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Original Paper

Research on the Construction of Intelligent Supervision System for Water Quality Protection of Dongting Lake by Digital Governance

Jinkai Shu[1*], Yirui Liang[1], Jianwu Sheng[1], & Liangcheng Jiang[1]

[1] School of Municipal and Geomatics Engineering, Hunan City University, Yiyang, Hunan 413000, China

[*] Corresponding Author

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Abstract

As a vital ecological barrier in the middle reaches of the Yangtze River, Dongting Lake's water quality critically impacts regional ecology and economic development. Confronted with pollution from industrial activities, agricultural non-point sources, and shipping operations, traditional regulatory approaches face challenges including delayed monitoring, fragmented data, and insufficient coordination, which hinder effective governance. Therefore, establishing a smart regulatory system through digital governance has become crucial for enhancing water quality protection. This study employs digital governance theory to analyze traditional regulatory pain points, proposing a framework across five dimensions: monitoring perception, data integration, intelligent analysis, collaborative coordination, and institutional safeguards, while exploring implementation pathways. The research aims to support water quality governance and decision-making for Dongting Lake, advance the Yangtze River Economic Belt strategy, and provide replicable models for water environment management in China's large-scale lakes.

Keywords

digital governance, Dongting Lake, water quality protection, smart supervision system

1. Introduction

Dongting Lake, spanning Hunan and Hubei provinces, serves as a vital ecological barrier in the middle reaches of the Yangtze River and China's second-largest freshwater lake. Known as the "kidney of the Yangtze," it plays crucial ecological roles like flood regulation and provides economic services such as irrigation. However, industrialization has intensified pressures on its water quality through industrial wastewater discharge, exacerbating eutrophication, frequent cyanobacterial blooms, and habitat destruction. In 2023, some tributaries still exceeded water quality standards, highlighting the complexity of water remediation. (Fu, Zhang, Li et al., 2025; Liu, Cao, Zhao et al., 2025; Liu, Cao, Zhao et al., 2024) Traditional monitoring methods relying on manual inspections suffer from coverage limitations and inadequate adaptability to complex aquatic governance needs. The advancement of digital technologies offers new pathways for water environment regulation, making the establishment of a smart monitoring system an essential choice to enhance water quality protection efficiency in Dongting Lake.

2. Domestic and Foreign Research Status

Research on smart water environment supervision abroad started earlier and has established mature technical systems and practical models. Developed countries like the United States, Europe, and Japan have leveraged digital technologies to build national or regional water environment monitoring networks and smart supervision platforms. For instance, the U.S. "National Water Quality Monitoring Network" integrates multi-department monitoring data, using big data analysis to assess water quality and issue pollution warnings. The EU's "Water Framework Directive" is supported by smart monitoring systems that employ satellite remote sensing technology to monitor and dynamically manage water quality in river basins in real time. Japan utilizes AI models to predict water quality changes and guide pollution control in lake and bay management. While foreign research focuses on technology application and platform development, emphasizing data sharing and cross-department collaboration, these efforts provide valuable references for China's smart water quality supervision. However, due to differences in governance models and institutional environments, localized innovations are required.

Chinese scholars have conducted extensive research on intelligent water environment monitoring. The technological applications focus on developing IoT monitoring devices, building big data analysis models, and applying satellite remote sensing technology. Pilot projects in multiple regions have established smart water environment monitoring platforms to integrate and visualize monitoring data. In terms of institutional mechanisms, studies explore cross-departmental data sharing, collaborative governance models, and legal safeguards.

Current research on Dongting Lake primarily focuses on evaluating water quality status, with limited exploration of smart supervision system development. Existing studies on water quality monitoring network optimization often concentrate on single technologies or specific processes, lacking systematic and holistic framework construction that fails to leverage digital governance advantages. To address these gaps, this study proposes a multi-layered smart supervision system through a digital governance perspective, aiming to comprehensively improve current research shortcomings.

3. Digital Governance and Smart Supervision

Digital governance refers to the application of digital technologies to integrate multi-source data in public administration, optimize processes, innovate models, and enhance governance efficiency, precision, and coordination. Its core features include: data-driven decision-making that leverages multi-source data as key elements; technology empowerment that breaks through traditional governance limitations through digital solutions; collaborative coordination that eliminates departmental barriers to form synergistic efforts; and precise efficiency that employs intelligent methods for targeted governance.

Smart regulation represents the application of digital governance in regulatory domains, utilizing digital technologies to establish intelligent supervision systems that achieve automation, real-time monitoring, and intelligent decision-making. The smart water environment regulation system focuses on water quality monitoring data, integrating multi-departmental information through various technologies to enable real-time monitoring, early warning, traceability, and response mechanisms, thereby enhancing regulatory precision and efficiency. The smart water quality protection system for Dongting Lake in this study, grounded in digital governance principles and supported by digital technologies, integrates comprehensive water resources to build a full-chain framework. This system enables real-time water quality monitoring, early warning, decision-making, and collaborative governance, ultimately elevating water quality protection standards.

4. Analysis of the Current Situation of Water Quality in Dongting Lake and the Pain Points of Traditional Supervision Mode

4.1 Water Quality of Dongting Lake

4.1.1 Overall Water Quality

According to monitoring data from the Hunan Provincial Department of Ecology and Environment, the water quality of Dongting Lake has remained generally stable in recent years, predominantly classified as Class III with localized pollution occurrences. In 2023, the lake maintained an average Class III water quality, showing no significant year-on-year change. The primary pollutants were total phosphorus and ammonia nitrogen, with total phosphorus concentration decreasing by 0.01 mg/L compared to the previous year while ammonia nitrogen levels remained unchanged. Spatially, the eastern section of Dongting Lake exhibited better water quality, mainly ranging from Class II to III. Some tributaries in the southern and western parts occasionally reached Class IV standards. At the four major river systems entering the lake, water quality was primarily Class II-III, though certain tributaries exceeded permissible limits.

4.1.2 Major Pollution Problems

(1) Agricultural non-point source pollution is prominent. The surrounding area is an important agricultural production area. The application of chemical fertilizers and pesticides and livestock and poultry breeding lead to a large amount of nitrogen and phosphorus into the lake, contributing more

than 60% of the total phosphorus load.

(2) The risk of industrial pollution is still there. Although the surrounding enterprises meet the emission standards, there are suspicions of illegal discharge and leakage, and the wastewater treatment facilities are unstable.

(3) Domestic sewage and shipping pollution are aggravated, the sewage collection and treatment rate of surrounding towns is low, some direct discharge or leakage; shipping ship sewage discharge and garbage disposal affect water quality.

(4) Ecological function degradation, water pollution, eutrophication, cyanobacterial bloom, destruction of aquatic habitat, forming a cycle of “pollution-ecological degradation-water quality deterioration”.

4.2 Pain Points of Traditional Regulatory Models

4.2.1 The Monitoring Network Is not Perfect, and the Real-time and Coverage Are Insufficient

Traditional monitoring relies primarily on manual sampling and laboratory analysis, supplemented by a limited number of automatic monitoring stations. Currently, there are approximately 20 automatic monitoring stations, which are sparsely distributed and insufficiently covered for lake areas and remote tributaries. Manual monitoring is conducted periodically, making real-time monitoring difficult, delayed in responding to sudden pollution, and limited in monitoring indicators.

4.2.2 Data Fragmentation Is Serious and the Sharing Mechanism Is not Sound

Regulation involves multiple departments, each with its own monitoring system and database, but there is a lack of unified standards and sharing mechanism. Data standards are not uniform, sharing is not smooth, and utilization rate is low, forming “information islands”, which cannot provide comprehensive support for decision-making.

4.2.3 Single Regulatory Means and Low Level of Intelligence

Traditional supervision is mainly based on manual inspection and post-punishment, and lacks intelligent analysis, prediction and early warning capabilities. It is difficult to identify the source of pollution, and the prediction and early warning are weak, and the supervision efficiency is low.

4.2.4 The Collaborative Governance Mechanism Is not Perfect, and the Joint Supervision Force Is Insufficient

Dongting Lake spans Hunan and Hubei provinces and involves many cities and counties, requiring cross-regional and cross-departmental coordination. However, there is insufficient cross-departmental coordination, difficulties in cross-regional coordination, and poor channels for public participation, making it difficult to form a multi-stakeholder governance pattern.

4.2.5 Insufficient Institutional Guarantee and Imperfect Support System

The laws and regulations are not sound, and there is a lack of special laws and regulations on the application of digital technology; the standard system is missing, and the systems of various departments are difficult to interconnect; the lack of talent and capital security restricts the construction and operation of the smart supervision system.

5. Framework for Building a Smart Regulatory System

Based on the theories of digital, collaborative and precision governance, and combined with the current situation of water quality of Dongting Lake and the pain points of traditional supervision, the framework of "five-level, whole-chain" intelligent supervision system is constructed to achieve the governance objectives of "precise monitoring and perception, integrated data integration, intelligent analysis and intelligent, efficient collaborative linkage, and systematic institutional guarantee".

5.1 Monitoring and Sensing Layer: Build a Monitoring Network Covering all Elements, all Regions and all Time Periods

The monitoring and perception layer forms the foundation of the smart supervision system, with its core mission being to achieve comprehensive and real-time monitoring of Dongting Lake's water quality and surrounding pollution sources through diversified detection methods. First, optimize the ground monitoring network by adding automatic monitoring stations at key locations such as remote tributaries, lake interior areas, and discharge outlets, building upon the existing 20 stations. These stations will be equipped with instruments for monitoring conventional parameters (pH, dissolved oxygen, ammonia nitrogen, total phosphorus, total nitrogen) and trace pollutants and toxic substances, ensuring full coverage of critical areas. Additionally, mobile monitoring equipment (e.g., monitoring boats, drones) will be deployed for emergency response to sudden pollution incidents, compensating for the spatial limitations of fixed stations. Second, enhance satellite remote sensing capabilities by utilizing high-resolution satellite technology to conduct large-scale, routine monitoring of Dongting Lake's water surface area, cyanobacterial bloom distribution, and suspended solids concentration. This enables macro-level ecological oversight and timely identification of large-scale pollution risks. Third, supplement pollution source monitoring by installing online monitoring devices at key emission points including industrial discharge outlets, livestock farms, urban sewage treatment plants, and ship docks. This real-time tracking of pollutant concentrations and emission volumes ensures full-chain monitoring from source to process to endpoint. Finally, integrate hydrological and meteorological data by connecting with water level, flow rate, and velocity data from water conservancy departments, as well as precipitation, wind speed, and temperature data from meteorological departments, providing robust support for analyzing water quality trends. Through the integration of multi-source monitoring methods, an integrated "sky and land" monitoring network is built to realize the monitoring of all elements (water quality, hydrology, meteorology, pollution sources), all regions (lake area, tributaries, lake inlet, pollution sources) and all time periods (real time, all weather) of the water quality of Dongting Lake.

5.2 Data Integration Layer: Build a Unified Data Sharing and Management Platform

The data integration layer serves as the core hub of the intelligent supervision system, designed to break down "information silos" and achieve standardized integration and efficient sharing of multi-source data. First, provincial ecological environment departments lead the development of a unified data sharing platform, consolidating monitoring, management, and operational data from environmental protection, water conservancy, and other departments to form a "data resource pool" for

Dongting Lake water quality protection. Second, a unified data standard system is established, including the formulation of the “Dongting Lake Water Quality Intelligent Supervision Data Standards” to clarify data specifications. A data quality review mechanism is implemented to enhance data integrity and lay the foundation for subsequent analytical applications. Third, a data security framework is constructed using encryption and other technical measures to prevent data breaches and misuse. Clear data sharing permissions are defined, with access rights allocated to different departments and users according to established principles to ensure data security and privacy. Through this unified platform and standardized approach, the system achieves “one-time collection, multi-party sharing, and efficient utilization” of multi-source data, effectively addressing data fragmentation issues.

5.3 Intelligent Analysis Layer: Using Digital Technology to Realize Accurate Early Warning and Decision Support

The intelligent analysis layer serves as the “brain” of the smart supervision system. By leveraging big data and artificial intelligence technologies, it conducts in-depth analysis of integrated multi-source data to achieve water quality early warning, source tracing, and decision support. First, a water quality prediction and early warning model is established. Based on historical water quality data, hydro-meteorological data, and pollution source data, machine learning algorithms (such as random forests and LSTM neural networks) are employed to create a water quality trend prediction model, accurately forecasting changes in water quality indicators across different regions of Dongting Lake over a future period. Simultaneously, early warning models for cyanobacterial blooms and sudden pollution incidents are developed. When monitoring data exceeds thresholds or model predictions indicate pollution risks, automatic alerts are triggered to provide time for emergency response. Second, precise source tracing of pollution is achieved. By integrating pollution source monitoring data, water quality monitoring data, and hydrological data, spatial analysis and source tracing algorithms are applied to construct a “pollution source-water quality change” correlation model. When abnormal water quality occurs in a specific area, the system rapidly identifies pollution sources (such as illegal discharges from industrial enterprises or agricultural non-point source pollution) and clarifies responsible entities and pollution pathways. Third, intelligent decision support is provided. Based on data analysis results, scientific evidence is generated for formulating water quality protection policies and optimizing pollution control measures. For instance, regarding prominent agricultural non-point source pollution issues, precise recommendations for fertilizer reduction and livestock breeding control are proposed by analyzing correlations between fertilizer/pesticide usage, livestock breeding scale, and water quality indicators. For cross-regional pollution challenges, data-driven support and solution references are provided for collaborative governance between Hunan and Hubei provinces. Through intelligent analysis, the transition from “post-disposal” to “prevention and control” is realized, and the precision and scientificity of supervision are improved.

5.4 Collaborative Linkage Layer: Building a Multi-department, Multi-regional and Multi-stakeholder Governance Pattern

The collaborative linkage layer serves as the operational foundation of the smart supervision system, with its core mission being to establish a robust collaborative governance mechanism that creates regulatory synergy. First, a cross-departmental coordination mechanism will be established through a data-sharing platform, enabling regular communication, joint law enforcement, and data interoperability among environmental protection, water resources, and other relevant departments. For instance, when the environmental protection department detects abnormal water quality, it can promptly share information via the platform to coordinate joint investigations and address the issue, while clearly defining each department's responsibilities in water quality supervision. Second, cross-regional collaboration will be optimized through the establishment of a joint meeting system for Dongting Lake water quality protection between Hunan and Hubei provinces, ensuring unified standards. The platform will facilitate data sharing, synchronized early warnings, and coordinated responses across the two provinces, effectively tackling cross-regional pollution challenges. Finally, public engagement channels will be expanded by incorporating a public service section on the smart supervision platform, disclosing water quality data and governance progress, providing reporting portals, and offering rewards for verified reports to foster a multi-stakeholder governance framework. Through these collaborative efforts, institutional barriers will be dismantled, significantly enhancing governance efficiency.

5.5 Institutional Guarantee: Improve the Legal System and Standard System

The institutional safeguards form the cornerstone for the sustainable operation of smart regulatory systems, providing essential support through comprehensive institutional frameworks. Firstly, enhancing the legal framework involves revising regulations such as the Dongting Lake Ecological Environment Protection Regulations to clarify requirements for digital technology applications and data sharing responsibilities, while introducing supportive policies to encourage participation in technology R&D and platform development. Secondly, refining the standardization system requires establishing both technical specifications and management standards alongside data standards, ensuring standardized construction and operational processes. Finally, strengthening talent and financial support entails creating a multi-skilled talent development mechanism to cultivate professionals, along with diversified funding mechanisms to meet capital requirements. These institutional safeguards collectively establish a robust foundation for the long-term operation of smart regulatory systems.

6. Implementation Path of Regulatory System Construction

6.1 Promoting the System Step by Step

Given the complexity of water quality management in Dongting Lake and the long-term nature of establishing a smart supervision system, the phased implementation plan unfolds as follows: 1. Pilot Phase (Years 1-2): Select East Dongting Lake as a demonstration site to optimize monitoring networks, establish a regional data-sharing platform, develop preliminary early-warning models, and create cross-departmental coordination mechanisms to accumulate operational experience. 2. Expansion Phase (Years 3-4): Roll out the system across the entire lake, complete the construction of a unified data-sharing platform and intelligent analysis system, and strengthen interdepartmental and cross-regional collaboration mechanisms. 3. Sustainable Phase (Years 5+): Continuously upgrade equipment, refine models, and enhance mechanisms based on operational needs and technological advancements, achieving dynamic system optimization and long-term sustainable operation.

6.2 Strengthening Technology Research, Development and Application

Strengthen collaboration with universities, research institutions, and tech enterprises to advance key technology development. Focus on creating high-precision, low-cost water quality monitoring systems, predictive warning models for complex aquatic environments, and secure cross-departmental data-sharing solutions. Drive the application of proven technologies in system development to enhance technical capabilities and practical effectiveness. For instance, partnering with satellite remote sensing and AI companies to refine monitoring techniques and boost model accuracy.

6.3 Strengthen Publicity and Training

Conduct relevant publicity activities to publicize the significance, progress and effect of smart supervision to the public, enterprises and government staff, and improve the public participation and environmental awareness of enterprises; Strengthen the training of government staff, focusing on the operation of the platform, the use of the system, the operation of the mechanism, etc., to improve the professional ability and ensure the effective operation of the system.

7. Conclusion

This study establishes a five-tiered smart supervision framework for Dongting Lake water quality protection based on relevant theories. The system addresses data fragmentation through a unified sharing platform, employs intelligent analysis models for precise early warnings and decision support, and fosters collaborative governance mechanisms through coordinated linkage. A robust institutional safeguard system ensures sustainable operation. With advancements in digital technologies and growing demands for water environment governance, the framework requires optimization. Future improvements will focus on three key areas: enhancing technological innovation by introducing digital twin technologies to boost intelligence; expanding data sources through social data integration to improve analytical comprehensiveness and accuracy; and deepening multi-stakeholder governance by refining public participation mechanisms to create a broader collaborative governance pattern. The implementation of this system will enhance water quality protection efficiency in Dongting Lake, promote ecological environment improvement, provide support for Yangtze River Economic Belt development, and offer practical experience for water environment governance in China’s major lakes.

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