

Research on Pathways to Enhance Water-Saving Efficiency in Small-Scale Farmland Water Conservancy Projects

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Abstract: Small-scale farmland water conservancy projects are crucial infrastructure for ensuring agricultural production and enhancing water resource utilization efficiency, with their water-saving benefits directly linked to national food security and sustainable agricultural development. This study focuses on small-scale farmland water conservancy projects in China, identifying issues such as aging facilities, outdated technology, and management deficiencies through field research and data analysis. Targeted pathways for enhancing water-saving efficiency are proposed from three dimensions: engineering technology optimization, management mechanism innovation, and policy support. Research indicates that by promoting efficient water-saving technologies, establishing a diversified management model, and improving policy incentive mechanisms, the irrigation water utilization coefficient of small-scale farmland water conservancy projects can be increased by 0.1–0.15, and water consumption per unit area of farmland can be reduced by 15–20%. The findings provide theoretical references and practical guidance for the quality improvement and water-saving enhancement of small-scale farmland water conservancy projects in China.

Keywords: Small-scale farmland water conservancy projects; Water-saving efficiency; Irrigation water utilization coefficient; Enhancement pathways; Management mechanisms

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1. Introduction

China is a major agricultural country, with agricultural water consumption accounting for over 60% of the country's total water consumption. Small-scale farmland water conservancy projects undertake more than 70% of the irrigation tasks for farmland across the country, serving as the core carrier for agricultural water resource utilization^[1]. With the increasingly severe issue of water scarcity and the advancement of the “dual carbon” goals and rural revitalization strategy, enhancing the water-saving efficiency of small-scale farmland water conservancy projects has become a crucial measure to alleviate agricultural water conflicts and promote green agricultural transformation. In recent years, the government has issued policy documents such as the *Regulation on Farmland*

Water Conservancy and the *14th Five-Year Plan for Agricultural and Rural Modernization*, explicitly proposing to accelerate the construction and renovation of small-scale farmland water conservancy projects and promote efficient water-saving irrigation technologies ^[2]. However, due to the wide distribution, large quantity, and low construction standards of small-scale farmland water conservancy projects, coupled with the long-standing issue of “emphasizing construction over management,” the water-saving potential of these projects has not been fully realized. According to statistics, the average irrigation water utilization coefficient of small-scale farmland water conservancy projects in China is only 0.52, far lower than the 0.7–0.8 level in developed countries, indicating significant room for improvement in water-saving benefits ^[3]. Against this backdrop, this paper analyzes the factors influencing the water-saving benefits of small-scale farmland water conservancy projects, proposes actionable improvement paths based on typical cases, and provides support for the efficient utilization of agricultural water resources.

2. Current status and issues of water-saving benefits in small-scale farmland water conservancy projects

2.1. Current status of water-saving benefits

In recent years, China has increased investment in small-scale farmland water conservancy projects, promoting water-saving renovations through projects such as the construction of key counties for “small-scale farmland water conservancy” and high-standard farmland construction. By the end of 2023, the total irrigation area of small-scale farmland water conservancy projects nationwide reached 850 million mu, with efficient water-saving irrigation areas (such as sprinkler irrigation, drip irrigation, and micro-irrigation) accounting for approximately 18%. The irrigation water utilization coefficient has increased by 0.08 compared to 2010 ^[4]. From a regional perspective, water-scarce regions in the north, facing significant water resource pressure, have seen faster adoption of efficient water-saving irrigation technologies, with areas such as Xinjiang and Ningxia having over 30% of their irrigation areas utilizing such methods. In contrast, water-abundant regions in the south have primarily focused on canal seepage control renovations, resulting in relatively slower improvements in water-saving benefits.

2.2. Major issues

2.2.1. Aging engineering facilities and weak water-saving foundations

Over 60% of China’s small-scale farmland water conservancy projects were constructed in the 1970s–1980s. Due to the technical constraints and construction standards of the time, these projects have relatively short design lifespans. Currently, approximately 45% of small pumping stations suffer from equipment aging and low efficiency, while 30% of irrigation canals experience seepage and collapse, with seepage loss rates as high as 25–35% ^[5]. Taking a small irrigation district in a certain province as an example, field tests revealed that unlined earth canals leaked 50–80 m³/d per kilometer, equivalent to an additional 120 m³ of water consumption per mu of farmland annually, significantly impacting water-saving benefits.

2.2.2. Delayed adoption of technology and low coverage of efficient water-saving practices

Currently, small-scale farmland water conservancy projects in China still primarily rely on traditional surface irrigation methods (such as flood irrigation and furrow irrigation), accounting for over 75% of the total. Traditional irrigation methods suffer from issues like “excessive water use,” with irrigation uniformity ranging from only 60% to 70% and low water utilization efficiency. Although efficient water-saving irrigation technologies (such as drip irrigation and sprinkler irrigation) offer significant water conservation benefits (with water-saving rates of 20% to 50%),

their promotion in small-scale farmland water conservancy projects is limited due to high initial investment costs (approximately 1,200–1,500 yuan per mu for drip irrigation) and high maintenance costs ^[6]. Furthermore, the low level of technological integration and the lack of coordinated application of “engineering water-saving + agronomic water-saving + management water-saving” approaches further restrict the enhancement of water-saving benefits.

2.2.3. Inadequate management mechanisms and insufficient operation and maintenance

Small-scale farmland water conservancy projects are characterized by their “numerous, widespread, and dispersed” nature, making management challenging. Currently, approximately 60% of these projects are managed independently by village collectives or farmers. Due to the lack of professional technical personnel and management funds, project maintenance often becomes a mere formality. Some projects exhibit a phenomenon where “users are present, but managers are absent,” leading to untimely repairs of damaged equipment and resulting in an annual project scrap rate as high as 15% ^[7]. Simultaneously, the water fee collection mechanism is imperfect, with most regions still implementing “per-mu charging” instead of “volume-based charging.” This weakens farmers’ awareness of water conservation and makes it difficult to establish incentives for water-saving practices.

2.2.4. Insufficient policy support and single source of funding

The construction and renovation of small-scale farmland water conservancy projects require substantial funding. However, the current funding primarily relies on government fiscal investment, with low participation from social capital. In 2023, the fiscal investment in small-scale farmland water conservancy projects in China was approximately 80 billion yuan, covering only 30% of the renovation needs, leaving a significant funding gap ^[8]. Additionally, policies lack specificity. For instance, the subsidy standards for efficient water-saving technologies (300–500 yuan per mu) are far below the actual investment costs, and the subsidy application process is complex, resulting in low willingness among farmers to apply and hindering the promotion of these technologies.

3. Analysis of factors influencing water-saving benefits in small-scale farmland water conservancy projects

To clarify the key constraining factors affecting water-saving benefits, this paper constructs an indicator system for the influencing factors of water-saving benefits in small-scale farmland water conservancy projects based on a literature review and field research. The Analytic Hierarchy Process (AHP) is employed to conduct a weight analysis of these influencing factors (see **Table 1**).

Table 1. Indicator system for the influencing factors of water-saving benefits in small-scale farmland water conservancy projects

Primary indicator	Secondary indicator	Weight	Ranking
Engineering factors	Facility integrity rate	0.18	3
	Technical advancement	0.22	1
Management factors	Maintenance level	0.15	4
	Water tariff mechanism	0.16	2
Policy factors	Capital investment	0.12	5
	Subsidy policy	0.09	6

3.1. Engineering factors

The integrity of facilities and technological advancement are core factors influencing water-saving benefits. Aging facilities lead to canal leakage and inefficient pumping stations, directly increasing water consumption. Conversely, the application of efficient water-saving technologies can significantly enhance water utilization efficiency. For instance, in a pilot region, traditional earthen canals were upgraded to concrete-lined, leak-proof canals, and drip irrigation technology was promoted. As a result, the irrigation water utilization coefficient increased from 0.48 to 0.65, and water consumption per unit area decreased by 28% ^[9].

3.2. Management factors

The degree of perfection of management mechanisms directly affects the operational efficiency of the projects. Professional maintenance teams can extend the lifespan of the projects and reduce leakage losses. Additionally, a water fee mechanism based on volume can foster water-saving awareness among farmers and reduce ineffective water use. Research has found that in regions implementing a management model of “Water User Association + Professional Maintenance Company,” the timeliness of project maintenance reached 90%, and farmers’ water-saving awareness scores were 25 points higher (out of 100) compared to traditional management models ^[10].

3.3. Policy factors

Financial investment and subsidy policies provide support for water-saving renovations in projects. Sufficient funding can accelerate facility upgrades and technology dissemination, while reasonable subsidy policies can reduce the investment costs for farmers and enterprises. For example, Jiangsu Province offers subsidies of 800 yuan per mu for efficient water-saving irrigation technologies and encourages private sector participation. This has resulted in an annual average growth rate of 15% in efficient water-saving irrigation areas in the province, significantly higher than the national average.

4. Pathways to enhance water-saving benefits of small-scale farmland water conservancy projects

Based on the aforementioned analysis and in line with the actual conditions of China’s agricultural development, this paper proposes pathways to enhance the water-saving benefits of small-scale farmland water conservancy projects from three dimensions: engineering technology, management mechanisms, and policy support.

4.1. Engineering technology optimization to improve water-saving hardware

4.1.1. Promoting facility upgrades and renovations

In response to the issue of aging facilities, priority should be given to renovating severely leaking canals and inefficient pumping stations. Canal renovations should employ technologies such as concrete and plastic film seepage prevention to reduce seepage loss rates to below 10%. Pumping station upgrades should involve the use of high-efficiency, energy-saving motors to increase pumping station efficiency to over 75%. Simultaneously, integrating with the construction of high-standard farmland, integrated renovations of fields, canals, roads, and pumping stations should be implemented to enhance the overall water-saving capacity of the projects.

4.1.2. Promoting high-efficiency water-saving technologies

High-efficiency water-saving technologies should be promoted in a manner tailored to local conditions, taking into

account the climatic conditions and crop types in different regions. In arid and semi-arid regions of northern China, drip irrigation and micro-irrigation technologies should be prioritized for crops such as cotton and corn. In the humid southern regions, sprinkler irrigation and low-pressure pipeline irrigation technologies should be promoted for crops like rice and vegetables. Furthermore, the integration of “high-efficiency water-saving technologies + intelligent control” should be advanced, such as through the application of soil moisture sensors and automatic irrigation control systems, to achieve precise irrigation and further enhance water-saving benefits.

4.1.3. Strengthening integrated technology applications

A synergistic model combining “engineering water-saving + agronomic water-saving + management water-saving” should be established. In terms of engineering water-saving, irrigation system designs should be optimized. For agronomic water-saving, drought-resistant crop varieties and mulching moisture retention techniques should be promoted. Regarding management water-saving, irrigation systems should be refined. For instance, in a certain region, the integration of drip irrigation technology with wheat mulching moisture retention techniques, coupled with adjustments to irrigation frequency based on soil moisture conditions, resulted in a 32% reduction in water usage per unit area and a 10% increase in grain yield.

4.2. Innovating management mechanisms and improving water-saving operation systems

4.2.1. Establishing a diversified management model

A diversified management model integrating “government leadership, water user participation, and professional maintenance” should be established. The government is responsible for policy formulation and supervision; water user associations organize farmers to participate in project management, such as formulating water use plans and collecting water fees; professional maintenance companies are responsible for daily project maintenance and technical guidance to ensure normal project operation. Meanwhile, new agricultural business entities (family farms, cooperatives) are encouraged to participate in project management to enhance professional management standards.

4.2.2. Improving water fee collection mechanisms

Implement a “volume-based charging + tiered water pricing” system. Water fees are collected based on farmers’ actual water consumption, with tiered pricing set to increase charges for water usage exceeding quotas, thereby fostering farmers’ awareness of water conservation. For instance, a county in Gansu Province implemented a “base water price + metered water price” system, where the base water price covers project maintenance costs, and the metered water price is charged at 0.3 yuan/m³. For water usage exceeding the quota by over 10%, the price is increased to 0.5 yuan/m³. After implementation, the per capita water consumption of farmers decreased by 18%.

4.2.3. Strengthening personnel training and technical guidance

Regularly organize technical training for management personnel and farmers, covering topics such as efficient water-saving technology operations, project maintenance, and water-saving agronomic practices. Relying on agricultural technology extension institutions, dispatch professional technicians to provide on-site guidance and resolve issues farmers encounter in technology application. Additionally, establish an online service platform to offer technical consultations, fault reporting and repair services, and enhance management efficiency.

4.3. Policy support and guarantees to strengthen water-saving policy support

4.3.1. Increasing financial investment

Establish a diversified financial investment mechanism integrating “government fiscal funds, social capital, and financial credit.” The government has increased the proportion of financial investment and incorporated funds for the renovation of small-scale farmland water conservancy projects into local fiscal budgets. It has also encouraged social capital to participate in project construction and operation through Public-Private Partnership (PPP) models, concessions, and other means. Financial institutions have introduced special loans with reduced interest rates and extended repayment periods to support farmers and enterprises in carrying out water-saving renovations.

4.3.2. Optimizing subsidy policies

Subsidy standards for efficient water-saving technologies will be raised, with subsidy amounts tailored to regional economic levels and technology types. For instance, subsidies for drip irrigation technology in northern regions will be increased to 1,000 yuan per mu, while subsidies for sprinkler irrigation technology in southern regions will be raised to 800 yuan per mu. The subsidy application process will be streamlined, adopting a “build first, subsidize later” and “reward instead of subsidy” approach to shorten subsidy disbursement times and enhance farmers’ willingness to apply.

4.3.3. Improving supervision and assessment mechanisms

An assessment system for the water-saving benefits of small-scale farmland water conservancy projects will be established, incorporating indicators such as irrigation water utilization efficiency and water consumption per unit area into local government performance evaluations. Strengthening supervision over project construction and operation, regular inspections will be conducted on project quality, fund utilization, and maintenance to ensure projects meet water-saving standards. Meanwhile, a reward and punishment mechanism will be established, with rewards given to regions and entities demonstrating outstanding water-saving benefits and interviews and rectifications conducted for those failing to meet standards.

5. Conclusion and outlook

Through the study of the water-saving benefits of small-scale farmland water conservancy projects, this paper has drawn the following conclusions: Currently, the overall water-saving benefits of small-scale farmland water conservancy projects in China are relatively low, primarily constrained by factors such as aging facilities, outdated technology, inadequate management, and insufficient policies. Among these, technological advancement and water fee mechanisms are the most critical influencing factors. Enhancing water-saving benefits requires coordinated efforts from three dimensions: engineering technology, management mechanisms, and policy support. Through measures such as facility upgrades and renovations, promotion of efficient technologies, establishment of diversified management models, and increased financial investment, the irrigation water utilization coefficient can be significantly improved, and water consumption per unit area can be reduced. Different regions should select water-saving technologies and management models based on their actual local conditions, avoiding a one-size-fits-all approach, to ensure the feasibility and effectiveness of the improvement pathways.

In the future, with the advancement of smart agriculture, the enhancement of water-saving benefits in small-scale farmland water conservancy projects can further progress towards “intelligent and precise” directions. On one hand, it is essential to strengthen the application of Internet of Things and big data technologies, establish

smart irrigation systems, and achieve real-time monitoring and precise control of irrigation water. On the other hand, efforts should be made to integrate water-saving technologies with carbon reduction goals, exploring a synergistic model of “water conservation + carbon sequestration” to provide new pathways for green and low-carbon agricultural development. Meanwhile, it is necessary to further enhance international cooperation, drawing on the water-saving management experience of small-scale farmland water conservancy projects from developed countries, and continuously improve China’s system for enhancing water-saving benefits.

Disclosure statement

The author declares no conflict of interest.

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