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Comprehensive Assessment of Regional Water Usage Efficiency Control Based on Game Theory Weight and a Matter-Element Model

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Abstract: The efficient control of water usage is one of the core goals of the strictest water resources management system in China. Therefore, the objective and reasonable evaluation of the effects of implementing this system is crucial. Based on the natural and social water cycle theories and the mechanism of the influence of agricultural, industrial, domestic and ecological water utilization, this paper proposes an evaluation index system through the qualitative and quantitative analysis of external and internal factors affecting the efficiency of water usage. Then, a matter-element model is developed on the basis of game theory weight to evaluate the effects of the implementation of efficiency control measures for regional water usage. By calculating the comprehensive correlation, this model can directly indicate the level of regional water use efficiency control. The model is applied to water usage in Jiangxi Province for the period 2011–2014. The results indicate a gradual improvement in the efficiency of water usage in this province. The matter-element extension evaluation model is simple and practical, and the evaluation results are in agreement with the facts. In summary, this method can provide a new theoretical basis for controlling the efficiency of regional water usage.

Keywords: matter-element model; extension engineering; game theory; water usage efficiency control; evaluation index system

1. Introduction

The development of water resources and their utilization are gaining global importance owing to the increasingly prominent imbalance between the demand for and the availability of water resources. As one of the countries facing a shortage of water resources, China established and implemented "the strictest water resources management system" in 2011, involving three management and control aspects: total amount of water usage, efficiency of water usage and limited pollutant carrying capacity of water function zones. Among these aspects, controlling the efficiency of water usage is a key means for realizing the sustainable development of water resources. This article evaluates the efficiency of water usage control objectively and systematically. Thus, our research not only contributes to enhancing system construction, it also offers a scientific basis for water management authorities and helps guarantee the implementation of the strictest water resources management system. Consequently, sustainable development of water resources can be realized.

In the face of increasingly severe water scarcity, scholars around the world have been studying the efficiency of water usage in terms of efficiency theory [1–5], index system building [6–10], efficiency measurement and assessment methods [11–15]. Initially, these studies mainly focused on the efficiency of agricultural water usage from the perspective of irrigation techniques and economic benefits in terms of produce [16–18]. In 2002, Hoekstra put forward the concept of a water footprint based on the concept of an ecological footprint and evaluated the water footprint for every country [19]. Following this, many studies evaluated the efficiency of agricultural water usage based on the water footprint [20,21]. The acceleration in industrialization and urbanization increased the prominence of water problems in industrial regions. Studies have been conducted to assess industrial water usage [22] and the operating efficiency of urban water systems [23,24]. In addition, comprehensive studies of the efficiency of water usage were carried out [25,26]. Moreover, the scope of the research has also been extended beyond regional usage to watersheds and the world at large. At the same time, some scholars have carried out research on the safety assessment [27,28], failure analysis [29], failure prediction [30] and usage during crisis situations [31] of water resource management systems. The establishment of the existing index system is based on sustainable development theory. Singh et al. summarized the sustainability assessment methodologies in [8,9]. In an attempt to realize the sustainable usage of water resources, the hierarchical method and pressure-state-response (PSR) theory are used to establish an index system. This is the basis of the water utilization efficiency evaluation index system proposed in this paper. With respect to the evaluation method, most researchers commonly use the analytic hierarchy process (AHP), the stochastic frontier production function [11–13], date package analysis (DEA) [14], fuzzy comprehensive evaluation (FCE) [15], the artificial neural network (ANN) model and other comprehensive methods. AHP provides a simple way to quantify the indices comprehensively. However, although AHP reflects the decision-maker's intention, the subjectivity of its weight determination is larger. The stochastic frontier production function method and DEA measure the efficiency of water usage based on the input-output theory. The efficiency value obtained from this calculation is a relative number and does not represent the absolute level of efficiency. FCE can solve problems that are fuzzy and difficult to quantify and is suitable for solving all kinds of uncertain problems. However, the results are prone to distortion, homogenization, discontinuities and other issues. The ANN model is fault tolerant and self-adaptive and is suitable to process nonlinear large complex system problems characterized by nonlocality. However, it requires many training samples to achieve evaluation precision. The application range is small, and network convergence is inefficient in assessing the work.

The incorporation of the impact of major factors relating to the efficiency of water usage requires the factors to be assigned weights first. The weight analysis method can either be a subjective or objective weighting method, each of which has its own advantages and disadvantages. In addition, the two methods complement each other to a certain extent [15,32]. The combination weighting method considers the preference of the engineers, which allows specialists to assign relative importance to major factors, as well as a matrix that shows the contributions of major factors toward the efficiency of water usage.

From the above discussion, it is obvious that several existing studies use the relative measurement model to evaluate the efficiency of regional water usage. The current index system focuses on the efficiency of agricultural water usage, as opposed to water usage in the domestic and ecological environments. Moreover, there are very few index systems capable of comprehensive system evaluation. Many studies have investigated regions facing water shortage or economically-developed regions, whereas few have investigated regions with abundant water resources or regions where the economy is in the early stages of development.

In order to bridge this gap, we base our research in Jiangxi Province, a developing region with abundant water resources, but a relatively underdeveloped economy. The definition of the composition of the total quantity of water consumption in the strictest water resources management system is taken as the basis. We start by analyzing the mechanism influencing the efficiency of water usage in regional agricultural, industrial, domestic and ecological environments in a chosen district. This is performed by identifying the key factors influencing the water usage in various industries. We built a comprehensive system to evaluate the efficiency of regional water usage based on the sustainable utilization of water resources. Our approach is a combination of game theory and matter-element evaluation methods. We determine the weight of each index in the evaluation model of the optimization method in game theory, increase the accuracy of the weight of the index and then calculate the correlation degree comprehensively. We followed this procedure to evaluate the efficiency of the control of regional water usage.

2. Methods

Because of the different degrees of influence of the major factors affecting the efficiency of water usage, it is necessary to assign a weight to each major factor. The game theory method, which combines subjective and objective weighting methods, is used to obtain a more rational major factor weight. Subjective weights are acquired by the analytic hierarchy process (AHP), whereas objective weights are determined by the entropy method. Based on the major factor weights, the extension method is introduced to analyze the efficiency of water usage control.

2.1. Confirmation of Index Proportions Based on the Game Theory Method

Determining how the major factors affect the efficiency of water usage control requires the weights of the factors to be assigned first. Weight analysis involves subjective and objective weighting methods, with their own advantages and disadvantages. Combination weighting not only reflects the preferences of various decision makers, but also decreases the influence of subjective factors. Therefore, this paper adopts game theory based on the subjective and objective evaluation of AHP and the entropy method.

2.1.1. AHP

The analytic hierarchy process (AHP) is a system analysis approach that was proposed by Saaty in the early 1970s [33]. It is a multi-criteria decision making method that organizes and quantifies the human thinking process and decomposes the relevant elements of the decision problem into objectives, criteria, programs and other levels, based on which qualitative and quantitative analyses are combined [34].

The core concept of AHP is to introduce measure theory based on establishing a clear hierarchy to decompose complex problems by pair-wise comparison, use a relative scale to quantify a person's judgment, establish the corresponding judgment matrix layer by layer, determine the weights of the judgment matrix and, finally, calculate the comprehensive weight for the water use efficiency evaluation index. Its basic steps are as follows.

(1) Construct the hierarchical structure model: The hierarchy is shown in Figure 1.

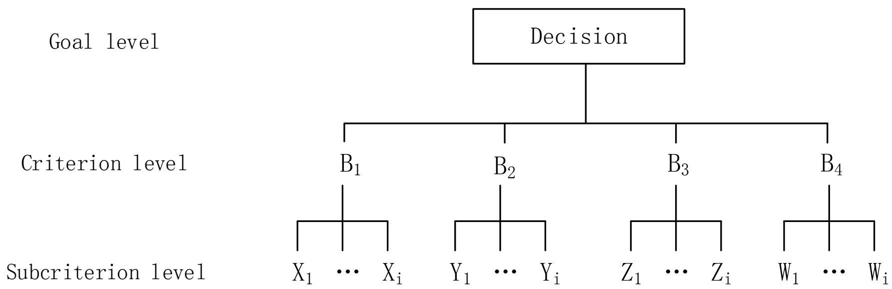

Figure 1. Schematic illustration of the hierarchical structure for the analytic hierarchy process (AHP) method.

(2) Establish the judgment matrix: Pair-wise comparisons can be made between two arbitrary factors at the criterion or sub-criterion level, with respect to their contributions toward the superior hierarchical level. If factors $X_1, X_2, \ldots, X_u$ are at the same hierarchical level and have contributions toward B_j at the superior hierarchical level, then the X_1–X_u relationships can be presented as a comparison matrix with the elements shown in Table 1.

Table 1. Comparison matrix elements.

	X_1	X_2	...	X_u
X_1	x_{11}	x_{12}	...	x_{1u}
X_2	x_{21}	x_{22}	...	x_{2u}
...	...	...	...	...
X_u	x_{u1}	x_{u2}	...	x_{uu}

X_1–X_u relationships (i.e., comparisons) are established on a scale of 1–9 based on Saaty's [12] scaling method, as shown in Table 2. The comparisons follow a reciprocal $u \times u$ matrix, where $x_{ii} = 1$ and $x_{ij} = 1/x_{ji}$.

Table 2. Definitions of comparative importance.

1	Two decision factors (e.g., indicators) are equally important
3	One decision factor is more important
5	One decision factor is strongly more important
7	One decision factor is very strongly more important
9	One decision factor is extremely more important
2, 4, 6, 8	Intermediate values
Reciprocals	If a_{ij} is the judgment value when i is compared to j, then $a_{ji} = 1/a_{ij}$ is the judgment value when j is compared to i

(3) Calculate the weights: The normalized eigenvector of the maximum eigenvalue $\lambda_{\max}$ of the comparison matrix $\{w_1, w_2, \ldots, w_u\}$ consists of the weights X_1–X_u with respect to B_j.

(4) Test the consistency: Saaty [33,35] proved that $\lambda_{\max} - u$ can be used to measure the consistency of the $u \times u$ matrix. Considering the matrix dimension, the consistency index (CI) for a $u \times u$ comparison matrix with the maximum eigenvalue $\lambda_{\max}$ can be estimated by:

$$CI = (\lambda_{\max} - u)/(u - 1) \quad (1)$$

Random $u \times u$ matrices can be generated, and the consistency indexes can be determined. The random average CI is denoted as RI, with the values listed in Table 3. Using CI and RI, Saaty [33,35] defined the consistency ratio (CR) as:

$$CR = CI/RI \quad (2)$$

CR is a more rational measure of consistency of the matrix. When $CR < 0.1$ or $\lambda_{\max} = n$, $CI = 0$, the comparison matrix is consistent, and the assessment result is rational. Otherwise, it needs to be adjusted until a satisfactory result is obtained.

Table 3. Average random consistency index *RI*.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.26	1.36	1.41	1.45

2.1.2. Entropy Method

Entropy is the quantitative representation of the degree of turbulence of a system. Accordingly, the entropy method is proposed for factor weight determination. The basic principle is based on the degree of variation among the characteristic values of the evaluation indexes; the greater the degree of variation and the smaller the information entropy, the greater is the weight of the corresponding index, and vice versa. This method avoids human subjectivity and thus yields accurate results [36,37]. The specific steps of the method are as follows.

(1) Data standardization:

In the rating system that was constructed for assessing the efficiency of water usage control, the dimensions, orders of magnitude, etc., differ among the indicators. Moreover, there are contradictory indicators. Among them, positive indicators are those for which a greater index value signifies a more accurate evaluation index. Conversely, for negative indicators, the smaller the index value, the more accurate the evaluation index. Therefore, standardization is necessary.

$$x'_{ij} = \frac{x_j - x_{\min}}{x_{\max} - x_{\min}} \tag{3}$$

$$x'_{ij} = \frac{x_{\max} - x_j}{x_{\max} - x_{\min}} \tag{4}$$

Equation (3) is used for the standardization of positive indicators, whereas Equation (4) is used for the standardization of negative indicators.

(2) Weight assignment for each indicator:

$$P_{ij} = \frac{x'_{ij}}{\sum\limits_{i=1}^{m} x'_{ij}} (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{5}$$

where P_{ij} is the weight of an indicator.

(3) Determination of the entropy value for each indicator:

$$e_j = -K \sum_{i=1}^{m} P_{ij} \ln P_{ij} \ (i = 1, 2, \cdots, m; 1, 2, \cdots, n) \tag{6}$$

where K is constant, i.e., $K = 1/\ln m$ (assumption: if $P_{ij} = 0$, then $P_{ij} \ln P_{ij} = 0$).

(4) Calculation of the entropy weights for the indicators:

$$\omega_j = \frac{1 - e_j}{\sum\limits_{i=1}^{m} 1 - e_j} \quad (j = 1, 2, \cdots, n) \tag{7}$$

where $\sum\limits_{j=1}^{n} \omega_j = 1$. According to Equation (7), the greater the entropy value, the smaller is the entropy weight and the smaller the contribution to the assessment results, and vice versa.

2.1.3. Combination Weighting Based on Game Theory

Considering the corresponding features of subjective and objective weighting methods, we developed a hybrid method that combines them using game theory [38].

For example, to assign each indicator scientifically and comprehensively in a multi-index assessment, a weighted set of indicators was obtained using L methods. The weighting vector can be expressed as $w_k = \{w_{k1}, w_{k2}, \cdots, w_{kn}\}$ $(k = 1, 2, \cdots L)$. The arbitrary linear combination is expressed as:

$$w = \sum_{k=1}^{L} \alpha_k \cdot w_k^T \tag{8}$$

The coefficient α_k was optimized using game theory to minimize the dispersion between w and each w_k in order to obtain the most satisfactory weighting vector w_k^*. Thus, the countermeasure model was deduced as:

$$\min \left\| \sum_{k=1}^{L} \alpha_k \cdot w_k^T - w_k \right\|_2 \quad (k = 1, 2, \cdots L) \tag{9}$$

According to the differential characteristics of the matrix, the equivalent linear simultaneous equations of the optimal derivative conditions are as follows:

$$\begin{bmatrix} w_1 \cdot w_1^T & w_1 \cdot w_2^T & \cdots & w_1 \cdot w_L^T \\ w_2 \cdot w_1^T & w_2 \cdot w_2^T & \cdots & w_2 \cdot w_L^T \\ \vdots & \vdots & \vdots & \vdots \\ w_L \cdot w_1^T & w_L \cdot w_1^T & \cdots & w_L \cdot w_L^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_L \end{bmatrix} = \begin{bmatrix} w_1 \cdot w_1^T \\ w_2 \cdot w_2^T \\ \vdots \\ w_L \cdot w_L^T \end{bmatrix} \tag{10}$$

where $(\alpha_1,\ \alpha_2, \cdots \alpha_L)$ is obtained after calculation and then normalized as:

$$\alpha_k^* = |\alpha_k| \bigg/ \sum_{k=1}^{L} |\alpha_k| \tag{11}$$

Thus, the integrated weighting vector can be expressed as follows:

$$w_k^* = \sum_{k=1}^{L} \alpha_k^* \cdot w_k^T \tag{12}$$

2.2. Comprehensive Evaluation Model for Extension Method

Extenics was first proposed by Wen in the 1980s to solve contradictions and incompatibilities both qualitatively and quantitatively [39]. In the extension assessment model, the evaluation index system and its characteristic value are taken as the matter-elements. Based on the evaluation grade and measured data, the classical field, controlled field and correlation degree are obtained, and the method of quantitative comprehensive evaluation is established. Using this model, the evaluation results can be presented in a quantitative manner, and then, the comprehensive level of the effect of implementing water usage efficiency control can be completely reflected. The specific calculation and evaluation steps of matter-element extension evaluation are as follows [39,40]:

(1) Determine the classical field:

There are three components of the matter-element model that form an ordered three-dimensional group to describe the characteristics of objects. The model is known as the n-dimensional matter-element model when there are n characteristic values, and the matter elements can be expressed as:

$$R_{0j} = \begin{bmatrix} N_{0j} & C_1 & V_{0j1} \\ & C_2 & V_{0j2} \\ & \cdots & \cdots \\ & C_n & V_{0jn} \end{bmatrix} = \begin{bmatrix} N_{0j} & C_1 & \langle a_{0j1}, b_{0j1} \rangle \\ & C_2 & \langle a_{0j2}, b_{0j2} \rangle \\ & \cdots & \cdots \\ & C_n & \langle a_{0jn}, b_{0jn} \rangle \end{bmatrix} \tag{13}$$

where N_{0j} denotes all of the levels of water usage efficiency control, C_n denotes the n-th index of the evaluation index system, V_{0jn} is the classical field that is the range of the n-th index's value in level j and a_{0jn} and b_{0jn} represent the upper and lower bounds of the range of values, respectively.

(2) Determine the controlled field:

$$R_P = \begin{bmatrix} N_P & C_1 & V_{p1} \\ & C_2 & V_{p2} \\ & \cdots & \cdots \\ & C_n & V_{pn} \end{bmatrix} = \begin{bmatrix} N_P & C_1 & \langle a_{p1}, b_{p1} \rangle \\ & C_2 & \langle a_{p2}, b_{p2} \rangle \\ & \cdots & \cdots \\ & C_n & \langle a_{pn}, b_{pn} \rangle \end{bmatrix} \quad (14)$$

where N_P denotes all of the evaluation levels of water usage efficiency and V_{pn} is the controlled field that is the range of C_n in level P. In the classical field, $V_{0ji} \in V_{pi}$.

(3) Determine the matter-elements:

The data of the water usage efficiency level in the area to be evaluated is expressed by the matter-elements as:

$$R = \begin{bmatrix} p & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_n & v_n \end{bmatrix} \quad (15)$$

where p is the matter element to be evaluated, c_n is n-th characteristic value in level j and v_n is the actual value of the evaluation index of water usage efficiency in the area to be evaluated.

(4) Determine the correlation function:

In extenics, the concepts of extension distance and position are introduced to describe the position relation between points and intervals. By constructing the correlation function, the degrees of some properties of an object can be described. The expressions are as follows:

$$K_j(v_i) = \begin{cases} \frac{-\rho(v_i, V_{ji})}{|V_{ji}|} & (v_i \in V_{ji}) \\ \frac{\rho(v_i, V_{ji})}{\rho(v_i, V_{pi}) - \rho(v_i, V_{ji})} & (v_i \notin V_{ji}) \end{cases}$$

where $\rho(v_i, V_{ji})$ and $\rho(v_i, V_{pi})$ can be determined as:

$$\rho(v_i, V_{ji}) = \left| v_i - \frac{1}{2}(a_{ji} + b_{ji}) \right| - \frac{1}{2}(b_{ji} - a_{ji}) \quad (18)$$

$$\rho(v_i, V_{pi}) = \left| v_i - \frac{1}{2}(a_{pi} + b_{pi}) \right| - \frac{1}{2}(b_{pi} - a_{pi}) \quad (19)$$

and they represent the distance between v_i and its classical field V_{0ji} and that between v_i and the controlled field V_{pi}, respectively.

(5) Calculate the integrated incidence degree, and determine the evaluation level:

$$K_j(p) = \sum_{i=1}^{n} \omega_j K_j(v_i) \quad (20)$$

where ω_j is the weight coefficient of the evaluation index of water usage efficiency control and $K_j(p)$ is the integrated incidence degree of the object to be evaluated in level j.

If $K_{j0}(p) = \max K_j(p)$, $(j_0 = 1, 2, \cdots, m)$, the level of water usage efficiency p in the study area is subordinate to level j, and the value of $K_{j0}(p)$ reflects the subjection degree to level j. Further, $K_{j0}(p) > 0$ implies that the object to be evaluated is within the scope of this level, and the subjection degree is proportional to its value. When $-1 \leq K_{j0}(p) \leq 0$, the object to be evaluated is beyond the scope of this level, but it can be transformed to this level; the higher the value, the higher the feasibility. Moreover, when $K_{j0}(p) < -1$, the object to be evaluated is beyond the scope of this level, and it does not qualify to be transformed to this level; the smaller the value, the farther away it is from the level.

(6) Determine the degree of subjection of the matter elements:

If:

$$\overline{K_j}(p) = \frac{K_j(p) - \min K_j(p)}{\max K_j(p) - \min K_j(p)} \tag{21}$$

then:

$$j^* = \frac{\sum\limits_{j=1}^{m} j\overline{K_j}(p)}{\sum\limits_{j=1}^{m} \overline{K_j}(p)} \tag{22}$$

where j^* is the eigenvalue of the grade variables. By using j^*, the degree of the implementation effect of water usage efficiency control tending to a certain evaluation level in the study area can be determined.

3. Study Area and Data Sources

3.1. Study Area

Jiangxi Province is taken as an example in this study (Figure 2). Jiangxi Province, which is located in Central Asia, lies in southeast China along the southern bank of the middle and lower reaches of the Yangtze River. It is located between latitude 24°29′14″–30°04′44″ N and longitude 113°34′36″–118°28′58″ E. Jiangxi Province covers an area of 166,900 km^2, accounting for 1.74% of the total area of the country. It has a humid tropical monsoon climate. The average annual temperature is in the range of 16.4–19.8 °C, and the average annual precipitation is 1638.4 mm. Its average annual water resource capacity is 156 billion and 500 million cubic meters, making this province one of the areas with abundant water resources in China. However, the spatial and temporal distribution of precipitation is uneven. Precipitation in the months from April to July accounts for approximately 58% of the total annual precipitation. Geographically, the precipitation levels in the southern and eastern parts exceed those in the northern and western regions, respectively.

Jiangxi Province is dominated by agriculture and is one of main grain producing areas in China. Until recently, the level of economic development lagged behind, but it is rapidly improving because of initiatives, such as the "11th five-year plan period" (2006–2010). The contribution of industries to the national economy is increasing, which might accelerate the development of the economy of the entire province. According to statistical information about water resources in Jiangxi Province, the total water consumption in the province increased from 2000 to 2014. With respect to water utilization, agricultural, industrial, domestic and ecological environments contribute to 66.2%, 23.7%, 9.3% and 0.8% of the total consumption, respectively. The water utilization efficiency of the various industries in the region is not high, with different degrees of water wastage. The irrigation technology is undeveloped, with techniques, such as flood irrigation and border irrigation being mainly used. The water-carriage system is relatively old, and the rate of water consumption is high. In 2014, the effective utilization coefficient of farmland irrigation water was 0.484, lower than the national average level of 0.530. The water consumption per ten thousand value-added is 88 cubic meters. The repeated utilization factor of industrial water is about 81% (Jiangxi Water Resources Bulletin 2014). Because of the sustained and rapid development of the economy, the imbalance between water availability and demand in Jiangxi Province has become increasingly prominent. The efficient utilization of water resources is the key to realizing sustainable development of regional water resources. The basis of implementing the most strict water resource management system is to correctly evaluate and diagnose the control level of regional water utilization efficiency. Moreover, it provides the scientific basis and decision support for the sustainable development of regional water resources.

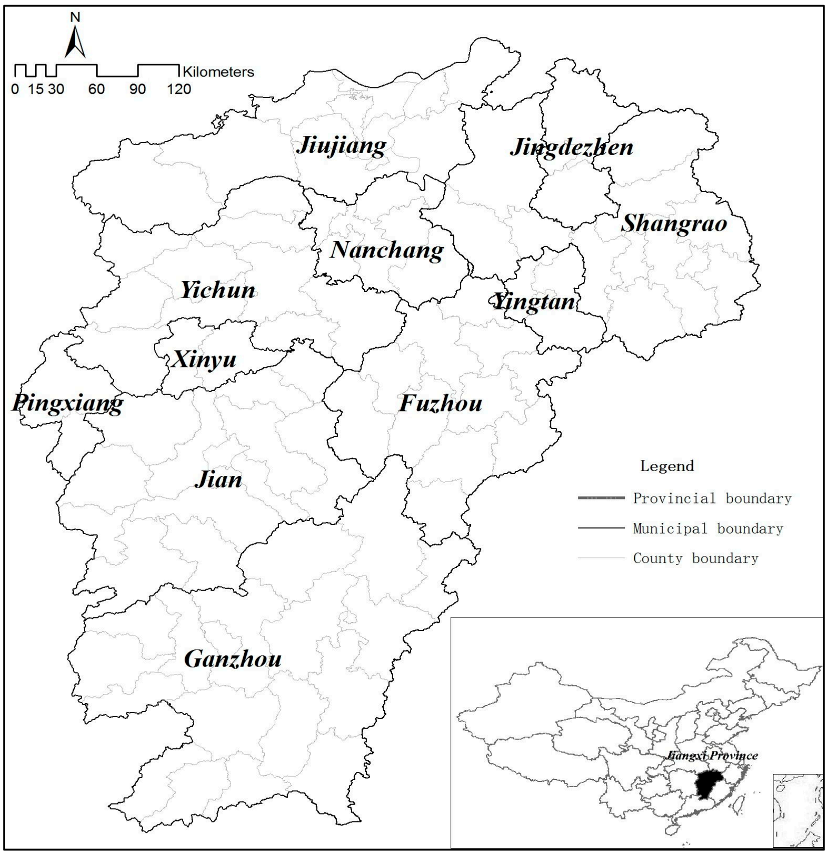

Figure 2. Location of the study region (Jiangxi Province).

3.2. Data Sources

The data relating to the social and economic indexes for this study were mainly obtained from the "Jiangxi Statistical Yearbook (2000–2014)" and the "Jiangxi middle- and long-term science and technology development plan (2006–2020)". Data about the water consumption indexes and water quota indexes were obtained from the "Jiangxi Water Resources Bulletin (2000–2014)" and the "The integrated plan of water resources of Jiangxi". Moreover, in order to eliminate the effect exerted by the rise in prices and inflation between years, all economic indexes used the year 2000 as a base year, which was used to correct the economic indicators for other years by using a price index.

4. Construction of Water Usage Efficiency Control Evaluation Index System

A regional water usage system is a large and complex system that involves the economy, society, natural resources and the ecological environment. Hence, a single index or several indexes cannot objectively reflect the entire situation regarding the efficiency of regional water usage control. Therefore, based on the current situation of regional economic development combined with the requirements of the strictest water resource management system for the red line efficiency of water usage, elements influencing the efficiency of water usage are proposed. By using a method that combines both qualitative and quantitative analyses, preliminary and optimal screening are both conducted with respect to the indexes. Thus, the level and structure of the index system can be determined, and an index system for the evaluation of the efficiency of scientific and reasonable regional water usage control can established.

The above index system should comply with the principles of combining representative and comprehensive aspects, scientific and practical aspects and qualitative and quantitative aspects in order to take the relations of the various aspects into comprehensive consideration.

4.1. Connotation of Water Usage Efficiency Control

The red line of water usage efficiency control is one of the core features of the strictest water resources management system. It can be used not only as a macro control index to assess the efficiency of water usage of a region or drainage basin, but also as a micro index to assess the water usage efficiency of an industry, enterprise or individual [41]. Under the framework of the strictest water resources management system, water usage efficiency control refers to controlling the efficiency of water usage according to the water resource conditions of different regions, economic development stage, industrial structure and status of water resources management in terms of scientific and technological progress at the given level of water resource investment through the control of economic benefit, social benefit and ecological benefit generated by a unit of water.

Water usage efficiency control is a multiple-target decision problem. It should be able to reflect the coordinated development degree of a regional society, economy, environment and water resources. In addition, it should be able to reflect the degree of regional water resource development and utilization. Further, it should be able to reflect the positive role of science and technology in improving water usage efficiency control. Moreover, it should be able to reflect the motivational role of water resources management systems, as well as policies and measures for water control.

4.2. Preliminary Screening of Evaluation Indexes

The components of the strictest water resource management system cover four types of regional water usage, i.e., agricultural, industrial, domestic and ecological. The water usage features vary among these types, thus distinguishing the influencing elements from one another. Previous studies on index systems have focused on the efficiency of agricultural water usage to a greater extent, whereas the efficiency of domestic or ecological water usage has not received much attention. Moreover, few studies have analyzed the internal and external elements influencing water usage from the viewpoint of the formation mechanism of water. Therefore, existing guidelines on the significance of actual water usage efficiency control are insufficient. High-intensity human activities have altered the structure and process of the natural water cycle. Merrett proposed the term "hydrosocial-cycle" corresponding to "hydrological-cycle" and described a brief model of the social water cycle with reference to the urban water cycle model [42]. Qingqiu described the social water cycle as the movement of water in the human socioeconomic system [43], whereas Jianhua et al. believed that it referred to the impact of humans in the socioeconomic system on the life and metabolism of water [44]. The social water cycle is a circular system (see Figure 3) that consists of five basic elements, water intake, water delivery, water usage, drainage and return, according to the human water activity law in the framework of the natural water cycle. Figure 3 describes the relation between the social and natural water cycles and shows the entire process of water resource utilization under the theory of the social water cycle.

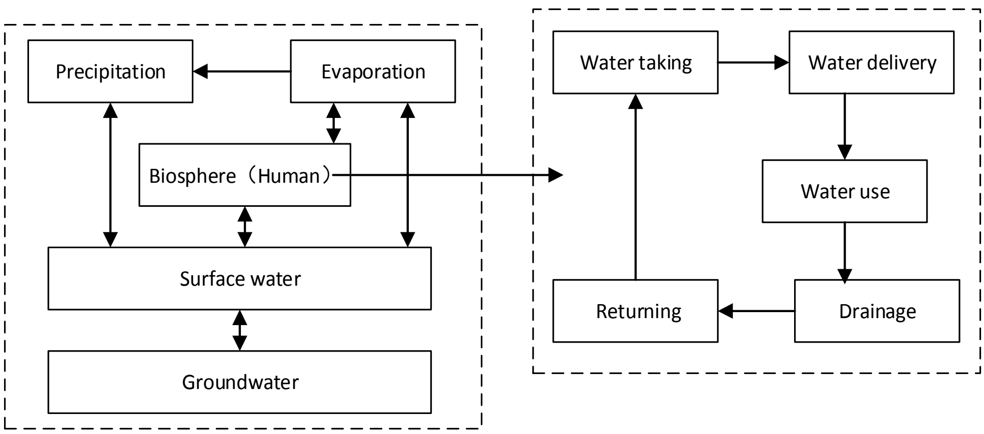

Figure 3. Relationship between the social water cycle and the natural water cycle.

Hence, in this study, the social water cycling theory serves as the foundation for building the index system [42–44]. The mechanism influencing water usage in various sectors is discussed in terms of the abovementioned five steps. Thus, the main elements that influence the various aspects of the efficiency of water usage are analyzed. The main elements influencing the efficiency of agricultural water usage include precipitation, the types and scale of irrigated areas, engineering measures adopted in the irrigated area, water-saving technologies and the irrigation management level. The main elements influencing the efficiency of industrial water usage include industrial structures and patterns, industrial water-saving technologies, the economic development level and the industrial scale. The elements influencing the efficiency of domestic water usage include the income and consumption level of residents, the size and structure of the population, the urban construction status, water resources and water price, public consciousness and water resource policies. The elements influencing the efficiency of ecological water usage include wastewater treatment capacity, chemical oxygen demand (COD) emission levels and the structure of ecological water usage.

According to the main elements influencing water usage efficiency in various sectors, existing studies on the evaluation of water usage efficiency have been reviewed, and the frequency statistics approach is adopted to obtain the statistics for the index with the highest frequency. Then, combined with the connotation and features of water usage efficiency control and based on experts' opinions, strongly representative and systematic indexes are chosen in the preliminary collection of indexes, as shown in Table 4. Because the indexes chosen in the preliminary collection are the results of a qualitative analysis, they are relatively subjective. In order to guarantee the reliability and correctness of the evaluation results, optimal selection is subsequently conducted by quantitative analysis of the preliminary collection of indexes.

Table 4. Evaluation index system of water usage efficiency control: initial set.

Water Use Sectors	Influencing Factors
Agricultural	rural population, per capita GDP, total power of farm machinery, quantity of chemical fertilizers used for farming, quantity of pesticide consumed, per capita net income of rural residents, proportion of agriculture in the national economy, rice planting areas in the total corn areas, per capita average agrarian area, water-saving irrigation rate, reservoir storage capacity, number of reservoirs, per acre irrigation water, effective utilization coefficients of irrigation water
Industrial	per capita water resources, per capita GDP, foreign real direct investment, per capita added value of industry, flexibility coefficient of industrial water, added value ratio of industry, reuse rate of industrial wastewater, proportion of added value of high-tech industry in total added value, attainment rate of waste water, proportion of high-water-consumption industries in the industrial GDP, concentration of pollutant exhaust emissions, proportion of technological expenses in China's financial expenditure, proportion of industrial employees in total employees, per capita water consumption
Domestic	per capita domestic water consumption of urban residents, per capita domestic water consumption of farmers, utilization of water reuse, water-efficient appliance penetration, education level, urbanization rate, proportion of domestic water in total water use, utilization of pipe network leakage
Ecological	sustainability of water sources, rate of sewage disposal, water pollutant carrying capacity, COD emissions per 10,000 Yuan of GDP, per capita wastewater emissions, water functional zone attainment rate

Note: Domestic capitation does not include non-potable sources.

4.3. Optimal Selection of Evaluation Indexes

The preliminary collection of evaluation indexes covers the various elements influencing water usage efficiency in different sectors; hence, it can comprehensively reflect the regional water usage efficiency control situation; however, there might be information repetition and intervention among indexes. Therefore, a scientific method is needed to conduct the optimal selection of indexes.

The optimal selection of indexes mainly involves statistical and mathematical methods. The approaches frequently adopted include analytical methods based on index distinguishing degrees, relevance analytical methods, the analytical hierarchy process, screening methods based on regression equations, principal component analysis, survey research and expert consultation.

Based on compliance with the index system construction principles, the relevance analysis method is combined with principal component analysis to screen the established index system [45,46]. First, principal component analysis is adopted to eliminate the indexes with small load capacities among the various principal components. Then, the remaining indexes are subject to relevance analysis. Based on the suggestions made by experts, indexes with relatively large relevance are eliminated to reduce the repetition of information. These suggestions are based on the experience of the experts, from actual representative analysis of the significance of indicators and by comprehensive analysis of the relationship between the indicators. The reserved index has a wide coverage and reflects the level of efficiency of water usage accurately in the final evaluation index. Next, gray correlation analysis is performed to distinguish the key factors influencing water usage efficiency control [47]. Finally, combined with the specific situation of the areas under evaluation, the final evaluation index system is determined.

4.4. Establishment of Evaluation Index System

Preliminary selection and optimal selection of the evaluation indexes enable the target decomposition method to be adopted to set the water usage efficiency control indexes as an index system with a three-layer hierarchical structure, including the target layer, criterion layer and index layer. The target layer is for the evaluation of the regional water usage efficiency control, which comprehensively reflects the management situation of water usage efficiency in the water usage steps, namely supply, utilization, consumption and emission. The criterion layer is for the water usage efficiency in different water usage departments and reflects the influence of water usage efficiency in various sectors on the implementation effects of regional water usage efficiency control. The index layer is for decomposing the indexes in the criterion layer into specific single indexes and for representing the specific objectives of the evaluation of water usage efficiency. The compositions and index computation formulas are shown in Table 5.

Table 5. Evaluation index system of regional water use efficiency control.

Target Layer	Criterion Layer	Index Layer	Index Calculation
Regional water usage efficiency control evaluation	Efficiency of agricultural water usage	Per capita net income (Yuan)	According to the Jiangxi Statistical Yearbook
		Water-saving irrigation rate (%)	Water-saving irrigated area/effective irrigated area
		Effective utilization coefficients of irrigation water	According to the Jiangxi Water Resources Bulletin
		Rice planting areas in the total corn areas (%)	Sown area of cereal/total sown areas of farm crops
	Efficiency of industrial water usage	Proportion of added value of high-tech industry in total added value (%)	High-tech industries added value/gross industrial added value of industrial enterprises above designated size
		Water consumption per 10,000 thousand Yuan industrial added value (m^3)	According to the Jiangxi Water Resources Bulletin
		Reuse rate of industrial wastewater (%)	According to the Jiangxi Statistical Yearbook
	Efficiency of domestic water usage	Per capita domestic water consumption of urban residents (m^3)	According to the Jiangxi Water Resources Bulletin
		Per capita domestic water consumption of farmers (m^3)	According to the Jiangxi Water Resources Bulletin
	Efficiency of ecological water usage	Rate of sewage disposal (%)	According to the Jiangxi Statistical Yearbook
		Sustainability of water sources (m^3)	(Gross water resources-total water usage)/ total population

Notes: Source: Calculations based on Jiangxi Water Resources Bulletin and the Jiangxi Statistical Yearbook. The data on water-saving irrigated area, effective irrigated area, sown area of cereal, total sown areas of farm crops, high-tech industries added value and gross industrial added value of industrial enterprises above designated size are from the Jiangxi Statistical Yearbook. The data on gross water resources and total water usage are from the Jiangxi Water Resources Bulletin.

5. Analysis of Water Usage Efficiency Evaluation

5.1. Weights of Indicators

Based on the statistical data obtained from the Jiangxi Statistical Yearbook for the period 2008–2014, a water usage efficiency evaluation database was established (see Table 6). AHP and the entropy method were used to calculate the weight coefficients of the evaluation indexes, namely μ_1 and μ_2, respectively. Then, based on the viewpoints and methods of game theory, the subjective and objective results were inserted into Equations (6)–(9) to yield weight coefficients α_1^* and α_2^* as 0.7859 and 0.2141, respectively. Furthermore, the integrated weighting vector ω^* was obtained. The weight of every evaluation factor is listed in Table 7.

Table 6. Statistical data of the water usage efficiency evaluation index of Jiangxi Province during 2008–2014.

Evaluation Index	Indicator Value						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Per capita net income (Yuan)	4697	5075	5789	6892	7828	8781	10,117
Water-saving irrigation rate (%)	13.5	14.5	16.2	18.2	19.3	20.2	23.3
Effective utilization coefficients of irrigation water	0.428	0.435	0.446	0.463	0.471	0.478	0.484
Rice planting areas in the total corn areas (%)	61.1	61.0	60.8	61.2	60.2	60.1	59.9
Proportion of added value of high-tech industry in total added value (%)	21.4	23.5	18.1	25.4	23.8	24.4	24.9
Water consumption per 10,000 Yuan industrial added value (m^3)	217	168	132	75.1	71.6	66.4	63.8
Reuse rate of industrial wastewater (%)	74.8	74.4	76.8	76.9	78.4	84.6	81.5
Per capita domestic water consumption of urban residents (L/d)	194	205	223	220	164	165	164
Per capita domestic water consumption of farmers (L/d)	80	91	90	94	94	70	95
Rate of sewage disposal (%)	51.5	74.9	80.8	85.1	84.3	83.1	83.8
Sustainability of water sources (m^3)	2550	2053	4562	1727	4289	2563	2981

Table 7. Comprehensive weight values of evaluation indexes.

Criterion Layer	Indexes Layer	μ_1 (AHP)	μ_2 (Entropy)	ω^* (Game Theory)
	α_k^*	0.7859	0.2141	
Efficiency of agriculture water usage: 0.6224	Per capita net income	0.0826	0.1766	0.1027
	Water-saving irrigation rate	0.1649	0.1494	0.1616
	Effective utilization coefficients of irrigation water	0.3255	0.1409	0.2860
	Rice planting areas in the total corn areas	0.0421	0.1826	0.0722
Efficiency of industrial water usage: 0.2586	Proportion of added value of high-tech industry in total added value	0.032	0.0483	0.0355
	Water consumption per 10,000 Yuan industrial added value	0.1465	0.0804	0.1324
	Reuse rate of industrial wastewater	0.0839	0.1160	0.0908
Efficiency of domestic water usage: 0.0843	Per capita domestic water consumption of urban residents	0.0543	0.0628	0.0561
	Per capita domestic water consumption of farmers	0.0272	0.0318	0.0282
Efficiency of ecological water usage: 0.0347	Rate of sewage disposal	0.0274	0.0034	0.0223
	Sustainability of water sources	0.0137	0.0077	0.0124

5.2. Division of Index Evaluation Grade

By combining the current approaches to formulate the evaluation standards, in accordance with the economic development, water resource development and utilization situation of the research area from 2008 to 2014 and by considering the relevant research results and technical codes or specifications concerning water usage efficiency, the extreme values and planned values among the index statistics data were chosen to determine the scope within which the evaluation indexes vary. In addition, by considering the regulations for the evaluation index target values and evaluation grades in the Assessment Methods of Implementing the Strictest Water Resource Management System, the water usage efficiency evaluation indexes could be divided into four grades, i.e., excellent (I), good (II), qualified (III) and unqualified (IV) [48]. The grading standard was determined by the proportional relation between the evaluation target index values and the actual values in the Assessment Methods of Implementing the Strictest Water Resource Management System, i.e., the target value, 0.9 (1.1) times the target value, and 0.8 (1.2) times the target value were taken as the critical points of the grading [48]. The grading standard of the various evaluation indexes are shown in Table 8. Among these, the evaluation of domestic water usage efficiency emphasizes the improvement of water use efficiency in terms of satisfying human comfort requirements. In other words, with respect to assuring a certain quality of life, the lesser the capitation water consumption, the higher the domestic water usage efficiency. Therefore, this is set as the intermediate index. Determination of the classification of the index requires the living conditions of the residents in the study area and water resources endowments to be taken into account. As for the other evaluation indexes, larger values indicate that they are more conducive to improving the efficiency of water usage, and hence, they are positive indexes; otherwise, they are negative indexes.

Table 8. Evaluation index system and standard of classification of Jiangxi Province regional water usage efficiency control.

[a] Evaluation Index	Indicator Type	Standard of Classification of Evaluation Index			
		Excellent (I)	Good (II)	Qualified (III)	Unqualified (IV)
C_1	Positive	>12,000	11,000–12,000	10,000–11,000	<10,000
C_2	Positive	>32.2	29.5–32.2	26.8–29.5	<26.8
C_3	Positive	>0.572	0.525–0.572	0.477–0.525	<0.477
C_4	Negative	<48.2	48.2–54.2	54.2–60.2	>60.2
C_5	Positive	>30.0	27.5–30.0	25.0–27.5	<25.0
C_6	Negative	<30	30–55	55–80	>80
C_7	Positive	>90.0	82.5–90.0	75.0–82.5	<75.0
C_8	Intermediate	150–200	135–150 200–220	120–135 220–240	<120 >240
C_9	Intermediate	100–130	90–100 130–143	80–90 143–156	<80 >156
C_{10}	Positive	>96.0	88.0–96.0	80.0–88.0	<80.0
C_{11}	Positive	>3393	3110–3393	2828–3110	<2828

Notes: [a] C_1 (Yuan) represents the per capita net income; C_2 (%) is the water-saving irrigation rate; C_3 denotes the effective utilization coefficients of irrigation water; C_4 (%) represents rice planting areas in the total corn areas; C_5 (%) is the proportion of added value of high-tech industry in total added value, C_6 (m^3) is the water consumption per 10,000 Yuan of industrial added value; C_7 (%) denotes the reuse rate of industrial wastewater; C_8 (L/d) is the per capita domestic water consumption of urban residents; C_9 (L/d) represents the per capita domestic water consumption of farmers; C_{10} (%) is the rate of sewage disposal; and C_{11} (m^3/p) represents the sustainability of water sources.

5.3. Water Usage Efficiency Analysis

Based on the designed evaluation index system and standard of classification, this study evaluated the effect of water usage efficiency control in Jiangxi Province during the years 2011–2014. The calculation procedures and results are as follows.

(1) Construction of the controlled field and classical field:

According to the standard of classification shown in Table 8, the matter-element matrices of the controlled field and classical field were constructed as shown in Equations (23) and (24):

$$R_{0j} = \begin{bmatrix} N & N_1 & N_2 & N_3 & N_4 \\ C_1 & \langle 12000 \sim 14000 \rangle & \langle 11000 \sim 12000 \rangle & \langle 10000 \sim 11000 \rangle & \langle 6000 \sim 10000 \rangle \\ C_2 & \langle 32.2 \sim 35.0 \rangle & \langle 29.5 \sim 32.2 \rangle & \langle 26.8 \sim 29.5 \rangle & \langle 12.0 \sim 26.8 \rangle \\ C_3 & \langle 0.572 \sim 0.625 \rangle & \langle 0.525 \sim 0.572 \rangle & \langle 0.477 \sim 0.525 \rangle & \langle 0.424 \sim 0.477 \rangle \\ C_4 & \langle 45.9 \sim 48.2 \rangle & \langle 48.2 \sim 54.2 \rangle & \langle 54.2 \sim 60.2 \rangle & \langle 60.2 \sim 65.5 \rangle \\ C_5 & \langle 30.0 \sim 35.0 \rangle & \langle 27.5 \sim 30.0 \rangle & \langle 25.0 \sim 27.5 \rangle & \langle 15 \sim 25.0 \rangle \\ C_6 & \langle 15 \sim 30 \rangle & \langle 30 \sim 55 \rangle & \langle 55 \sim 80 \rangle & \langle 80 \sim 100 \rangle \\ C_7 & \langle 90.0 \sim 100 \rangle & \langle 75.0 \sim 90.0 \rangle & \langle 65.0 \sim 75.0 \rangle & \langle 50.0 \sim 65.0 \rangle \\ C_8 & \langle 150 \sim 200 \rangle & \left\langle \begin{matrix} 135 \sim 150 \\ 200 \sim 220 \end{matrix} \right\rangle & \left\langle \begin{matrix} 120 \sim 135 \\ 220 \sim 240 \end{matrix} \right\rangle & \left\langle \begin{matrix} 80 \sim 120 \\ 240 \sim 260 \end{matrix} \right\rangle \\ C_9 & \langle 100 \sim 130 \rangle & \left\langle \begin{matrix} 90 \sim 100 \\ 130 \sim 143 \end{matrix} \right\rangle & \left\langle \begin{matrix} 80 \sim 90 \\ 143 \sim 156 \end{matrix} \right\rangle & \left\langle \begin{matrix} 50 \sim 80 \\ 156 \sim 170 \end{matrix} \right\rangle \\ C_{10} & \langle 80 \sim 100 \rangle & \langle 60 \sim 80 \rangle & \langle 30 \sim 60 \rangle & \langle 0 \sim 30 \rangle \\ C_{11} & \langle 3890 \sim 4900 \rangle & \langle 3110 \sim 3890 \rangle & \langle 2200 \sim 3110 \rangle & \langle 1500 \sim 2200 \rangle \end{bmatrix} \quad (23)$$

$$R_p = \begin{bmatrix} P & C_1 & \langle 6000 \sim 14000 \rangle \\ & C_2 & \langle 12.0 \sim 35.0 \rangle \\ & C_3 & \langle 0.424 \sim 0.625 \rangle \\ & C_4 & \langle 45.9 \sim 65.5 \rangle \\ & C_5 & \langle 15.0 \sim 35.0 \rangle \\ & C_6 & \langle 15 \sim 100 \rangle \\ & C_7 & \langle 50.0 \sim 100 \rangle \\ & C_8 & \left\langle \begin{matrix} 80 \sim 200 \\ 150 \sim 260 \end{matrix} \right\rangle \\ & C_9 & \left\langle \begin{matrix} 50 \sim 130 \\ 100 \sim 170 \end{matrix} \right\rangle \\ & C_{10} & \langle 0 \sim 100 \rangle \\ & C_{11} & \langle 1500 \sim 4900 \rangle \end{bmatrix} \quad (24)$$

(2) Determination of the matter-elements:

The values of the evaluation indexes related to the water usage efficiency in Jiangxi Province from 2011 to 2014 (see Table 6) were inserted as the matter-element R for this evaluation.

(3) Calculation of the integrated incidence degree and assessment of the results:

The corresponding software was developed; AHP was used to calculate the criterion weights; and the ordering results were obtained by fuzzy synthetic evaluation methods.

Along with the weight of each index, which was calculated using game theory, each value of the correlation functions for every evaluation value was calculated using Equations (9)–(15). Thus, the results of the water efficiency evaluation for Jiangxi Province from 2011 to 2014 were obtained (see Table 9).

Table 9. Evaluation results of water use efficiency control in Jiangxi Province during 2011–2014.

Evaluation Index	2011			2012			2013			2014		
	max $K(p)$	**Level**	j^*	max $K(p)$	**Level**	j^*	max $K(p)$	**Level**	j^*	max $K(p)$	**Level**	j^*
Per capita net income	0.0229	IV	3.8865	0.0469	IV	3.7992	0.0313	IV	3.6420	0.0120	III	3.1771
Water-saving irrigation rate	0.0676	IV	3.8375	0.0797	IV	3.8156	0.0721	IV	3.7814	0.0382	IV	3.6105
Effective utilization coefficients of irrigation water	0.0755	IV	3.5503	0.0324	IV	3.4283	0.0060	III	3.3099	0.0417	III	3.2124
Rice planting areas in the total corn areas	0.0140	IV	3.4987	0.0004	IV	3.3475	0.0011	III	3.3290	0.0030	III	3.3050
Proportion of added value of high-tech industry in total added value	0.0057	III	3.1529	0.0043	IV	3.4407	0.0021	IV	3.3532	0.0004	IV	3.2685
Water consumption per 10,000 Yuan industrial added value	0.0260	III	3.1854	0.0443	III	3.0933	0.0601	III	2.9754	0.0466	III	2.9125
Reuse rate of industrial wastewater	0.0118	II	2.4071	0.0203	II	2.2442	0.0330	II	1.9132	0.0392	II	2.0445
Per capita domestic water consumption of urban residents	0.0150	I	1.4293	0.0157	I	1.3968	0.0168	I	1.3788	0.0157	I	1.3968
Per capita domestic water consumption of farmers	0.0056	II	2.2093	0.0056	II	2.2093	0.0014	III	3.2903	0.0070	II	2.1628
Rate of sewage disposal	0.0055	II	1.8408	0.0064	II	1.8703	0.0077	II	1.9085	0.0069	II	1.8869
Sustainability of water sources	0.0040	IV	3.7866	0.0049	I	1.3660	0.0050	III	3.0577	0.0018	III	2.6909
Regional water use efficiency control level	0.0750	IV	3.4894	0.0319	IV	3.4055	−0.0405	IV	3.2897	0.0043	III	3.0890
Agriculture water use efficiency control level	0.0579	IV	3.6218	0.0434	IV	3.5277	0.0213	IV	3.4243	0.0117	III	3.2782
Industrial water use efficiency control level	0.0161	III	3.0345	0.0177	III	2.9410	0.0181	III	2.7233	0.0154	III	2.6838
Domestic water use efficiency control level	0.0071	I	1.5549	0.0076	I	1.5365	0.0051	I	1.4086	0.0076	I	1.5375
Ecological water use efficiency control level	−0.0012	II	2.2070	0.0018	II	1.7252	0.0028	II	2.1312	0.0037	II	2.0116

(4) Analysis of the evaluation results:

To improve our understanding of the water usage efficiency level of Jiangxi Province during the years 2011–2014, Figures 4–6 were plotted on the basis of the evaluation results listed in Table 9. The dividing line in Figures 4–6 represents the threshold water usage efficiency level. Above the dividing line, the water usage efficiency levels are low, and in such cases, it is necessary to improve the efficiency of water resource utilization in the future. Contrary to this, the water use efficiency levels below the dividing line meet the requirements; the efficiency improves with increasing distance from the dividing line.

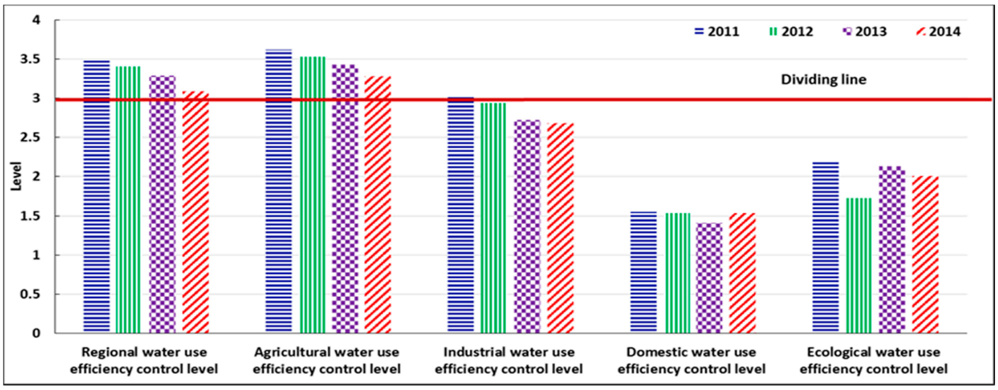

Figure 4. Water usage efficiency control level of Jiangxi Province during 2011–2014.

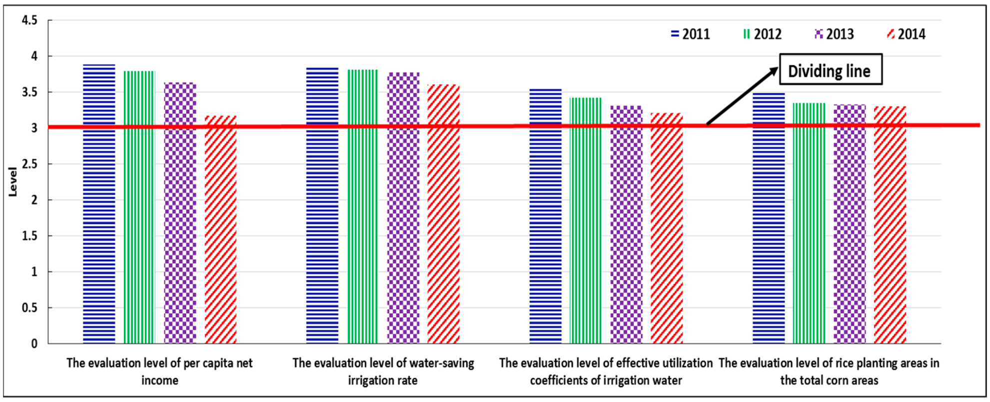

Figure 5. Agricultural water usage efficiency control level in terms of its efficiency indicator parameters in Jiangxi Province during 2011–2014.

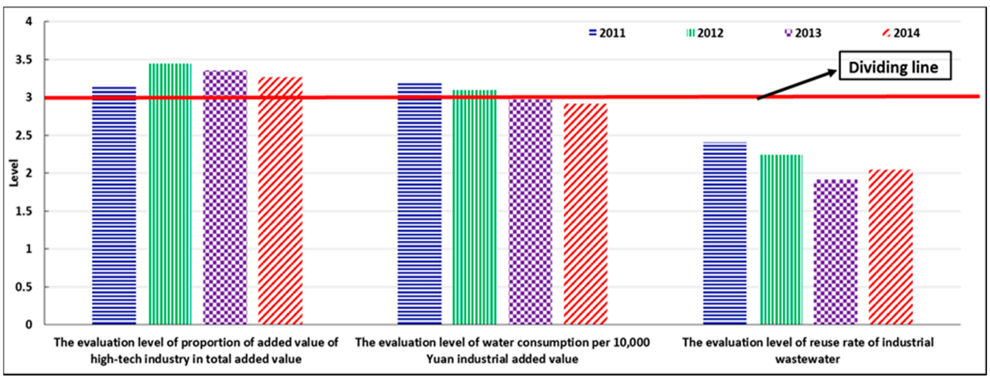

Figure 6. Industrial water usage efficiency control level in terms of its efficiency indicator parameters in Jiangxi Province during 2011–2014.

(1) From the evaluation results of the water usage efficiency control target layer, we observe that the level of water usage efficiency in Jiangxi Province changed from IV to III during the period 2011–2014. The comprehensive water usage efficiency increased on a year-by-year basis. It can be seen from Figure 4 that the efficiency level was above the "dividing line", and the rank variable characteristic value j^* was 3.0890 in 2014. The integrated incidence degree $\max K(p)$ was $0.004 > 0$, and the evaluation level was III. This implies that the level of regional water usage efficiency control was at the "qualified" level, and the attempt was progressing in the right direction. At the same time, the plot showed that some factors responsible for inhibiting the management of regional water usage efficiency continued to exist. Therefore, it is necessary to analyze the evaluation indexes in the guideline layer and to diagnose the industry water consumption that leads to a low level of regional integrated water usage efficiency.

(2) From the evaluation results of the indicators in the criterion layer, Figure 4 indicates that the agricultural water usage efficiency in Jiangxi Province is the lowest, and the efficiency of industrial water usage is the second lowest. During the years 2011–2014, the control levels determining the efficiency of agricultural water usage exceeded the "dividing line," which resulted in a low level of regional integrated water usage efficiency control. The efficiency of industrial water usage was at Level III, although the rank variable characteristic value j^* increased from 3.0345 in 2011 to 2.6838 in 2014. Therefore, improvements in agricultural and industrial water usage efficiency will be the focus of efforts to strengthen water usage efficiency management in Jiangxi Province in the future. This is especially true of the efficiency of agricultural water usage. Further examination of the reasons that currently contribute to the low efficiency of water usage is necessary. This requires the specific evaluation indexes in the indicator layer to be analyzed to direct the management focus and propose improvement measures for the management of regional water usage.

(3) The results of the evaluation of the indicators in the index layer shown in Figure 5 show that the indicators of agricultural water usage efficiency have improved to a different degree. It objectively reflects the positive role of adjusting and optimizing the planting structure, improving the construction of water-saving irrigation structures and other measures in Jiangxi Province in recent years. The efficiency of agricultural water usage of the evaluation indicators is above the "dividing line", especially the water-saving irrigation rate indicators. Therefore, future management of the regional water usage efficiency would require us to promote the implementation of water saving irrigation technology and to adjust and optimize the proportion of planting. Improving the coefficient indicating the effective use of irrigation water is the main method for increasing the efficiency of agricultural water use in the future. Figure 6 shows that during the period 2011–2014, the evaluation levels of various indexes in the industrial water efficiency index exhibited varying degrees of improvement. However, the grade level for the proportion of value added by high-tech industry of the total added value still remains above the "dividing line". The rank variable characteristic value of water consumption per 10,000 Yuan industrial added value j^* was 2.9152 in 2014, which was slightly below the "dividing line". These two indexes reflect the status of the industrial structure and industrial water usage in Jiangxi Province. Therefore, based on the present evaluation result, we can say that a fundamental improvement in the efficiency of industrial water usage would require adjusting the industrial structure scientifically, stimulating the development of high-tech industries and strengthening the quota management of industrial water.

The results of the comprehensive evaluation of the water usage efficiency in this paper are consistent with the implementation of water usage efficiency control in Jiangxi Province, which indicates that the evaluation method is feasible for controlling the efficiency of regional water usage. Therefore, the analysis of the evaluation results of various layers enabled us to detect the problems that existed in the control level of water efficiency in Jiangxi Province over the years. This provided the basis for implementing the most strict management measures for improving water resources in Jiangxi Province.

6. Conclusions

This study used the matter-element evaluation method for the comprehensive evaluation of the water usage efficiency in Jiangxi Province. The advantage of this method is that it involves simple calculations. Moreover, the evaluation results are scientific and reasonable. The method quantitatively describes the level of any index in the system and properly demonstrates and reflects the exact level to which an index belongs, as well as the different stages in the same level through variable grade eigenvalues. It is a novel and effective solution for evaluating the regional water efficiency control level.

Game theory was used to collect and integrate the weights determined by a subjective weighting method (AHP) and an objective weighting method (the entropy method) to overcome the subjective influence of the traditional process of empowerment and the adverse consequences of relying entirely on index data while ignoring the indexes. This approach also overcomes other defects and ensures that the determination of the weight coefficients is more reasonable; thus, the evaluation results are more accurate.

On the basis of the classical definition of domains and joint domains in the extension study, we can make real-time adjustments to the evaluation standards and goals according to the regional situation. If the planning indexes of different stages are taken as the upper limits of the joint domains, the evaluation of long-term and short-term management goals for the efficient control of water usage can be realized. In addition, we would be able to evaluate the control status of water efficiency across many cities in the country, in order to track the problems from the provincial level to that of a specific city. This would help us design specific management improvements to account for the spatial differences among different regions.

The proposed technique is based on game theory weight and the matter-element model. It uses quantitative values for a comprehensive evaluation of the level of water usage efficiency in a region. The criteria and index levels are comprehensively reflected in the evaluation results. Thus, we demonstrated that the proposed method can provide a technological guarantee for the realization of the efficient control of regional water usage via quantitative management. However, this study still has some limitations. That is, due to the lack of an authoritative and rational indicator system, as well as rating standards, the division of these evaluation standards based on regional geography and economic features as specified in this paper is limited to the region to some degree. At the same time, this approach also has some subjective influence on the calculation of the correlation function. The appraisal research of water usage efficiency is based on data. All of the data used in this paper were obtained from statistics of the region being studied. These data introduced errors in the evaluation results because of their statistical caliber and the short time span of data collection. Therefore, future research emphasis should be placed on the establishment of a scientific evaluation system for water usage efficiency control to determine a rating standard for regional water usage efficiency. As for data acquisition, it is suggested that the application of new technologies can acquire more detailed index data to improve the accuracy of the evaluation results.

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