

# Technological Innovation for Source Watershed Governance: A Case Study of the Maota River Basin in the South-to-North Water Diversion Project

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**Abstract:** The governance of small watersheds in the water source area of the South-to-North Water Diversion Middle Route Project holds significant strategic importance for ensuring sustained northward flow of clean water from the reservoir. Taking the Maota River small watershed governance project as a case study, this research systematically analyses the progress and effectiveness of technological innovation in promoting watershed management within the framework of six key initiatives. The study finds that the project has achieved notable progress in enhancing water conservation functions, improving incoming water quality, and fostering green industrial transformation through measures such as constructing a new energy vehicle industry chain, implementing micro-power rural wastewater treatment, establishing green factories, and promoting smart system upgrades. However, shortcomings remain in areas like technological investment, monitoring systems, collaborative mechanisms, and public participation. Countermeasures are proposed, including increasing support for green technology research and development and industrial upgrading, building an integrated sky-land-water smart watershed monitoring and management platform, establishing cross-regional and multi-level collaborative governance mechanisms, and improving the policy system and public participation channels for water source protection. This research can provide technological support pathways and policy references for the systematic management and green, low-carbon development of small watersheds in the water source area of the Middle Route Project and other critical ecological function zones.

**Keywords:** South-to-North Water Diversion Middle Route Project; Water source protection; Small watershed governance; Technological innovation; Smart monitoring; Collaborative governance

## 1. Introduction

The South-to-North Water Diversion Middle Route Project is a major strategic infrastructure for optimizing China's water resource allocation. The water quality safety of its source area directly concerns the drinking water security of hundreds of millions of people in the receiving regions and the sustainable socio-economic development of these areas [1]. The core water source region of the Middle Route is primarily located in the middle and upper reaches of the Han River, spanning Shaanxi, Hubei, and Henan provinces. Within this, the Danjiangkou Reservoir area and its upper watershed in Shiyan, Hubei Province, undertake crucial functions of water conservation and quality assurance [2]. As fundamental units of the water source ecosystem, the effectiveness of small watershed governance directly impacts the quality of water entering the reservoir.

In recent years, scholars have conducted research on protecting the Middle Route's water source from various perspectives. Concerning pollution prevention and control, studies have focused on agricultural non-point source pollution [3], urban wastewater treatment [4], industrial point source management, and soil-water conservation [5]. In ecological restoration, research has explored the application of technologies like wetland rehabilitation [6], forest stand improvement [7], and ecological buffer zone construction [8]. Regarding management mechanisms, studies have investigated innovations in models such as ecological compensation [9], collaborative governance [10], and smart supervision [11]. However, existing research often focuses on single elements or localized areas, lacking a systematic exploration of the pathway system and implementation strategies for comprehensive small watershed management from the holistic perspective of technological innovation-driven approaches. Particularly for small watersheds like the Maota River, which serve compound functions of water conservation, urban-rural integration, and

industrial transformation as tributaries directly feeding the reservoir, how to leverage technological innovation to achieve the dual goals of enhanced management efficiency and water source security warrants deeper exploration.

Based on field investigations, policy analysis, and case study, this research systematically summarizes the progress and technological application effectiveness in the governance of the Maota River small watershed. It identifies current key problems and constraining factors, subsequently proposing pathways and countermeasures for water source small watershed governance with technological innovation as the core driving force. This aims to provide references for the systematic management and high-quality development of small watersheds in the Middle Route water source area and other similar regions.

## **2. Study Area and Methods**

### **2.1. Study Area**

The Maota River is a first-order tributary of the Si River (which flows into the Danjiangkou Reservoir), with a total length of 43.3 km and a watershed area of approximately 200 km<sup>2</sup>. As an important reservoir-feeding tributary within the core water source area of the Middle Route Project, its water quality directly affects the safety of the Danjiangkou Reservoir water quality. The watershed has a population of about 50,000, with an industrial structure primarily based on automobile manufacturing, eco-agriculture, and rural tourism. The watershed exhibits a diverse pattern of mountains-waters-forests-farmlands-lakes-grasslands-towns-villages from south to north, encompassing ecological conservation zones, agricultural production areas, industrial clusters, and urban built-up areas.

### **2.2. Methods**

This study employs a combination of field surveys, semi-structured interviews, literature analysis, and comparative case studies. Between October 2023 and March 2024, multiple rounds of surveys were conducted targeting government departments, enterprises, and rural communities within the Maota River watershed, collecting data such as policy documents, monitoring data, and project reports. Simultaneously, other small watershed management cases within the Middle Route water source area were selected for comparative analysis to summarize transferable experiences. The research follows the logical framework of status-problem-pathway-proposal with a focus on the bidirectional enabling role of technological innovation in water source protection and watershed development.

## **3. Progress in Governance and Effectiveness of Technology Application in the Maota River Watershed**

### **3.1. Overall Progress in Governance**

Since the pilot launch in 2023, Shiyan has coordinated the advancement of six major actions outlined in the Maota River Small Watershed Governance Pilot Plan: safety assurance, water environment improvement, green industrial park development, agro-cultural-tourism revitalization, ecological protection and restoration, and coordinated urban-rural development. Through systematic management, the water quality within the watershed has stabilized at Class III or above, the collection and treatment rate of rural domestic wastewater has exceeded 90%, several new green factories and intelligent manufacturing demonstration units have been established, and integrated development of eco-agriculture and rural tourism has shown initial success. As a vital component of the Middle Route water source area, the effectiveness of the Maota River management directly relates to the safety of incoming reservoir water quality. The pilot work has preliminarily explored a synergistic pathway of ecological industrialization and industrial ecologization for coordinated water source protection and development.

### **3.2. Effectiveness of Technology Application in Key Areas of Water Source Protection**

#### **3.2.1. Green Industrial Transformation Aids Source Reduction of Pollution**

In response to the stringent requirements for water source protection, the Maota River watershed has prioritized promoting green industrial transformation. The rapid development of the new energy vehicle (NEV) industry chain serves as a typical example. The watershed has attracted 15 NEV supporting enterprises, including BJEV (Baic Ivenco) and Dongshi Dayang, forming production capabilities for core

components like batteries, motors, and electronic controls. Compared to traditional internal combustion engine vehicle industries, NEVs significantly reduce pollutant emissions throughout their entire lifecycle (production, use, and recycling), particularly substantially lowering potential pollution risks to the water environment. For instance, Dongshi Dayang Company possesses synchronous production capacity for both commercial and passenger NEV electric drive systems, with an annual capacity of 150,000 units/sets. Through process optimization and clean production retrofits, it has achieved near-zero discharge of production wastewater, providing a demonstration for industrial pollution prevention in water source areas.

### ***3.2.2. Distributed Wastewater Treatment Technology Ensures Control of Rural Non-point Source Pollution***

Rural domestic wastewater treatment is a focal and challenging aspect of water source protection. The Maota River watershed innovatively adopted a model which includes categorized collection, on-site treatment, and resource reuse. Tailored to the scattered nature of rural settlements, integrated micro-power treatment facilities were constructed for clusters of more than 10 households. For scattered households, a decentralized, non-powered system that includes flush toilet, three-compartment septic tank, sedimentation tank and constructed wetland was promoted. A total of 28 micro-power facilities and 202 decentralized systems were built, achieving a rural domestic wastewater collection and treatment rate exceeding 90%. The effluent quality meets the Grade I standard of Hubei Province's Discharge Standard for Water Pollutants from Rural Domestic Wastewater Treatment Facilities. Part of the treated effluent is reused for agricultural irrigation or landscape water supplementation, realizing wastewater resource utilization, reducing the direct discharge of nutrients like nitrogen and phosphorus into the river, and effectively controlling the potential impact of agricultural non-point source pollution on water source quality.

### ***3.2.3. Smart Monitoring Enhances Risk Prevention Capacity for Water Source Areas***

Addressing the sensitivity and complexity of water source protection, the watershed has begun exploring the application of smart monitoring technologies. By installing automatic water quality monitoring stations and video surveillance points, combined with drone patrols and remote sensing monitoring, a preliminary three-dimensional monitoring network consisting of fixed-point monitoring, mobile patrol, remote sensing retrieval has been established. Key monitoring points achieve real-time online monitoring of critical indicators such as pH, dissolved oxygen, ammonia nitrogen, total phosphorus, and total nitrogen, with data automatically transmitted to a supervision platform. When abnormal data is detected, the system can automatically issue alerts and initiate emergency response procedures, significantly improving the timeliness and effectiveness of water quality risk prevention and control in the source area.

### ***3.2.4. Ecological Restoration Technologies Strengthen Water Conservation Function***

In terms of ecological protection and restoration for the water source, the Maota River watershed has comprehensively applied various ecological engineering technologies. In the upper ecological conservation zone, measures like afforestation and mountain closure for natural reforestation have increased forest coverage, enhancing water conservation capacity. Along riverbanks, ecological slope protection and vegetative buffer strips have been constructed to reduce soil erosion and direct non-point source pollutant inflow. At key nodes, constructed wetlands and ecological floating beds have been built to improve water self-purification capacity. Particularly for the challenging ecological restoration of mining sites, comprehensive technologies like soil amelioration and vegetation restoration have been adopted to gradually rehabilitate damaged ecosystems and restore their water conservation functions.

## **4. Major Problems and Challenges**

Despite achieving phased results, the management of the Maota River small watershed, as a crucial part of the Middle Route water source area, still faces the following prominent issues.

### ***4.1. Persistent Conflicts between Protection and Development***

As a core water source region for the Middle Route Project, the Maota River watershed faces strict water quality protection requirements that somewhat restrict traditional industrial development space. While green industries such as new energy vehicles have developed, overall industrial restructuring requires time, and some traditional enterprises face multiple constraints regarding technology and

funding in their transformation and upgrading. How to achieve sustainable socio-economic development within the rigid constraints of water source protection remains an urgent challenge.

#### ***4.2. Incomplete Monitoring and Early Warning Systems***

Current monitoring network coverage and indicators remain limited, particularly regarding monitoring capabilities for emerging contaminants and biological toxicity. Integrated analysis and deep mining of monitoring data are insufficient, failing to fully leverage big data for risk identification, trend prediction, and source tracing in water source areas. Application of intelligent monitoring technologies remains in preliminary stages, with significant gaps compared to truly "smart water source" management.

#### ***4.3. Deficient Cross-Regional Collaborative Mechanisms***

The Maota River watershed spans multiple administrative regions, requiring clarification of protection responsibilities and benefit-sharing relationships between upstream and downstream areas. While basic coordination mechanisms have been established, issues regarding unclear responsibilities and coordination difficulties persist in specific problem-solving. Cross-regional ecological compensation mechanisms have not been substantially established, with insufficient economic compensation from downstream areas to upstream water conservation regions, affecting upstream protection enthusiasm.

#### ***4.4. Insufficient Technological Innovation Support***

Technology research and development specifically addressing special water source protection requirements lags behind, particularly regarding breakthrough innovations in high-efficiency low-consumption wastewater treatment technology, precise non-point source pollution control technology, and long-term ecological restoration technology. Technology transformation channels are not smooth, with many advanced technologies failing to be widely applied in water source areas due to high costs or poor adaptability. Insufficient enterprise investment in technological innovation and inadequate industry-university-research cooperation constrain overall improvement of water source area governance technology levels.

### **5. Innovation-Driven Pathways and Strategies**

#### ***5.1. Building Green Industrial Systems for Win-Win Outcomes***

First, the government should establish negative lists for industrial access and positive lists for green development in water source areas, strictly restricting high-pollution and high water-consumption industries while prioritizing support for green industries such as new energy vehicles, ecological agriculture, and ecological tourism. Second, the government should establish special funds for industrial transformation in water source areas to support traditional enterprises in green transformation and promote clean production technologies and circular economy models. Third, the government should explore mechanisms for realizing ecological product value, transforming ecological benefits of water source protection into economic benefits through ecological compensation, carbon sink trading, and other mechanisms, ensuring protectors receive reasonable returns.

#### ***5.2. Improving Intelligent Monitoring and Early Warning Systems***

First, the environment protecting department should intensify and optimize monitoring network layouts to achieve comprehensive coverage of key areas, sensitive sections, and risk sources, while increasing monitoring indicators for emerging pollutants and comprehensive biological toxicity. Second, the environment protecting department should construct intelligent supervision platforms for water source areas, integrating multi-source monitoring data and utilizing big data and artificial intelligence technologies for deep analysis, achieving intelligent early warning, rapid source tracing, and scientific prediction of water quality risks. Third, the environment protecting department should promote new technologies such as remote sensing monitoring, UAV patrols, and underwater robots to enhance spatiotemporal resolution of monitoring and emergency response capabilities.

### ***5.3. Innovating Cross-Regional Collaborative Protection Mechanisms***

First, the government should establish joint prevention and control mechanisms between upstream and downstream watershed areas, unifying protection standards and coordinating law enforcement supervision to achieve planning coordination, synchronized monitoring, and emergency linkage. Second, the government should improve horizontal ecological compensation systems, establishing scientifically reasonable compensation standards and dynamic adjustment mechanisms based on water quality improvement effectiveness and ecosystem service values. Third, the government should explore diversified compensation methods, including not only financial compensation but also industrial support, talent training, and project cooperation, enhancing compensation relevance and effectiveness.

### ***5.4. Strengthening Technology R&D and Transformation***

First, the government should establish special science and technology programs for water source protection, focusing on key technologies such as non-point source pollution control, aquatic ecological restoration, and risk early warning, organizing collaborative research among industry, academia, and research institutions. Second, the government should construct pilot bases and demonstration projects for water source area governance technologies to accelerate localization adaptation and large-scale application of advanced suitable technologies. Third, the government should improve incentives for technology transformation, providing rewards for technological achievements demonstrating significant effectiveness in water source protection to enhance enthusiasm among researchers and technical personnel.

### ***5.5. Improving Policy Guarantees and Public Participation***

First, the government should improve legal and regulatory systems for water source protection, clarifying responsibilities and rights of all parties and increasing penalties for violations. Second, the government should innovate policy tool combinations, comprehensively utilizing economic instruments such as fiscal subsidies, tax incentives, green credit, and environmental insurance to guide enterprises and public participation in water source protection. Third, the government should strengthen publicity and education to enhance public awareness of the importance of the South-to-North Water Diversion Project and the urgency of water source protection, broaden public participation channels, and build a co-governance pattern led by government, implemented by enterprises, supervised by society, and participated in by the public.

## **6. Conclusion**

Pilot practices in Maota River small watershed governance demonstrate that technological innovation serves as the critical lever for resolving conflicts between protection and development in South-to-North Water Diversion Middle Route water source areas. Through multi-dimensional innovations encompassing industrial green transformation, precise sewage treatment, intelligent monitoring upgrades, and ecosystem restoration, the pilot has promoted regional green development while ensuring water quality security, providing valuable experience for comprehensive small watershed management in water source areas.

However, achieving long-term effective protection of water source areas requires continuous deepening in institutional mechanisms, technological innovation, and policy guarantees. Future efforts should uphold systematic concepts, coordinate water source protection with watershed development, utilize technological innovation as the engine, intelligent management as the means, and collaborative governance as the safeguard. The goal is to establish a governance system for small watersheds in water source areas characterized by advanced technology, intelligent monitoring, flexible mechanisms, and extensive participation. Through continuous innovation and improvement, the Maota River watershed is positioned to become a model for water source protection featuring strong water quality assurance, complete ecological functions, green industrial development, and prosperous livelihoods, providing solid guarantees for long-term safe operation of the South-to-North Water Diversion Middle Route Project and offering replicable, scalable Maota River experience for water source protection and management in other important water source areas across China.

## Acknowledgements

This study is supported by the Doctoral Research Initiation Fund Project of Hubei University of Automotive Technology (BK202440), the Ministry of Education University-Industry Collaborative Education Program (250600116245053).

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