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A Comprehensive Post Evaluation of the Implementation of Water-Saving Measures in Xiangtan, Hunan Province, China

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Abstract: Water resource is an important foundation to support industrial and agricultural production, in the maintenance of national energy security role is irreplaceable. Water conservation and the effective use of water resources are essential for achieving sustainable development in China. The construction of water-saving society is a prerequisite for realizing efficient utilization of water resources and an important strategic development for moving towards environment-friendly society. This study established an index system to evaluate the implementation of water-saving measures in Xiangtan, Hunan province, China. The index system incorporated five aspects: (1) comprehensiveness; (2) agricultural water; (3) industrial water; (4) domestic water, and; (5) aquatic ecology and environmental management. Analytic hierarchy (AH) was used to determine the weights of indices, and AH was integrated with grey relative analysis to establish a comprehensive system for the evaluation of the water-saving measures in Xiangtan. The results showed that the implementation of water-saving measures in Xiangtan is generally progressing well. However, industrial added value water consumption per 10,000-yuan remains at the primary stage and wastewater reuse remains limited. In addition, water use per 10,000-yuan gross domestic product, the coverage of water-saving irrigation projects, industrial wastewater reuse, and the leakage rate of urban water supply network remain at an intermediate stage. The result of this study can scientifically reflect the level of the water-saving measures in place in Xiangtan and could guide future implementation of water saving measures in Xiangtan and in other cities.

Keywords: water-saving measures; analytic hierarchy process; grey relative analysis; index system

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1. Introduction

Water resources are becoming increasingly limited under the impacts of global economic development, climate change, and continuous population growth. Especially because of the discharge of industrial, agricultural and domestic wastewater, the water environment pollution is particularly prominent [1,2] (Fares R2015 and 2021). Therefore, there has been an increasing focus, both among regulatory agencies and academia, in identifying methods of improving the efficiency of utilization of water resources [3,4]. At present, many countries have not put forward the concept of water-saving society, the construction of water-saving society has not been formed, lack of experience [5]. The existing research is mainly, Sweden, Israel and other countries simply in the field of water demand management has made some theoretical model. Scholars of various countries focus on the impact of economic benefits on economic behavior, but there is little research on water-saving evaluation. Although there is a certain understanding of the research on water-saving society and its importance at present, there is a lack of systematic in-depth analysis on the connotation, evaluation system and incentive mechanism of water-saving society.

At present, China's first batch of water-saving society construction pilot is facing the urgent task of acceptance. How to scientifically and rationally evaluate the performance of the construction of water-saving society is the construction of water-saving society is an urgent need to answer the question, is also a basic guarantee of the effective implementation of the construction of water-saving society. The implementation of water saving measures not only facilitates the efficient use of water to avoid wastage, but also reduces discharge of wastewater to the environment, thereby having less impact on the aquatic ecology [6]. Establishing water saving measures is therefore one of the essential measures required to achieve sustainable development in China. Water saving measures have been piloted in various cities in China, all of which have committed to achieving targets of water consumption per unit of gross domestic product (GDP) and per-capita water consumption through the formulation of a total water consumption index and the implementation of a water supply plan [7–9]. To develop water-saving society construction after evaluation, will provide reference for the related research, is conducive to promoting water saving work in China, the implementation of resource, economy, society and ecological environment coordinated development, and for regional water environment protection and sustainable utilization of water resources to provide scientific decision basis. The present study conducted a post evaluation of the implementation of water saving measures within Xiangtan, one of the pilot cities in which the water saving measures have achieved a degree of maturity. The aim of the present study was to explore the different measures, evaluate their effectiveness, and analyze persisting challenges. It is hoped that the results of the present study can promote the further implementation of water saving measures in pilot cities and that the study can act as a reference for the implementation of water saving measures in other regions [10–12].

2. Literature Review

Most existing studies on water conservation have focused on policies and various water saving measures, and relatively few studies have analyzed the effects of these measures on society after they had been implemented, including a few studies in China. Wang et al. [13] evaluated the effects of water saving measures in a city located in the Chengdu plain using analytic hierarchy process (AHP). Yan et al. [14] established a fuzzy AHP model for evaluating water saving measure, which they applied to the Nianchu River Basin in Tibet. Che et al. [15] used the Pressure-State-Response (PSR) model to establish an index system for the comprehensive evaluation of water saving measures in a city, which they applied to the city of Yangzhou through principal component analysis (PCA). Zhao et al. [16] established an index system to evaluate water saving measures using matter-element analysis and calculated the weights of indices according to their contributions to total water savings, which they applied to evaluate the effect of water saving measures in Shanghai. Li et al. [17] proposed the water savings evaluation method TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), which is based on the AHP method, to evaluate the effects of water saving measures in Guangdong province.

While the AHP and fuzzy evaluation methods have been widely adopted within studies of water saving measures, PCA and matter-element analysis have been seldom applied. The current study established a water savings evaluation index for Xiangtan which represents all stages of the implementation of water saving measures. The AHP method was used to determine the weights of the evaluation indices, thereby constructing a comprehensive model for evaluating saving society measures in Xiangtan through integrating grey relative analysis (GRA) with AHP. The method was previously applied to evaluate the status of water saving measures in the city of Jiangyin.

The establishment of a complete and scientific index for evaluating water saving measures is necessary for the setting of scientific water savings targets and for scientifically assessing progress in water conservation initiatives in various cities and regions. It would not be optimal to apply the same water savings evaluation method to all cities, and instead the evaluation standard should be set according to the specific water resources, level of economic development, and development plans of the various regions. The construction of water-saving society is a multi-level and multi-factor complex system, which is a typical gray system in which part information is known and part information is unknown. The evaluation indexes of water-saving society construction in Xiangtan city are calculated by grey correlation analysis. On this basis, the analytic hierarchy process (AHP) is used to synthesize and calculate each correlation degree. The evaluation result obtained in this way is more accurate than that obtained by using a single one of the methods. The present study conducted a post evaluation of the implementation of water saving measures in Xiangtan, Hunan province, China using a method that integrated AHP and GRA, with the former used to determine the weights of indices and the latter used to comprehensive analyze and evaluate the indices.

3. Empirical Strategy

3.1. Determination of the Weights of the Evaluation Index

The Chinese Ministry of Water Resources approved the city of Xiangtan, Hunan Province as a pilot city for the implementation of water saving measures in April 2008. The construction of the evaluation index system was based on data for water saving measures implemented in which for 2011 and 2015. The index system consists of 19 indices in five categories: (1) comprehensiveness; (2) agricultural water; (3) industrial water; (4) domestic water, and; (5) aquatic ecology, environment targets and water saving management [18–20]. Table 1 shows the values of all the evaluation indices. The current study established an index system for evaluating water saving measures in which based on the indices in Table 1 and constructed an evaluation analysis model for the implementation of saving society measures in Xiangtan and for the determination of the weight of each index.

Table 1. The indices used within an index system to evaluate water savings measures implemented in the city of Xiangtan, Hunan, China for 2011 and 2015.

Category	Evaluation Index	Unit	2011	2015
Comprehensive index	Water consumption per 10,000-yuan gross domestic product (GDP)	m^3/10,000 yuan	291	211
	Decline in water consumption per 10,000-yuan GDP	%	14	5.2
Agricultural water index	Coverage rate of water-saving irrigation projects	%	22	45
	Proportion of irrigation water effectively utilized		0.61	0.65
Industrial water index	Water consumption per 10,000-yuan industrial added value	m^3/10,000 yuan	190	142
	Industrial water recycling rate	%	70	75
Domestic water index	Coverage of water saving devices	%	80	100
	Leakage rate of the urban water supply network	%	17.5	15
	Per capita domestic water consumption of urban residents	L/day	182	160
Water ecology and environment targets	Rate of treatment of domestic sewage	%	70	80
	Rate of wastewater reuse	%	60	65
	Qualified rate of water functional zone	%	62.5	75
Water saving management index	Water saving management institutions		100	95.0
	Laws and regulations for improvement of water resources and water saving		100	95.0
	Planning of water saving measures		100	90.0
	Operation of the water saving market		100	90.0
	Mechanisms for investing in water saving		100	90.0
	Water saving publicity and public participation		100	90.0
	Planned water consumption rate	%	100	95.0

The relative weight of each evaluation index was calculated according to the root method of single hierarchical arrangement:

$$q_i = \overline{W_i} / \sum_{j=1}^{n} \overline{W_j} \tag{1}$$

$$\overline{W_i} = M_i^{\frac{1}{n}} \tag{2}$$

$$M_i = \prod_{j=1}^{n} b_{ij} \tag{3}$$

In Equations (1)–(3), q_i is to the weight of each sub-index, n is the number of indices, and b_{ij} is the scale value between two indices [19] (see GB-T28284-2-12). Table 2 shows the calculated weights of the indices.

Table 2. The weights of indices used within an index system to evaluate water savings measures implemented in the city of Xiangtan, Hunan, China for 2011 and 2015.

Category	Weight of Index (Q)	Post-Evaluation Index	Unit	Weight of Sub-Index (q)
Comprehensive index	0.308	Water consumption per 10,000-yuan gross domestic product (GDP)	m^3/10,000 yuan	0.571
		Decline in water consumption per 10,000-yuan GDP	%	0.429
Agricultural water index	0.102	Coverage rate of water-saving irrigation projects	%	0.500
		Proportion of irrigation water effectively utilized		0.500
Industrial water index	0.102	Water consumption per 10,000-yuan industrial added value	m^3/10,000 yuan	0.750
		Industrial water recycling rate	%	0.250
Domestic water index	0.077	Coverage of water saving devices	%	0.223
		Leakage rate of the urban water supply network	%	0.433
		Per capita domestic water consumption of urban residents	L/day	0.344
Aquatic ecology and environment targets	0.102	Rate of treatment of domestic sewage	%	0.440
		Rate of wastewater reuse	%	0.200
		Qualified rate of water functional zone	%	0.360
Water saving management index	0.308	Water saving management institutions		0.294
		Laws and regulations for improvement of water resources and water saving		0.173
		Planning of water saving measures		0.173
		Operation of the water saving market		0.090
		Mechanisms for investing in water saving		0.090
		Water saving publicity and public participation		0.090
		Planned water consumption rate	%	0.090

3.2. Grey Relative Analysis

The GRA method is a branch of grey system theory which is used to assess the degree of correlation between a reference sequence and a comparison sequence according to the similarity in the geometrical shape of their curves [21]. The basic steps of the GRA method are as follows:

(1) Determine the reference sequence $X_0(k)$ and comparison sequence $X_i(k)$, adopt the indices of the evaluation area as the reference sequence and adopt the standard indices of the evaluation stage as the comparison sequence.

(2) Standardize the sequence as the evaluation could be affected by different models, dimensions, and index units through range transformation [22].

For the benefit-oriented indexes, the benefit of the index increases with increasing value:

$$Y_0(k) = \begin{cases} 1 & X_0(k) \geq X_{\max}(k) \\ \frac{X_0(k) - X_{\min}(k)}{X_{\max}(k) - X_{\min}(k)} & X_{\min}(k) \leq X_0(k) \leq X_{\max}(k) \\ 0 & X_0(k) \leq X_{\min}(k) \end{cases} \tag{4}$$

$$Y_i(k) = \frac{X_i(k) - X_{\min}(k)}{X_{\max}(k) - X_{\min}(k)} \tag{5}$$

For the cost indices, the benefit of the index increased with decreasing value:

$$Y_0(k) = \begin{cases} 1 & X_0(k) \geq X_{\max}(k) \\ \frac{X_{\max}(k) - X_0(k)}{X_{\max}(k) - X_{\min}(k)} & X_{\min}(k) \leq X_0(k) \leq X_{\max}(k) \\ 0 & X_0(k) \geq X_{\max}(k) \end{cases} \tag{6}$$

$$Y_i(k) = \frac{X_{\max}(k) - X_i(k)}{X_{\max}(k) - X_{\min}(k)} \tag{7}$$

(3) Calculation of the sequence of absolute deviation,

$$\Delta_{0i}(k) = |Y_i(k) - Y_0(k)| \tag{8}$$

(4) Calculation of the correlation coefficient,

$$\xi_{0i}(k) = \frac{\min_i\{\min_k[\Delta_{0i}(k)]\ \} + \rho\max_i\{\max_k[\Delta_{oi}(k)]\}}{\Delta_{0i}(k) + \rho\max_i\{\max_k[\Delta_{0i}(k)]\}} \tag{9}$$

In Equations (4)–(9), ρ is the resolution coefficient, with $\rho \in (0,1)$ and usually assigned a value of 0.5.

(5) Calculate the correlation coefficients of the indices of each criterion layer and list the related sequence. The stage with the highest correlation coefficient is adopted for the criterion layer. The correlation coefficients of the indices of each criterion layer were calculated according as:

$$\gamma_{0i}(j) = \sum_{k=1}^{n} \omega(k)\xi_{0i}(k) \tag{10}$$

In Equation (1), $\omega(k)$ is the weight of the index of each criterion layer calculated through the AHP method.

(6) Evaluate and integrate the stages of the implementation of water saving measures. Calculate the total weighted degree of relevance and list the correlation sequence. The stage with the highest degree of correlation was adopted for the water saving measures. The total weighted correlation degree was calculated as:

$$R_{0i} = \sum_{j=1}^{n} \omega(j)\gamma_{0i}(j) \tag{11}$$

In Equation (11), $\omega(k)$ is the weight of the index of each criterion and was calculated through the AHP method.

4. Empirical Results

4.1. Overview of the Study Area

The city of Xiangtan is in the north-central part of Hunan province along the banks of the Xiangjiang River and extends for ~81 km from south to north and ~108 km from east to west with a total land area of 5015 km^2 [23]. Xiangtan borders the city of Zhuzhou to the east, Hengdong, Hengshan, and Shaungfeng to the south, the city of Loudi to the west, and Ningxiang, Wangcheng, the city of Changsha and Changsha county to the north. The terrain of Xiangtan is high in the southeast, northwest, and southwest, tilted to the northeast, and relatively flat in the central parts. Xiangtan falls within a subtropical humid monsoon zone, and therefore has high vegetation cover, a developed river network, and abundant precipitation. The average annual precipitation of Xiangtan is 1362 mm whereas the average annual water surface evaporation (E601 evaporator) ranges between 700 and 900 mm, with low regional and interannual variation. Water resources are abundant in the Xiangjiang River Basin, with an average annual runoff depth of 751 mm (Xiangtan People's Government of Hunan Province, 2009).

4.2. Construction of the Index System for Evaluating Water Saving Measures

The use of many indices increases the rationality, comprehensiveness, systematicity, and operability of the index system proposed in the current study for the evaluation of water saving measures in the city of Xiangtan [24]. The implementation of water saving measures was divided into five stages based on the water saving index: (1) the initial stage; (2) the primary stage; (3) the intermediate stage; (4) the operation stage; (5) the maturity stage. The criteria for the deriving the stages can be found in the literature [25–27]. The qualitative index was quantified and then divided into standard stages from 0 to 10 to correspond with a quantitative index [28]. Table 3 shows the evaluation index system and the division of stages of the implementation of water saving measures.

Table 3. Evaluation indices and the division of stages for an index system to evaluate water savings measures implemented in the city of Xiangtan, Hunan, China.

Goal Layer	Criterion Layer	Index Layer	Unit	Stage Division				
				Initial Stage	Primary Stage	Intermediate Stage	Operational Stage	Maturity Stage
Comprehensive evaluation on water saving measures	Comprehensive index	Water consumption per 10,000-yuan gross domestic product (GDP)	m^3/10,000 yuan	>500	300–500	120–300	50–120	<50
		Decline in water consumption per 10,000-yuan GDP	%	<5	5–8	8–12	12–16	>16
	Agricultural water index	Coverage rate of water-saving irrigation projects	%	<20	20–35	35–60	60–75	>75
		Proportion of irrigation water effectively utilized		<20	20–30	30–40	40–60	>60
	Industrial water index	Water consumption per 10,000-yuan industrial added value	m^3/10,000 yuan	>108	108–70	70–40	40–30	<30
		Industrial water recycling rate	%	<30	30–50	50–70	70–90	>90
	Domestic water index	Coverage of water saving devices	%	<30	30–50	50–70	70–90	>90
		Leakage rate of the urban water supply network	%	>30	20–30	10–20	5–10	<5
		Per capita domestic water consumption of urban residents	L/day	>150	150–100	100–80	80–50	<50
	Aquatic ecology environmental targets	Rate of treatment of domestic sewage	%	<20	20–40	40–60	60–80	>80
		Rate of wastewater reuse	%	<20	20–40	40–60	60–80	>80
		Qualified rate of water functional zone	%	<45	45–55	55–65	65–70	>70

Table 3. *Cont.*

Goal Layer	Criterion Layer	Index Layer	Unit	Stage Division				
				Initial Stage	Primary Stage	Intermediate Stage	Operational Stage	Maturity Stage
	Water saving management index	Water saving management institutions		0–2	2–4	4–6	6–8	8–10
		Laws and regulations for improvement of water resources and water saving		0–2	2–4	4–6	6–8	8–10
		Planning of water saving measures		0–2	2–4	4–6	6–8	8–10
		Operation of the water saving market		0–2	2–4	4–6	6–8	8–10
		Mechanisms for investing in water saving		0–2	2–4	4–6	6–8	8–10
		Water saving publicity and public participation		0–2	2–4	4–6	6–8	8–10
		Planned water consumption rate	%	<35	35–55	55–75	75–95	>95

4.3. Grey Relative Analysis

The relative discrete data of each evaluation index for the various stages of the implementation of water savings were analyzed based on grey relative analysis. Table 4 shows the correlation between each evaluation index and each stage of the implementation of water saving measures. As shown in Figure 1, among all the evaluation indices, water consumption per 10,000-yuan industrial added value and per-capita domestic water consumption of urban residents were shown to be in their initial stages, the rate of wastewater reuse was in a primary stage, the decline in water consumption per 10,000-yuan GDP, coverage of water-saving irrigation projects, industrial water recycling rate, and the leakage rate of the urban water supply network were all in an intermediate stage, and all remaining indices were in an operational or mature stage.

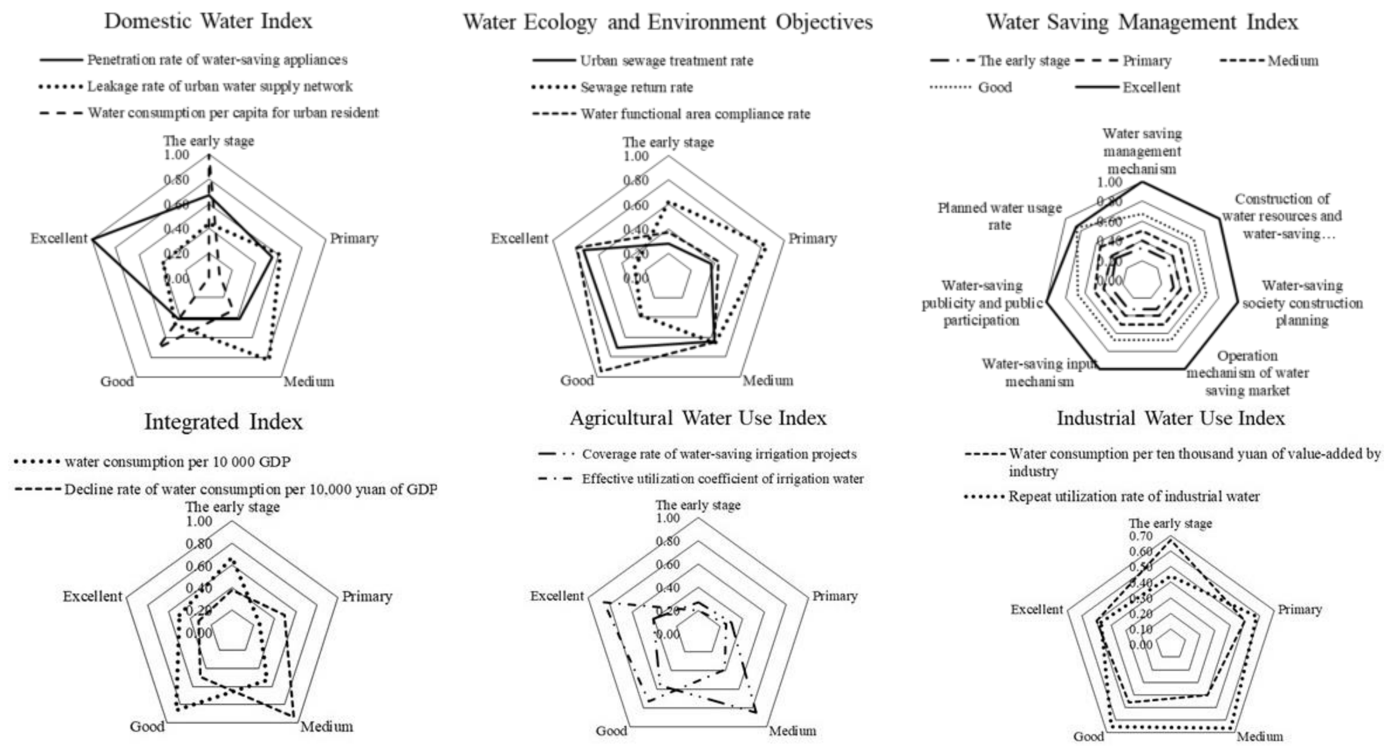

Figure 1. Determination of the index stages within an index system to evaluate water savings measures implemented in the city of Xiangtan, Hunan, China.

Table 4. Correlations between indices and stages within an index system to evaluate water savings measures implemented in the city of Xiangtan, Hunan, China.

Criterion Layer	Relative Discrete Data of Each Index among the Various Stages of Implementing Water Saving Measures $§_{ij}$				
	Initial Stage	Primary Stage	Intermediate Stage	Operational Stage	Mature Stage
Decline in water consumption per 10,000-yuan gross domestic product (GDP)	0.67	0.26	0.53	0.86	0.50
Water consumption per 10,000-yuan GDP	0.38	0.49	0.94	0.49	0.32
Coverage rate of water-saving irrigation projects	0.27	0.30	0.85	0.56	0.41
Proportion of irrigation water effectively utilized	0.20	0.25	0.39	0.73	0.86
Water consumption per 10,000-yuan industrial added value	0.67	0.50	0.40	0.46	0.50
Industrial water recycling rate	0.44	0.58	0.66	0.65	0.47
Coverage of water saving devices	0.67	0.54	0.42	0.42	1.00
Leakage rate of the urban water supply network	0.44	0.61	0.83	0.47	0.39
Per capita domestic water consumption of urban residents	1.00	0.09	0.33	0.71	0.00
Rate of treatment of domestic sewage	0.28	0.37	0.64	0.71	0.73
Rate of wastewater reuse	0.62	0.85	0.66	0.38	0.29
Qualified rate of water functional zone	0.37	0.43	0.65	0.94	0.79
Water saving management institutions	0.33	0.40	0.50	0.67	1.00
Laws and regulations for improvement of water resources and water saving	0.33	0.40	0.50	0.67	1.00
Planning of water saving measures	0.33	0.40	0.50	0.67	1.00
Operation of the water saving market	0.33	0.40	0.50	0.67	1.00
Mechanisms for investing in water saving	0.33	0.40	0.50	0.67	1.00
Water saving publicity and public participation	0.33	0.40	0.50	0.67	1.00
Planned water consumption rate	0.35	0.40	0.54	0.85	0.86

Table 5 shows the comprehensive evaluation results for the implementation of water saving measures in Xiangtan city, where it is evident that the comprehensive, agricultural water, aquatic ecology and environment target, and domestic water indices are in the operational stage, the industrial water index is in its initial stage, and the water saving management index is in the mature stage. By combining with the criterion layer of the evaluation, the results of the comprehensive evaluation indicate that the implementation of water saving measures in Xiangtan is generally in an operational stage.

Table 5. Results of the index system to evaluate water savings measures implemented in the city of Xiangtan, Hunan, China.

Criterion Layer	Correlation between Each Index to Various Stages of the Implementation of Water Saving Measures ζ_{0i}					Weight ω
	Initial Stage	Primary Stage	Intermediate Stage	Operational stage	Mature Stage	
Comprehensive index	0.53	0.38	0.74	0.68	0.41	0.308
Agricultural water index	0.24	0.28	0.62	0.65	0.64	0.102
Industrial water index	0.59	0.54	0.53	0.56	0.49	0.102
Domestic water index	0.70	0.41	0.53	0.53	0.46	0.078
Aquatic ecology and environment targets	0.42	0.55	0.65	0.68	0.60	0.102
Water saving management index	0.33	0.40	0.51	0.70	0.98	0.308
Comprehensive evaluation	γ_{0i} = (0.442,0.410,0.590,0.655,0.640)					

5. Conclusions and Policy Implications

The results of the comprehensive evaluation of water saving measures Xiangtan, Hunan province, showed that implementation of water saving measures is dependent on a steady development of the national economy, cooperation by the local government, and enhanced awareness of water saving measures among residents. The evaluation also showed that the implementation of water saving measures continues to face challenges in reforming the management system, in the establishment of water rights, and in the water market. The volumes of public and domestic water use are increasing with socioeconomic development. Therefore, the implementation of water saving measures should consider the challenge of increasing water consumption in various fields while emphasizing the importance of water conservation.

The evaluation of water saving measures implemented in Xiangtan showed that the comprehensive, agricultural water, aquatic ecology and environment targets, and water saving management indices are within the operational and mature stages, thereby indicating that the water saving measures taken by the Xiangtan government for the above five indices have had a positive effect on the final evaluation. The water saving measures implemented in Xiangtan from 2008 to 2015 have achieved a positive effect in general, while some challenges persist. Given the results of the current study, some suggestions for overcoming these challenges can be given:

(1) The industrial water index remains in the initial stage. Local government should strengthen the regulation of industries with large water consumption to ensure appropriate water saving measures, such as installing water saving and water treatment equipment to improve the rate of utilization of reclaimed water. The government should strengthen awareness of water saving measures among residents and popularize water saving habits.
(2) The rational exploitation and utilization of water resources and the implementation of water charges should be strengthened, and subsidies and water licenses should be revoked to ensure the societal adaptation to strict water resources management.
(3) The post evaluation of water saving measures aimed to consolidate and promote the water savings achieved in the pilot city, and the results of the present study can provide a reference for the implementation of water saving measures in other areas.

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