Selection of an evaluation index for water ecological civilizations of water-shortage cities based on the grey rough set

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Abstract. According to the characteristics and existing problems of water ecological civilization of water-shortage cities, the evaluation index system of water ecological civilization was established using a grey rough set. From six aspects of water resources, water security, water environment, water ecology, water culture and water management, this study established the prime frame of the evaluation system, including 28 items, and used rough set theory to undertake optimal selection of the index system. Grey correlation theory then was used for weightings in order that the integrated evaluation index system for water ecology civilization of water-shortage cities could be constituted. Xi’an City was taken as an example, for which the results showed that 20 evaluation indexes could be obtained after optimal selection of the preliminary framework of evaluation index. The most influential indices were the water-resource category index and water environment category index. The leakage rate of the public water supply pipe network, as well as the disposal, treatment and usage rate of polluted water, urban water surface area ratio, the water quality of the main rivers, and so on also are important. It was demonstrated that the evaluation index could provide an objectively reflection of regional features and key points for the development of water ecology civilization for cities with scarce water resources. It is considered that the application example has universal applicability.

1. Introduction
The aims of a water ecological civilization city are to construct a virtuous cycle that sustainably uses water resources and promotes water security, water ecosystem health and a harmonious and beautiful water environment, as well as having a profound water cultural background [1-3]. In accordance with the principles of ecology balance, a water ecological civilization city is one that is based on the characteristics of exploring the economic development level of the city, the resource conditions and the water ecological system.

Domestic scholars had proposed an evaluation system for water ecological civilizations, including basins, provinces, and regions. Liu F [4] had established a system of water ecological civilization indicators including water safety, water ecology, water environment, water utilize and so on; Tang K W [5] had established the evaluation index system of water ecological civilization from two aspects of water ecosystem and socio-economic system, and had divided the evaluation standard grade; Liu H J [6] was established the evaluation index system of ecological civilization from four part of the development and utilization of water resources, water ecological environment protection, landscape
construction, water management guarantee. Due to the complex and changeable regional conditions, these indicators cannot reflect the characteristics of water resources and the social economy in cities with scarce water resources, and the evaluation criteria and classification results are difficult to be generally speaking. The problem of establishing an effective scientific index system to evaluate the water ecological civilization is worthy of greater study.

The goal of the present study was to pick up representative indices from the complex database and establish an evaluation index system for water-shortage cities that reflected the primary problems of the water environment and the primary contents in constructing an ecological civilization. It was anticipated that this might help to guide water ecological civilization in water-shortage cities and provide an early warning on key indices. Rough Set Theory was applied to analyze several evaluation indices and Xi'an City was cited as an example on which to base index weightings. This provided an index of water ecological civilization in the Xi'an is obtained, which has a certain reference value for the establishment of a water ecological civilization index system in water-shortage areas.

2. Data and methods

2.1. Selection of study area
Xi'an, the capital city of Shaanxi Province, is located in the central region of the Guanzhong Plain. With the Qinling Mountains to the south and the Weihe River to the north, Xi'an is the political, economic and cultural center of Shaanxi Province. The city's total area is 10,108 km², with a resident population of 8.63 million at the end of 2014 and a per capita GDP (GDP = Gross Domestic Product) of 63.8 thousand yuan. Xi'an is a typical city where the water resources are limited in gross volume and are unevenly distributed. The total quantity of the annual mean water resources equals 2.35 billion m³, and the per capita water resource is only 275 m³. Furthermore, the inter-annual variation in precipitation is large and its distribution is uneven during the year. The maximum recorded rainfall was 840.6 mm (in 1958), and the minimum recorded precipitation was 346.2 mm (in 1997), giving an extremes ratio of 2.43.

2.2. Construction of the evaluation index system
Based on the related literature [4-13], standard and expert opinions, the preliminary framework of water ecological civilization evaluation index was obtained. The index system was in accordance with the prominent contradiction of the water-shortage. The index system regarded water resources as the first subsystem, followed by water security, water environment, water ecology, water culture, and water management. The index system consisted of six subsystems, including the following 28 indices (see table 1).

| Subsystem layer | Index layer | Preliminary framework index | Final evaluation index² |
|-----------------|-------------|-----------------------------|------------------------|
| water resource  | C1          | Standard-reaching rate of water consumption central control-- | √                      |
|                 | C2          | Water withdrawal of industrial added value per ten thousand Yuan | √                      |
|                 | C3          | Leakage rate of public water supply network | √                      |
|                 | C4          | Penetration rate of domestic water-saving appliances | √                      |
|                 | C5          | Water saving irrigation rate of farmland | √                      |
|                 | C6          | Treatment and usage rate of polluted water | √                      |
2.3. Index grade division
According to the relevant research results and national standards, the discrete grading standards were divided into five grades, of which “5” was the best value and “1” was the worst (see table 2).

| Index       | Grade | 5   | 4   | 3   | 2   | 1   |
|-------------|-------|-----|-----|-----|-----|-----|
| C1          |       | 100 |     |     |     |     |
| C2          |       | 0~35| 35~60|60~100|100~150|150 |
| C3          |       | 0~8 | 8~12|12~18|18~25|25~100|
| C4          |       | 100~90| 90~75|75~60|60~40|40~0 |
| C5          |       | 100~85| 85~70|70~60|60~50|50~0 |
| C6          |       | 100~50| 50~30|30~15|15~5 |5~0  |
| C7          |       | 100~90| 90~75|75~60|60~40|40~0 |

* “√” represents the index items that were retained after the selection.
2.4. Evaluation index selection based on rough sets

Rough set theory is a data analysis theory proposed by the Polish mathematician Pawlak in 1982. It is a method of dealing with vagueness and uncertainty, the key point of which is connecting classification with knowledge, in the belief that knowledge comes from the classification ability of humans and other species, and representing classifications in forms of equivalence relationships. Compared with fuzzy mathematics, probability statistics and other processing methods, rough set theory does not need to use the apriority knowledge, such as membership functions and probability distribution density, when dealing with uncertain information. It is also not bound by more premise conditions, and thus is widely applicable in the fields of theory and management [14, 15].

Step 1 is the establishment of the information system and decision table.

Information system:

\[ S = \{ U, A, V, f \} \]  

In the formula, \( U \) is a nonempty finite set of the research object; \( A \) is a nonempty finite set of attribute; \( V \) is the range of attribute set \( A \); \( f \) is the set of information function of \( U \) and \( A \).

Decision table:

\[ S = \{ U, C, D, V, f \} \]  

In the formula, \( C \) is the index set, \( D \) is the comprehensive evaluation result set, which is commonly used to describe the grade or the corresponding score as well as to describe the result of the comprehension evaluation. The comprehensive evaluation decision table is actually the data table which contains the evaluation index and the evaluation result.

Step 2 is the discretization of index data

As a mathematical tool for dealing with incomplete and uncertain problems, rough set theory can deal effectively with a discrete index but it cannot deal directly with a continuous index. Therefore, discretization of the continuity index must come first before the application of the rough set methods of index screening. In this study, the equal interval method was chosen, combined with the actual data

| C8  | 100 | 100-90 | 90-80 | 80-70 | 70-0 |
|-----|-----|--------|------|------|-----|
| C9  | 100-90 | 90-75 | 75-60 | 60-40 | 40-0 |
| C10 | 0     | 1-4    | 4-10 | 10-20 | 20  |
| C11 | 100-95 | 95-90 | 90-85 | 85-80 | 80-0 |
| C12 | 100-80 | 80-60 | 60-50 | 50-40 | 40-0 |
| C13 | 4-3.75 | 3.75-3.5 | 3.5-3 | 3-2  | 2-0 |
| C14 | 100-95A | 100-95 | 95-90 | 90-85 | 85-0 |
| C15 | 100-90 | 90-75 | 75-60 | 60-40 | 40-0 |
| C16 | 100-98 | 98-90 | 90-80 | 80-60 | 60-0 |
| C17 | 100-85 | 85-70 | 70-50 | 50-30 | 30-0 |
| C18 | 100-85 | 85-65 | 65-45 | 45-30 | 30-0 |
| C19 | 0-0.3  | 0.3-0.5 | 0.5-0.8 | 0.8-1.2 | 1.2 |
| C20 | 100-90 | 90-75 | 75-60 | 60-50 | 50-0 |
| C21 | 8      | 7-6    | 5-3  | 2-1  | 0   |
| C22 | 20     | 20-15  | 15-10| 10-5 | 5-0 |
| C23 | 100-85 | 85-70 | 70-60 | 60-50 | 50-0 |
| C24 | 100-90 | 90-80 | 80-60 | 60-50 | 50-0 |
| C25 | 100-90 | 90-75 | 75-60 | 60-40 | 40-0 |
| C26 | 100-90 | 90-75 | 75-60 | 60-40 | 40-0 |
| C27 | 100-90 | 90-75 | 75-60 | 60-40 | 40-0 |
| C28 | 2      | 1-2    | 0.5-1| 0.3-0.5 | 0.3-0 |
of Xi’an City.

Step 3 is the parsimonious model of the rough set

Definition: in the information system, where P belongs to C, the relationship between P and IND (P) is defined as:

$$\text{IND}(P) = \{ (x, y) \in U^2, \forall a \in P, x \neq y, f(x, a) = f(y, a) \}$$

(3)

IND (P) divides the object U into k equivalent classes, denoted as: $U/P = \{ x_1, x_2, \cdots, x_k \}$.

The information system, S, is set up, where $S = \{ U, A, V, f \}, R \in A, R$, R is a set of equivalence relationships, $r \in R$, if $\text{IND}(R) = \text{IND}(R - \{ a \})$, then r is called an unnecessary part of R, otherwise r is a necessary part of R; if $r \in R$ and every r is necessary, then R is said to be independent, otherwise it will be known as dependent.

Assuming that $Q \in R$, if Q is independent and $\text{IND}(Q) = \text{IND}(P)$, then Q is called reduction of U in the domain of attribute set P.

The specific steps are as follows:

a: On the index system of $C = \{ c_i \}, i = 1, 2, 3, \cdots, m$, work out $\text{IND}(C)$ and $\text{POS}_C(D)$;

b: On $i = 1, 2, 3, \cdots, m$, work out $\text{IND}(C - \{ c_i \}) \text{and } \text{POS}_{C-\{c_i\}}(D)$ successively;

c: If $\text{POS}_{C-\{c_i\}}(D) = \text{POS}_C(D)$, then $c_i$ is the removable redundant indicator of target system C; otherwise, $c_i$ is the necessary indicator that cannot be eliminated from the index system.

2.5. Index weighting based on grey correlation

After selecting the index system by the above method, the grey correlation degree method was used to calculate the weight of the index. The method is a quantitative comparison between the state and the trend of a developing system. Compared with regression analysis, there is no special requirement on the number and type of sample, with low computation requirements and reliable results [16].

Step 1 (for the weighting procedure):

First determine the reference sequence of $X_0$, in which the bigger the better index is called $X_{0k} = \max(x_{1k}, x_{2k}, \cdots, x_{mk})$, $k \in n$;

The smaller the better one is called $X_{0k} = \min(x_{1k}, x_{2k}, \cdots, x_{mk}), k \in n$. So then the judgment matrix M can be construct:

$$M = \begin{bmatrix}
x_{01} & \cdots & x_{0n} \\
\vdots & \ddots & \vdots \\
x_{mn} & \cdots & x_{nn}
\end{bmatrix}$$

(4)

Taking into account the difference of dimensions and orders of magnitude of different indicators, there is a need for M dimensionless processing in the calculation of the weighting; in this study, normalization is used to process the data.

Step 2: the matrix of correlation coefficient is calculated: calculate the correlation coefficient $\varepsilon_i(k)$ of the K index between the calculation sequence $X_i$ and the reference sequence $X_0$:

$$\varepsilon_i(k) = \frac{\min_{\bar{k}} \min_{\bar{k}} \left| x_0(k) - x_i(k) \right| + \rho \max_{\bar{k}} \max_{\bar{k}} \left| x_0(k) - x_i(k) \right|}{\left| x_0(k) - x_i(k) \right| + \rho \max_{\bar{k}} \max_{\bar{k}} \left| x_0(k) - x_i(k) \right|}$$

(5)

When $\rho \in [0, 1]$ (generally taken 0.5), the correlation coefficient matrix E can be obtained from the formula:
\[ E = \varepsilon_i(k) = \begin{bmatrix} \varepsilon_i(1) & \cdots & \varepsilon_i(k) \\ \vdots & \ddots & \vdots \\ \varepsilon_i(1) & \cdots & \varepsilon_i(k) \end{bmatrix} \]  

(6)

Step 3: the grey relational grade is calculated:

Equation (6) can be used to calculate the grey correlation degree of different flood disaster sequences \( r_i \):

\[
r_i = \varepsilon_i(k) \times \omega_i = (x_{i1}, x_{i2}, \ldots, x_{in}) \times [\varepsilon_i(1), \varepsilon_i(2), \ldots, \varepsilon_i(n)]^T
\]

(7)

Step 4: the grey correlation weight value is obtained.

After normalization of the correlation degree of each index factor, the grey correlation weight value \( \beta \) of the evaluation factor was obtained, so a complete evaluation index system is available.

3. Results and discussion

3.1. Index data discretization

The index data came from the "Statistical Yearbook of Shaanxi Province", "Shaanxi Water Resources Bulletin", "Xi'an Statistical Yearbook", "Xi'an Water Resources Report" and so on. The results of the discretization could be obtained by substituting the index data of Xi'an City into the discrete classification standard (see table 3).

| Year | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|------|------|------|------|------|------|------|------|------|------|------|
| C1   | 0    | 0    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| C2   | 3    | 3    | 4    | 4    | 4    | 4    | 5    | 5    | 5    | 5    |
| C3   | 2    | 2    | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
| C4   | 3    | 3    | 3    | 4    | 4    | 4    | 5    | 5    | 5    | 5    |
| C5   | 4    | 3    | 4    | 5    | 4    | 5    | 4    | 4    | 4    | 4    |
| C6   | 2    | 2    | 2    | 2    | 2    | 2    | 2    | 2    | 3    | 3    |
| C7   | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 2    | 2    | 2    |
| C8   | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| C9   | 3    | 4    | 4    | 4    | 4    | 4    | 4    | 4    | 5    | 5    |
| C10  | 2    | 2    | 2    | 3    | 3    | 3    | 3    | 4    | 4    | 4    |
| C11  | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| C12  | 2    | 1    | 2    | 2    | 2    | 2    | 3    | 3    | 3    | 3    |
| C13  | 2    | 2    | 3    | 3    | 4    | 4    | 4    | 5    | 5    | 5    |
| C14  | 2    | 2    | 3    | 2    | 2    | 4    | 4    | 2    | 1    | 3    |
| C15  | 2    | 2    | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
| C16  | 4    | 3    | 4    | 3    | 3    | 3    | 3    | 3    | 4    | 4    |
| C17  | 4    | 5    | 4    | 5    | 4    | 5    | 5    | 5    | 5    | 5    |
| C18  | 1    | 2    | 2    | 2    | 2    | 2    | 2    | 3    | 3    | 3    |
| C19  | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| C20  | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 2    | 2    | 2    |
| C21  | 4    | 4    | 4    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |
| C22  | 2    | 3    | 3    | 3    | 3    | 4    | 4    | 5    | 5    | 5    |
| C23  | 3    | 3    | 4    | 3    | 4    | 4    | 4    | 5    | 4    | 5    |
| C24  | 2    | 2    | 3    | 3    | 3    | 3    | 4    | 4    | 4    | 4    |
3.2. Selection of evaluation index system

According to the order of water resources, water security, water environment, water ecology, water culture, water management, these six kinds of index system were screened as follows:

- Screening of water resources index: According to the results of the discrete index and the model of the rough set index system, the index of water resources was screened. In the knowledge representation system composed of those indicators (see table 4), the domain of discourse $U$ was a collection of all of the research objects; the condition attribute was $C = \{c_1, c_2, c_3, c_4, c_5, c_6\}$, the decision attribute was replaced by the urban water surface area ratio, that $D = c_{13} = \{d\}$.

Divided by d, U:

$$U / d = \{[1, 2], [3, 4], [5, 6, 7], [8, 9, 10]\}$$

Divided by U, C:

$$U / C = \{[4, 6], [5, 7], [9, 10], [1, 2], [3], [8]\}$$

According to the rough set theory, the positive region:

$$POS_c(d) = \{1, 2, 3, 5, 7, 8, 9, 10\}$$

Divided by C2, C3, C4, C5, C6, C7, U:

$$U / \{C_2, C_3, C_4, C_5, C_6, C_7\} = U / C - \{C_1\} = \{[5, 7], [9, 10], [1], [2], [3], [8], [4], [6]\}$$

there were

$$POS_{C - \{C_1\}}(d) = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\} \neq POS_c(d)$$.

Therefore, C1 was a non-redundant index and couldn’t be deleted. Similarly, C2, C3, C4, C5, C6 were non-redundant indices, and couldn’t be deleted.

| Year | C1 | C2 | C3 | C4 | C5 | C6 | d |
|------|----|----|----|----|----|----|---|
| 2006 | 5  | 3  | 2  | 3  | 4  | 2  | 2 |
| 2007 | 5  | 3  | 2  | 3  | 4  | 2  | 2 |
| 2008 | 5  | 4  | 3  | 4  | 2  | 3  | 2 |
| 2009 | 5  | 4  | 3  | 4  | 2  | 3  | 2 |
| 2010 | 5  | 4  | 3  | 4  | 2  | 3  | 2 |
| 2011 | 5  | 4  | 3  | 4  | 2  | 3  | 2 |
| 2012 | 5  | 4  | 3  | 4  | 2  | 3  | 2 |
| 2013 | 5  | 5  | 3  | 4  | 2  | 3  | 2 |
| 2014 | 5  | 5  | 3  | 4  | 2  | 3  | 2 |
| 2015 | 5  | 5  | 3  | 4  | 2  | 3  | 2 |

- Screening of water safety index: In the knowledge expression system of the water safety index (see table 5), the domain of discourse $U$ was a collection of all research objects, the condition attribute $C = \{c_7, c_8, c_9, c_{10}, c_{11}\}$, the decision attribute $D = c_{14} = \{d\}$.

Divided by d, U:
\[ U / d = \{ \{1, 2\}, \{3, 4\}, \{5, 6, 7\}, \{8, 9, 10\} \} \]

Divided by \( U, C \):

\[ U / C = \{ \{1\}, \{2\}, \{3, 4, 5, 6, 7\}, \{8, 9, 10\} \} \]

And according to the rough set theory, the positive region:

\[ POS_C(d) = \{1, 2, 8, 9, 10\} \]

Divided by \( C_7, C_8, C_9, C_{10}, C_{11} \), \( U/\{C_8, C_9, C_{10}, C_{11}\} = U/C - \{C_7\} = \{1\}, \{2\}, \{3, 4, 5, 6, 7\}, \{8, 9, 10\} \), there were \( POS_{C,\{C_8\}}(d) = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\} \neq POS_C(d) \). Therefore, \( C_7 \) was a non-redundant index and couldn’t be deleted. Similarly, \( C_8, C_{11} \) were non-redundant indices, couldn’t be deleted, and \( C_9, C_{10} \), which were redundant indices, could be deleted.

**Table 5.** Knowledge representation system of the water safety index

| Year | C7 | C8 | C9 | C10 | C11 | d |
|------|----|----|----|-----|-----|---|
| 2006 | 1  | 5  | 3  | 2   | 5   | 2 |
| 2007 | 1  | 5  | 4  | 3   | 5   | 2 |
| 2008 | 1  | 5  | 4  | 3   | 5   | 3 |
| 2009 | 1  | 5  | 4  | 3   | 5   | 3 |
| 2010 | 1  | 5  | 4  | 3   | 5   | 4 |
| 2011 | 1  | 5  | 4  | 3   | 5   | 4 |
| 2012 | 1  | 5  | 4  | 3   | 5   | 4 |
| 2013 | 2  | 5  | 5  | 4   | 5   | 5 |
| 2014 | 2  | 5  | 5  | 4   | 5   | 5 |
| 2015 | 2  | 5  | 5  | 4   | 5   | 5 |

- Screening of the water environment, water ecology, water culture, and water management index.

Similarly, in the index of water environment, \( C_{14}, C_{15} \) were non-redundant indices, and couldn’t be deleted, and \( C_{12} \) was a redundant index, which could be deleted. In the index of water ecology, \( C_{16}, C_{18}, C_{20} \) were non-redundant indices; In the index of water culture, \( C_{21}, C_{22} \) were non-redundant indices; In the index of water management, \( C_{25}, C_{27}, C_{28} \) were non-redundant indices.

In summary, the total number of indicators of the water ecological civilization evaluation index system for Xi’an City had been reduced from 28 to 20 (see table 1).

### 3.3 Index weighting and results analysis

- Weighted by grey relational theory

The selected index system was put into the grey relational weight model, and the weight of the grey relational analysis was calculated:

\[ \beta_i = \left( 0.0349, 0.0416, 0.0704, 0.0522, 0.0503, 0.0722, 0.0405, 0.0311, 0.0357, 0.0682, 0.0486, 0.0553, 0.0357, 0.0577, 0.0503, 0.0424, 0.0695, 0.0447, 0.0515, 0.0472 \right) \]

The selected index system was put into the grey relational weight model and the weight of the grey relational analysis was calculated.
The weighting diagram was drawn, based on $\beta_i$ (see figure 1). It could be seen that the most influential index of Xi'an City's water ecological civilization are C3 ($\beta_3 = 0.0704$), C6 ($\beta_6 = 0.0722$), and these were followed by C13 ($\beta_{13} = 0.0682$), C18 ($\beta_{18} = 0.0695$), C15 ($\beta_{15} = 0.0553$), C22 ($\beta_{22} = 0.0577$). The weight of remainder indices were less than 0.055. In general, the greatest influence on the water ecological civilization index system was attributable to the indices of water resources and water environment.

![Radar diagram of indices weighting in Xi'an City.](image)

**Figure 1.** Radar diagram of indices weighting in Xi'an City.

- Calculation of evaluation results

According to the indices classification and the adoption of the method of five value logic partition to construct the membership function, “Ⅰ” was the worst grade and “Ⅴ” was the optimal grade. The value of the membership function was classified according to the index grade (see table 2). Taking 2012 as an example, the membership function was calculated from equation (8):

$$r_j(x) = \begin{cases} 1 - \frac{\max\{a_{i1} - x, x - a_{i2}\}}{\max\{a_{i1} - \min_j x, \max_j x - a_{i2}\}} & x \notin [a_{i1}, a_{i2}] \\ 1 & x \in [a_{i1}, a_{i2}] \end{cases} \quad i = 1, 2, \cdots, n; j = 1, 2, \cdots, m \quad (8)$$

where $a_{i1}$, $a_{i2}$ represent the upper limit and lower limit of the index value, and $x$ indicates the index value. Then, $B = \beta \cdot F$ was calculated, and the comprehensive evaluation result for 2012 was obtained:

$$B = \beta \cdot F = \begin{bmatrix} 0.0349 \\ \vdots \\ 0.0472 \end{bmatrix} \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} = \begin{bmatrix} 0.0745, 0.1305, 0.3881, 0.2573, 0.1496 \end{bmatrix}$$

The maximal value of the vectors, 0.3881, corresponds to section III. Therefore, the evaluation of water ecological civilization in 2012 was close to average. Similarly, comprehensive evaluation results were obtained in other years (see table 6).

From this result, it was evident that the general situation of water ecological civilization in Xi'an City was approximately average from 2006 to 2012, and achieved a better grade from 2013 to 2015. The results were consistent with the actual situation, which illustrates that the evaluation model was feasible.
Table 6. Evaluation interval and results of water ecological civilization in Xi'an City.

| Year | I     | II    | III   | IV    | V     | Results |
|------|-------|-------|-------|-------|-------|---------|
| 2006 | 0.2099| 0.3862| 0.1983| 0.1615| 0.0441| II      |
| 2007 | 0.1955| 0.3341| 0.3022| 0.1057| 0.0625| II      |
| 2008 | 0.1027| 0.2205| 0.3305| 0.3004| 0.0459| III     |
| 2009 | 0.0952| 0.2901| 0.2803| 0.2321| 0.1023| II      |
| 2010 | 0.0851| 0.2216| 0.3562| 0.2452| 0.0919| III     |
| 2011 | 0.1161| 0.0711| 0.3517| 0.2749| 0.1862| III     |
| 2012 | 0.0745| 0.1305| 0.3881| 0.2573| 0.1496| III     |
| 2013 | 0.0351| 0.1475| 0.2335| 0.4012| 0.1827| IV      |
| 2014 | 0.0504| 0.0705| 0.2598| 0.4841| 0.1352| IV      |
| 2015 | 0.0732| 0.0376| 0.1809| 0.5249| 0.1834| IV      |

- Evaluation results analysis

As is typical of cities that are short of water, although Xi'an City has made certain achievements in terms of water ecological civilization in recent years, the primary problem faced by the city that needs to be solved urgently is still the negative impact of water-shortage and future deterioration of the water environment for some time to come. The results shown that, during the study period, two of the most important indices that symptomized the water ecological civilization in Xi'an City were addressed by the water resources index. The city should strengthen the protection of water sources and water management, increase water recycling, accelerate the comprehensive management of soil and water loss, strengthen flood control and drainage capacity in both urban and rural areas, strengthen water pollution control etc., in order that total water resources can meet future demand.

4. Conclusions

Based on analysis of the evaluation index of water ecology civilization for Xi'an City, which was chosen as an example for the purpose of demonstrating the effectiveness of the analysis procedure, the preliminary framework of an evaluation index system was established that focused on the status, features and problems of water ecology of cities in China that are subject to water shortages. The ‘grey rough set’ theory was used to obtain optimization results of the evaluation index for such cities. From the specific results for Xi'an City, the conclusion was obtained that the key points of water was to guarantee the total available water resource, to improve water supply efficiency, to strengthen water pollution prevention & disposal and to renovate the water environment. Planning should be based on available water resources; synchronization of protection and utilization; broadening of income and reduction of expenditure; improvement of the overall water supply and drainage network; improvement of the water landscape and water culture; and implement a comprehensive water ecology civilization for concerned cities. In order to further verify the applicability of the analysis method, more empirical studies need yet to be carried out to refine the selection index of the evaluation indicators of water ecological civilization in other water-shortage cities.

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