Postprint: Operational Management Evaluation of Rural Drinking Water Safety Projects in Gansu Province

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Abstract

Rural drinking water safety projects constitute a critical livelihood initiative for achieving comprehensive moderate prosperity. This study, based on statistical data, field investigations, and survey questionnaires, employs the entropy weight method and fuzzy mathematics approach to evaluate the current operational management status of rural drinking water safety projects in Gansu Province. The objective is to establish a comprehensive, systematic, rational, and sustainable evaluation framework, while simultaneously analyzing existing problems in the operation and management of drinking water safety projects. The results indicate: (1) The operational management status of rural drinking water safety projects in Gansu Province is generally satisfactory; however, substantial inter-regional disparities exist, with the five cities in the Hexi Corridor exhibiting superior evaluation outcomes, while counties (cities, districts) in the southern region demonstrate relatively inferior results. (2) For regions receiving an evaluation grade of "fair," further optimization is required in policy implementation, updating and enforcement of management regulations, enhancement of public maintenance awareness, development of pipeline management personnel, and intelligentization of water supply pipeline infrastructure. Through years of practical exploration, Gansu Province has developed a distinctive construction model for drinking water safety projects that integrates both centralized and decentralized water supply systems. This study seeks to provide feasible policy recommendations for the construction of rural drinking water safety projects, while concurrently offering technical support and a scientific basis for future rural drinking water safety initiatives in Gansu Province and other regions across the nation.

Full Text

Evaluation of the Operation and Management of Rural Drinking Water Safety Projects in Gansu Province

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Abstract

Rural drinking water safety projects are major livelihood initiatives essential for achieving a comprehensively well-off society. Based on statistical data, field investigations, and questionnaire surveys, this study employs the entropy weight method and fuzzy mathematics to evaluate the current status of operation and management of rural drinking water safety projects in Gansu Province. The aim is to establish a comprehensive, systematic, and sustainable evaluation framework while analyzing existing problems in project operation and management. The results indicate that: (1) The overall operation and management status of rural drinking water safety projects in Gansu Province is good, but significant regional disparities exist within the province. The evaluation results for counties (cities, districts) in the Hexi region are relatively favorable, while those in the southern region are comparatively poor. (2) For areas rated as "general," further optimization is needed in policy implementation, updating and enforcement of management regulations, raising public maintenance awareness, building water management teams, and developing intelligent water supply pipeline systems. Through years of practical exploration, Gansu Province has developed a distinctive construction model that combines centralized and decentralized water supply projects. This study provides practical recommendations for rural drinking water safety project development and offers technical support and scientific basis for future rural drinking water safety initiatives in Gansu and other regions nationwide.

Keywords: rural drinking water safety; drinking water projects; operation and management; evaluation; Gansu

Introduction

Rural drinking water safety has long been a societal concern in China. Since the 13th Five-Year Plan period, the state has prioritized drinking water issues in rural impoverished areas. Under these circumstances, Gansu Province took the lead in completing rural drinking water safety poverty alleviation construction. However, current rural drinking water safety projects still face challenges including low construction standards, surface water pollution, and inadequate tap water penetration rates.

International attention to drinking water safety emerged earlier. Beginning in the 1970s, the United States, European Union, and Netherlands successively focused on rural water management guidelines and vigorously constructed drinking water projects. During implementation, it became evident that engineering technology alone could not solve all drinking water problems. Water shortages were largely related to poor water source management, necessitating new management systems for effective water source governance. Developed countries primarily ensure drinking water safety through improved legislation, water source protection, emergency mechanisms, water quality monitoring, and technical equipment.

Domestic attention to drinking water safety began later but has developed rapidly. Previous research has established various evaluation indicator systems from different perspectives. Kuang Weiming et al. surveyed the status of drinking water safety projects in Jiangxi Province, proposing a suitable evaluation index system covering pre-construction, construction, and post-construction phases. Liu Lixia et al. combined entropy weight method with comprehensive evaluation to quantitatively assess rural drinking water safety in Yunnan Province, demonstrating that this combination can objectively determine safety status. Yang Caijie et al. developed an evaluation system tailored for Zhejiang Province. Li Bin et al. established 18 specific indicators to evaluate rural drinking water safety project effectiveness. Zhang Li et al. studied water user satisfaction evaluation methods for drinking water safety projects in northern Jiangsu, identifying weak links and providing constructive suggestions. Chen Peng evaluated rural water supply projects in Jinan from water supply status, project operation, personnel systems, benefits, ecological environment, and economic indicators. Existing studies tend to be fragmented with different focuses, lacking broad applicability.

In recent years, numerous problems have emerged in the operation of built rural water supply projects. For instance, unreasonable overall layout of water supply systems causes insufficient raw water quantity; water source quality fails to meet requirements, particularly as water pollution intensifies; rural water treatment plants are small-scale with substandard water treatment; and inadequate operation management or high costs prevent genuine solutions to rural drinking water safety. Common characteristics of relevant research include proposing suitable evaluation indicators based on specific rural conditions and practical experience from different perspectives. Overall, further research is needed at different scales including regional, economic development, and natural condition levels.

Regarding evaluation methods, scholars have employed various approaches including Analytic Hierarchy Process, catastrophe theory, fuzzy mathematics, and entropy weight method. Some have established drinking water project evaluation models using these methods, while others have developed visualization models for rural drinking water safety project operation and management. Building upon previous research, this study constructs an evaluation model using entropy weight method and fuzzy comprehensive evaluation.

1. Data and Methods

1.1 Natural Conditions and Basic Information on Rural Drinking Water Safety Gansu Province is located in the inland northwest of China, belonging to arid and semi-arid regions with scarce water resources. The province features complex and diverse landforms, predominantly mountains, hills, deserts, and Gobi, with dense ridges and gullies, poor natural conditions, and scattered population distribution, making rural drinking water safety extremely difficult to address. By the end of 2020, Gansu Province had built 4,030,500 rural drinking water projects (serving over 100 people), covering 22.9 million rural population, including 19.4823 million people through centralized supply and 0.8228 million through decentralized supply. The rural drinking water centralization rate reached 85.1%, large-scale project coverage 82.28%, tap water penetration rate 88%, natural village water access rate 98%, and water source protection zone demarcation rate for projects serving over 1,000 people 100%.

1.2 Management Structure 1.2.1 Management Institutions
Gansu Province' s rural drinking water safety operation management institutions include: provincial Rural Drinking Water Safety Management Office, municipal/prefectural departments responsible for rural drinking water safety, county-level rural drinking water safety management stations, township-level water management stations, and village collective organizations and water user associations. County-level management institutions vary by county characteristics, primarily including county rural drinking water safety project management offices, management stations, water supply companies, water affairs investment companies, and integrated water conservancy technical service stations.

1.2.2 Management Models
Three main models exist: (1) Large-scale centralized water supply projects across regions or watersheds, managed primarily by county-level specialized agencies or professional companies; (2) Small-scale single-village water supply projects, managed mainly by township water stations, village collectives, or individuals and associations through contract management; (3) Decentralized water supply projects such as water cellars and small electric wells, managed by individual users.

1.2.3 Management and Service Mechanisms
All 86 counties (cities, districts) and Jiayuguan City have established "three responsibilities" (county government as main body, water administration department supervision, and water supply unit operation management) and "three systems" (specialized county-level management agencies, operation management

methods, and funding) according to the Gansu Province Rural Drinking Water Supply Management Regulations. "Three types of information" (operation management units, personnel, and water fee collection) are publicly disclosed. The province's 86 water quality testing centers and laboratories for large water plants have implemented equipment, personnel, and funding, basically achieving comprehensive routine water quality testing coverage. All projects have established pricing, forming a diversified water fee collection system based on single-part and two-part water pricing.

2.1 Data Sources Data on Gansu Province' s rural drinking water project operation management primarily come from questionnaires and provincial statistics (data up to 2020). Questionnaires were completed in 2020 through field investigations and online surveys. A total of 2,000 questionnaires were distributed, with 1,856 returned and 1,842 valid.

2.2 Evaluation System Construction This evaluation covers 87 administrative units (86 counties/cities/districts plus Jiayuguan City). Evaluation indicators must follow principles of scientific validity, operability, comprehensiveness, systematicity, hierarchy, and dynamism. Based on these principles and actual rural drinking water safety project conditions, the evaluation indicators were selected as shown in Table 1.

Table 1. Evaluation index system of rural drinking water project operation and management in Gansu Province

Primary Indicator	Secondary Indicator	Indicator Description
Organizational Management	Management Personnel Allocation	Whether professional water supply management personnel or trained part-time staff exist
	Sound Mechanisms and Execution	Principles and adjustment mechanisms for problem response; execution and efficiency of management personnel
Safety Management	Water Supply Guarantee Rate	Probability that expected water supply can be fully met in multi-year supply
	Production Technology and Equipment	Whether water extraction and purification processes are reasonable and treatment equipment is timely updated

Primary Indicator	Secondary Indicator	Indicator Description
	Facilities and Pipeline Conditions	Damage status of water storage facilities and pipelines; intact rate of water supply facilities
Engineering Management	Village-level Water Pipefitters	Quantity of village-level water pipefitters
	Water Quality Monitoring Rate	Regional water quality monitoring coverage ratio
Economic Management	Water Fee Collection Rate	Ratio of actual collected water fees to payable fees
	Fund Management	Whether fund management in construction and operation is reasonable
Sustainable Capacity	Maintenance and Repair	Timeliness of project maintenance and repair
	Special Funds	Whether special funds support project construction
	Water Source Protection	Whether water source protection measures exist

2.3 Evaluation Methods 2.3.1 Entropy Weight Method

Dimensionless Processing of Evaluation Indicators. Before evaluation, all indicators in the sample matrix are nondimensionalized using linear interpolation. The original indicator data matrix is given by formula (1). Indicators are typically classified as positive or negative. Positive indicators are those where values are directly proportional to evaluation grades, standardized using formula (2):

$$Y_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}}$$

Negative indicators are inversely proportional to evaluation grades, standardized using formula (3):

$$Y_{ij} = 1 - \frac{X_{ij} - X_{min}}{X_{max} - X_{min}}$$

where X_{max} is the maximum indicator value and X_{min} is the minimum.

Determination of Indicator Weights. The entropy weight method determines weights through the following steps:
Indicator entropy value e_j is calculated as:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} y_{ij}\ln y_{ij}$$

where $y_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}}$ represents the proportion of sample i in indicator j, and $k = 1/\ln m$ is used for calculation. The weight of indicator j is:

$$W_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)}$$

2.3.2 Fuzzy Mathematics Method

Evaluation of drinking water project operation and management is a typical multi-indicator decision problem that cannot rely on single-indicator results. Fuzzy mathematics can largely preserve original indicator information, making it suitable for this evaluation.

The evaluation standards are divided into four grades: excellent, good, general, and poor. U represents the membership degree matrix. The relative membership degree is calculated as follows:

For positive indicators, when the indicator value exceeds the "excellent" threshold, its membership degree to "excellent" is 1 and 0 to other grades. When indicator x_i falls between grade thresholds $s_{i,n}$ and $s_{i,n+1}$, its membership degrees to grades n and $n+1$ are calculated using formulas (5) and (6):

$$U_{in} = \frac{s_{i,n+1} - x_i}{s_{i,n+1} - s_{i,n}}$$

$$U_{i,n+1} = \frac{x_i - s_{i,n}}{s_{i,n+1} - s_{i,n}}$$

When the indicator value is below the "poor" threshold, its membership degree to "poor" is 1 and 0 to other grades. Negative indicators use the opposite calculation method.

2.4 Evaluation Index Grade Thresholds Evaluation grades for rural drinking water safety project operation and management in Gansu Province are divided into four levels using a percentile system. Thresholds for each indicator are shown in Table 2.

Table 2. Evaluation level threshold of rural drinking water project operation and management in Gansu Province

Indicator	Excellent	Good	General	Poor
Management Personnel Allocation	90-100	80-89	60-79	<60
Sound Mechanisms and Execution	90-100	80-89	60-79	<60
Water Supply Guarantee Rate	$ $98%	95-97%	90-94%	<90%
Production Technology and Equipment	90-100	80-89	60-79	<60
Facilities and Pipeline Conditions	$ $95%	90-94%	85-89%	<85%
Village-level Water Pipefitters	90-100	80-89	60-79	<60
Water Quality Monitoring Rate	$ $95%	90-94%	85-89%	<85%
Water Fee Collection Rate	$ $95%	90-94%	85-89%	<85%

3. Results

3.1 Weights of Rural Drinking Water Safety Project Operation and Management Indicators in Gansu Province Using the entropy method, weights for primary and secondary indicators were determined. Among primary indicators, organizational management and sustainable capacity have relatively large weights at 0.35 and 0.25 respectively, while safety management and engineering management each have 0.20, and economic management has the smallest weight at 0.15. After multiplying primary and secondary weights, final normalized weights for secondary indicators were obtained (Table 3).

Table 3. Evaluation index weight of rural drinking water project operation and management in Gansu Province

Primary Indicator	Weight	Secondary Indicator	Weight	Final Normalized Weight
Organizational Management	0.35	Management Personnel Allocation	0.30	10.5%
		Sound Mechanisms and Execution	0.40	14.0%

Primary Indicator	Weight	Secondary Indicator	Weight	Final Normalized Weight
		Water Supply Guarantee Rate	0.30	10.5%
Safety Management	0.20	Production Technology and Equipment	0.35	7.0%
		Facilities and Pipeline Conditions	0.35	7.0%
		Water Quality Monitoring Rate	0.30	6.0%
Engineering Management	0.20	Village-level Water Pipefitters	0.15	3.0%
		Water Fee Collection Rate	0.40	8.0%
Economic Management	0.15	Fund Management	0.60	9.0%
Sustainable Capacity	0.25	Maintenance and Repair	0.35	8.75%
		Special Funds	0.35	8.75%
		Water Source Protection	0.30	7.5%

Water quality monitoring rate has the highest weight (6.0%), followed by water fee collection rate (8.0%). Sound mechanisms and execution, maintenance and repair also have substantial weights at 14.0% and 8.75% respectively. The smallest weight is for village-level water pipefitters (3.0%). While village-level water pipefitter team building is crucial, the number of pipefitters per village is relatively fixed across Gansu' s rural areas, with no significant differences between cities or counties, resulting in a smaller weight.

3.2 Evaluation Results of Rural Drinking Water Safety Project Operation and Management in Gansu Province Among 87 counties (cities, districts), 17 have "excellent"ratings (19.5%), 64 have "good"ratings (73.6%), and 6 have "general" ratings (6.9%): Dangchang County (Longnan City), Kongdong District (Pingliang City), Qinzhou District (Tianshui City), Wushan County (Tianshui City), Xigu District (Lanzhou City), and Yongdeng County (Lanzhou City), Zhengning County (Qingyang City). Figure 2 shows the spatial distribution of evaluation grades.

At the municipal level, the average evaluation value is 3.4. Zhangye City and Wuwei City in western Gansu have values above 3.5, rated "excellent," while other cities range 2.9-3.5, rated "good."Through gradual improvement of systems, mechanisms, and responsibility frameworks, the province' s project operation and management levels are generally good, meeting current requirements.

4. Discussion

4.1 Attribution Analysis of Evaluation Grade Differences Comparing the six "general" rated counties with "good" and "excellent" counties reveals key influencing indicators. Differences between "general" and "good" grades mainly appear in policy systems, sound mechanisms and execution, maintenance and repair, village-level water pipefitters, and water quality monitoring. Differences between "general" and "excellent" grades additionally include water fee collection rate.

Survey results show: (1) Policy systems lack perfect operation management methods and targeted regulations; (2) Management units cannot efficiently resolve water use conflicts; (3) Public awareness of facility maintenance is weak with poor maintenance timeliness; (4) Water pipefitter training and capacity building are insufficient; (5) Professional water quality testing capabilities are weak. These areas require strengthening.

Previous studies on other provinces also emphasize strengthening water quality monitoring, post-construction management, funding availability, and information system development. Research on the Yellow River Basin suggests comprehensive measures including enhanced facility construction and management, water source protection and monitoring, and prioritized guarantee of water quantity and quality.

4.2 Discussion on Gansu Province' s Rural Drinking Water Safety Project Construction Model Gansu has implemented both centralized and decentralized water supply projects. In suitable areas, particularly western and central Gansu, large-scale centralized projects were built through merging smaller systems. These areas now lead the province in tap water penetration and centralization rates.

Decentralized projects (mainly small electric wells and water cellars) are distributed in central-eastern mountainous areas where centralized projects are costly and ineffective. Representative counties include Huan County, Huachi County, Qingcheng County, Zhenyuan County (Qingyang City), Maiji District (Tianshui City), Li County (Longnan City), Min County (Dingxi City), and Huining County (Baiyin City), each with over 5,000 decentralized projects.

Water cellars, the main water storage form in mountainous areas, face contamination risks from poor catchment environments. To improve water quality and sanitation awareness, authorities have provided water cellar purification equipment, widely used in Huan County, Huachi County, Qingcheng County, Yuzhong County (Lanzhou City), Huining County, Jingyuan County (Baiyin City), Li County, and Wudu District (Longnan City). These devices are popular among residents for reducing scale and impurities.

Overall, Gansu has formed a distinctive model combining centralized and decentralized approaches. In plains areas, large centralized projects with backup water sources improve supply guarantee rates. In mountainous areas, flexible decentralized projects with enhanced water quality monitoring and purification equipment improve drinking water safety.

5. Conclusions

Using entropy weight method and fuzzy mathematics, this study evaluates rural drinking water safety project operation and management in Gansu Province. Key conclusions are:

1. **Overall good status with regional disparities**: At county level, 19.5% are "excellent," 73.6% "good," and 6.9% "general." Western regions perform better than central-eastern areas. At municipal level, only Zhangye and Wuwei achieve "excellent" ratings.
2. **Key issues in "general" rated areas**: Deficiencies exist in policy systems, mechanism execution, maintenance awareness, water pipefitter capacity, and water quality monitoring technology. These require targeted strengthening.
3. **Distinctive construction model**: Gansu has developed a characteristic model combining centralized and decentralized projects. Plains areas use large centralized systems, while mountainous areas employ flexible decentralized approaches with water quality purification equipment. This model can be applied in other regions, particularly hilly and mountainous areas, adapting to local conditions to improve rural drinking water safety.

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Figures

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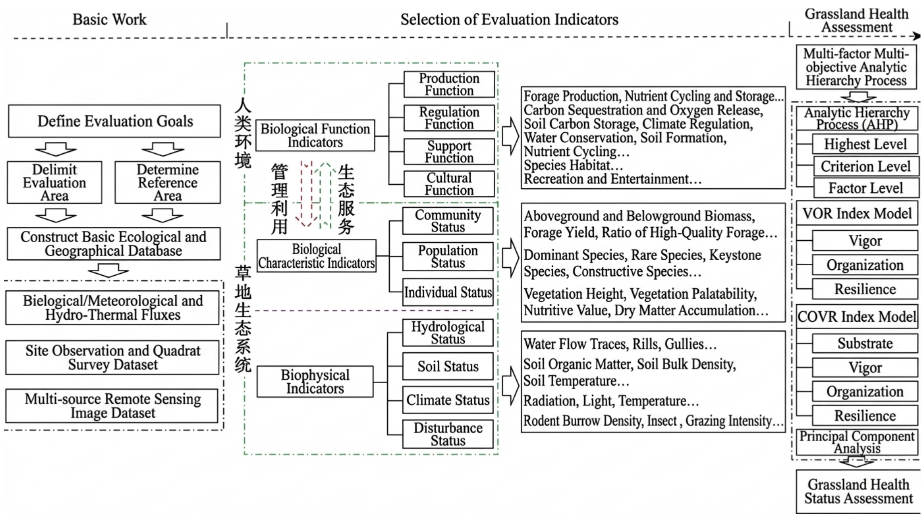

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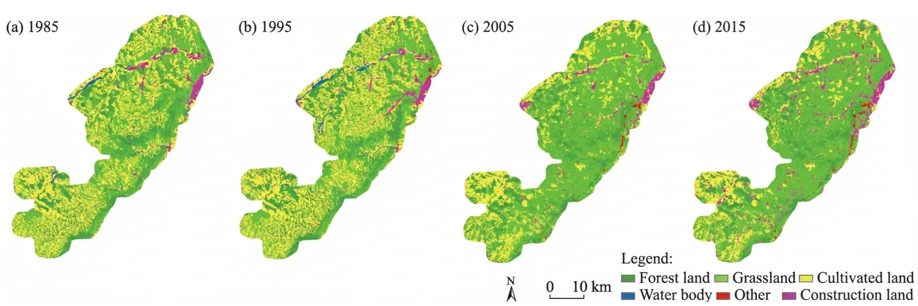

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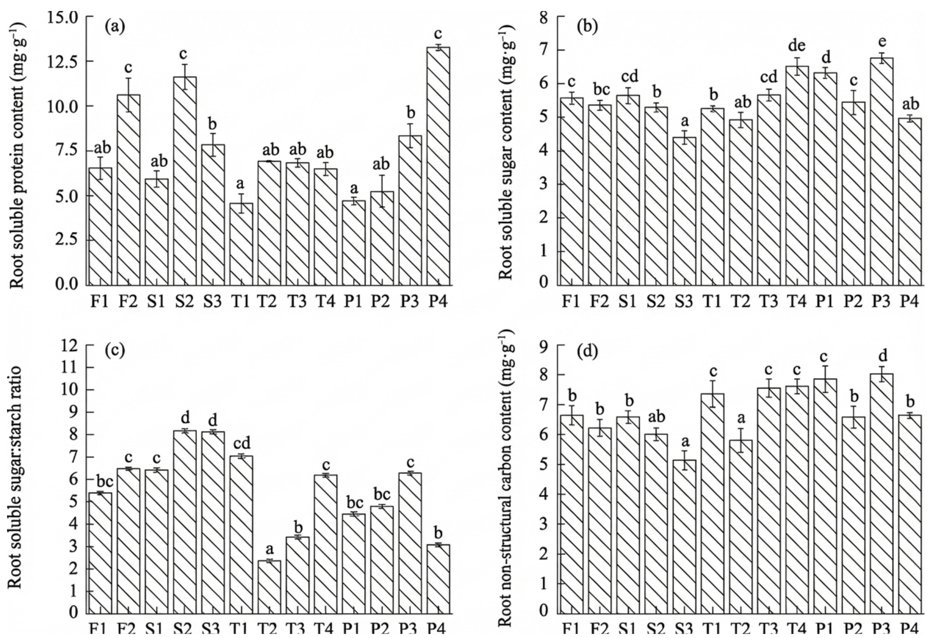

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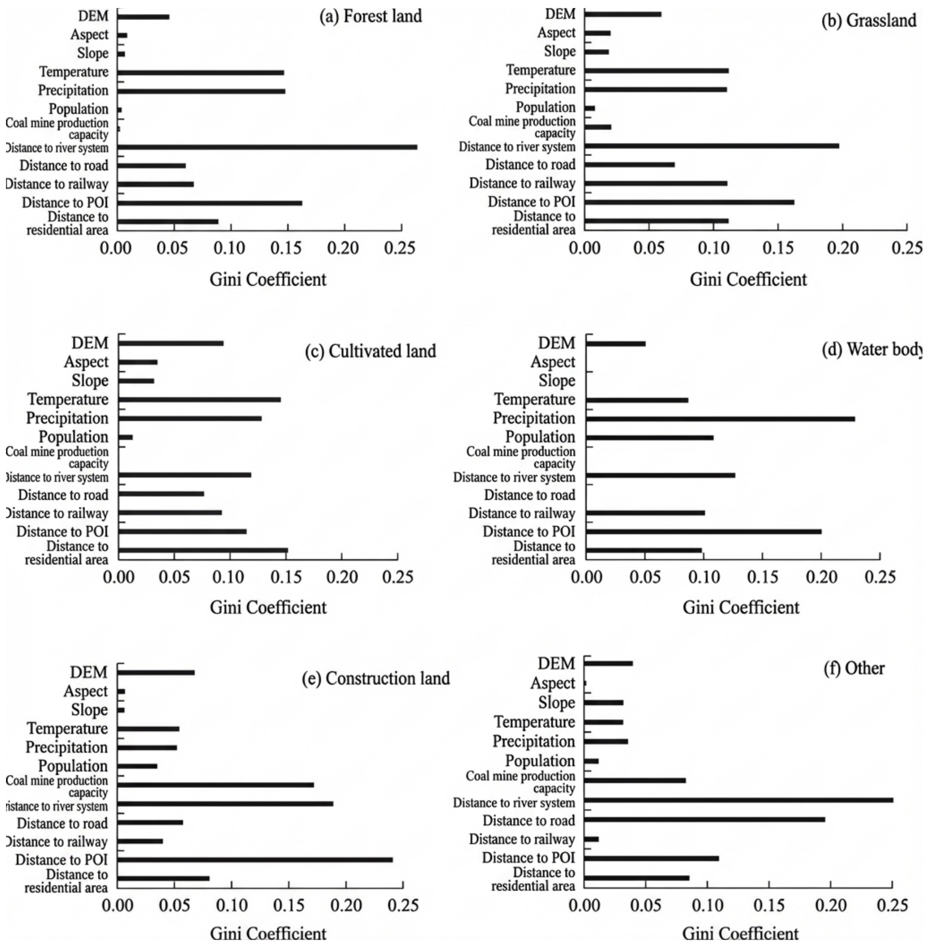

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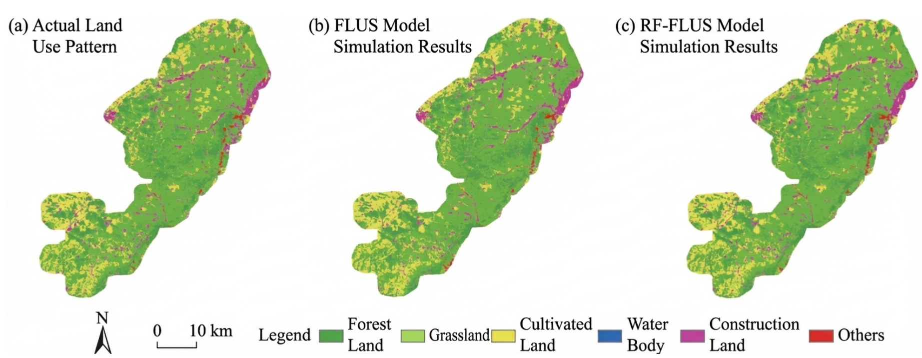

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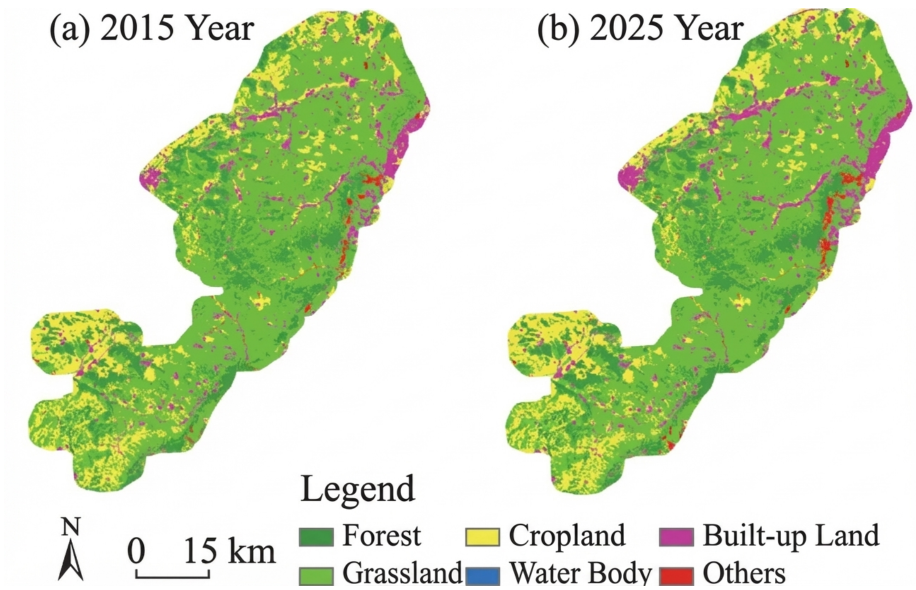

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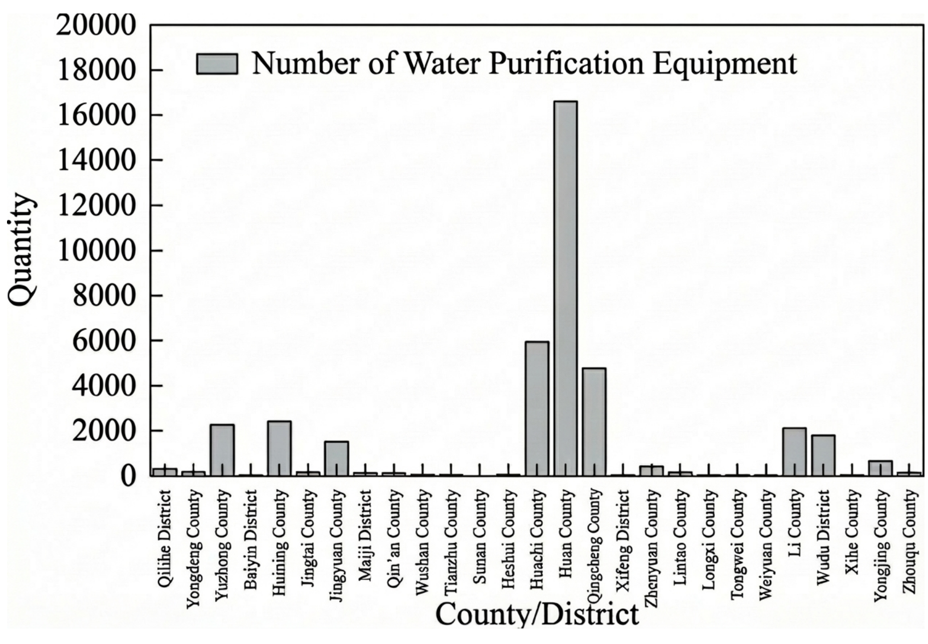

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