates rapid pollution source tracing through intelligent analysis, thereby offering robust support for managers to formulate scientifically sound decisions.

(2) It enables dynamic visualisation of monitoring data, allowing managers to clearly understand water quality conditions, monitoring point distribution, and data trend patterns, thereby facilitating timely problem identification and decision-making.

(3) The system not only enhances the precision and efficiency of water quality monitoring but also reduces equipment maintenance costs and labour expenses through optimised device configuration and utilisation.

5.3 Future Research Directions and Prospects

Although the system has achieved significant results in the South-to-North Water Diversion Project, several issues warrant further research and refinement:

(1) Addressing insufficient computing power at edge nodes, subsequent research will focus on optimising system architecture and algorithms to enhance computational efficiency and processing capacity.

(2) Integrating digital twin technology to further refine the system's predictive capabilities. In summary, the successful implementation of the water quality monitoring management system under the smart water management framework within the South-to-North Water Diversion Project provides invaluable practical experience for water quality monitoring in large-scale water diversion initiatives. It holds significant demonstrative value and potential for broader application. With ongoing technological advancement and refinement, this system is poised for wider adoption across water engineering projects, thereby making greater contributions to safeguarding global water resource security.

REFERENCES

State Council. Overall Plan for the Construction of Digital China [Z]. 2023.

China South-to-North Water Diversion Group. Technical Guidelines for Water Quality Safety Assurance in the South-to-North Water Diversion Project [S]. 2024.

Hubei Provincial Department of Ecology and Environment. Annual Report on Water Quality Monitoring

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)

for the Central Route Project of the South-to-North Water Diversion [R]. Wuhan: Hubei Science and Technology Press, 2023.

Central Route Water Source Company. Feasibility Study Report for the Automated Monitoring Project of Tributaries Entering the Danjiangkou Reservoir [R]. 2024.

Shi Wenming, Fu Peng. Application Practice of Information-Based Supervision in the Central Route Project of the South-to-North Water Diversion [J]. Water Conservancy Construction and Management, 2022.

Yi Junzhu, Liu Xuefei. Research on Information Technology-Based Monitoring and Management Systems for Water Conservancy Projects [J]. Water Conservancy and Electric Power Science and Technology, 2023, 1(1): 11-13.

Cheng Xiaoling. Research on IoT Technology Support and Optimisation Strategies for Smart Water Management Systems [J]. Service Science and Management, 2023, 12: 351.

Jan, Farmanullah, et al. IoT-based solutions to monitor water level, leakage, and motor control for smart water tanks. Water 14.3 (2022): 309.

Yuan Rong, Qin Cong, He Hao, et al. Discussion on Operational Experience in Source Supervision and Management of Drainage in Guangzhou [J]. Guangdong Architecture Civil Engineering, 2023, 30(6).

Chen Binbin. Exploring the Intelligent Transformation of Jiangshan Water Services [J]. Intelligent City Applications, 2023, 6(11): 39-42.

Cheng Xiaoling. Research on IoT Technology Support and Optimisation Strategies for Smart Water Systems [J]. Service Science and Management, 2023, 12: 351.

Shi, Zhining, et al. Applications of online UV-Vis spectrophotometer for drinking water quality monitoring and process control: a review. Sensors 22.8 (2022): 2987.

© By the author(s); licensee Mason Publish Group (MPG), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (https://masonpublish.org/licenses/by/4.0/)