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Comprehensive evaluation of urban water-saving based on AHP-TOPSIS

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ABSTRACT

A comprehensive evaluation of water-saving is a measurement of the degree of efficient use of water resources in a region. The scientific evaluation of water-saving management and capacity in a region is an important basis for formulating water-saving development management and policies. By analyzing the operation mechanism of the urban water cycle, this study aims to explain the interaction between urban operation and ecological cycle, establish a different perspective on water conservation in traditional cities, and apply analytic hierarchy process and technique for order preference by similarity to an ideal solution to construct an evaluation model of water-saving. By using this model to analyze the state of water-saving in Henan Province for nearly 10 y of saving water. It is concluded that the overall water-saving status of Henan Province is at a general degree, however, various water-saving capabilities are gradually increasing. Among them, the largest contribution is water-saving in production. The water-saving level of Henan province decreased in 2009 and 2013, which was caused by the decrease of water-saving capacity in life, agriculture, and ecology. In the areas where water resources are scarce and water-saving capacity is average, a more moderate economic and water-saving policy should be formulated.

Keywords: Evaluation of water-saving; Water environment; AHP; TOPSIS

1. Research background

Water is the source of life, the key to production, and the basis of ecology. With the gradual construction of ecological civilization, water ecology, and water environment have been paid more attention. China's rapid development in recent decades is at the cost of environmental damage and over-exploitation of resources, including over-exploitation and pollution of water resources. Due to China's large population and rapid industrial and technological development, China has a huge demand for water, therefore, under these prerequisites and backgrounds, water conservation has become an important goal. It is urgent to construct a water-saving evaluation system to evaluate the current water-saving status and put forward suggestions on the future direction and key points of water-saving.

1.1. Research progress

Scholars at home and abroad have done research on the water-saving evaluation system. In 1959, the former China National Construction Commission proposed the city's water-saving slogan for the first time. New water-saving ideas were put forward by General Secretary Xi in 2014 at the Fifth Meeting of the Central Financial and Economic Leading Group. During this time, in 1989, Zhu made quantitative evaluations of industrial water-saving levels in 18 cities in North China. Xu and Shan [1] made a brief introduction to water-saving agriculture and its physiological and ecological basis. Kang et al. [2] conducted research on water-saving irrigation in farmland. Feng [3–5] summarized and considered the current water-saving work in China. Chen et al. [6] explained the connotation of

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water-saving society and conducted a preliminary study on the index system of water-saving society. Liu [7] researched and explained the water-saving evaluation of large-scale irrigation areas. Li [8] established an urban water-saving evaluation system based on the most stringent water resources management methods. In the beginning, foreign water-saving evaluations considered economic costs, and then gradually transformed them into holistic ones [9]. For example, Israel's drip irrigation technology, which mixes water and nutrients by the drip irrigation center, greatly improves the utilization of irrigation water. Horton first proposed a water quality evaluation index system in 1965, the Howden Water Quality Index. Renato and Fibeiro [10] applied neural networks to construct optimal irrigation schemes to achieve water-saving effects in 1998. Tsadilas and Vakalis [11] proposed a long-term model framework for river basin framework and regional development. These studies are aimed [12], to a certain point to water-saving evaluation models for cities, irrigation districts, watersheds, etc., do not take the environment into account in which the evaluation subjects are located. It should be noted that any subject exchanges material energy with the surrounding environment [13–15]. The interaction of water, the most basic substance of nature, with its surroundings should be considered. The scientific evaluation of water-saving management and capacity in a region is an important basis for formulating water-saving development management and policies. In recent years, the comprehensive evaluation of water-saving capacity has developed from qualitative evaluation to quantitative evaluation and from simple main indicators to build an evaluation system to multiple indicators to build a comprehensive evaluation system. Analytic hierarchy process, fuzzy comprehensive evaluation, factor analysis, gray correlation method, etc., have been applied to the comprehensive evaluation of water-saving among them, the analytic hierarchy process is based on the hierarchical structure model and the construction of the judgment matrix to find the eigenvalues to determine the weight of each index factor. The judgment matrix is dominated by the evaluation criteria, and the objectivity of the evaluation criteria is difficult to reflect. Fuzzy comprehensive evaluation needs to construct a complicated membership function for a more complicated water-saving capacity evaluation system. When the factor analysis method processes the normal standardization of indicators, information loss and feature extraction decline will occur. The gray correlation method is based on the results of the correlation and comparison of indicators for objective evaluation, but it cannot reflect the interaction between water-saving management and the objective environment. Technique for order preference by similarity to an ideal solution (TOPSIS) is a new method for solving multi-attribute decision-making problems proposed in recent years. The principle is to sort according to the closeness of the evaluation object to the ideal target. The good value and bad value in the actual sample can be introduced into the final result, which can well reflect the objectivity of each indicator. Therefore, the analytic hierarchy process (AHP) and TOPSIS are combined to construct a water-saving evaluation model, which avoids decision-making errors caused by the one-sidedness of single-factor decision-making and differences in human subjective understanding. This can make more scientific and comprehensive judgments, and provide guidance for reality.

1.2. Research purposes

The research direction of this article is based on a macro perspective and a large area of human activity, including urban factors, irrigation area factors, and natural environment factors within this area. The main carrier of water conservation assessment is the city. The city and its surrounding water environment are inseparable, interacting, and interdependent. This article explains the concept of the water environment, analyzes the operating mechanism of the water environment to show the interaction between the city and the surrounding environment, and proposes a new concept of the water environment. Through, the coupling of AHP and TOPSIS method, an urban water-saving evaluation model is built for water-saving evaluation of the water environment of Henan Province in the past 10 y. Its water-saving status and future water-saving development trends and priorities are analyzed.

1.3. Water-saving analysis of urban operation

The water cycle in nature forms precipitation through evaporation, surface water is then formed, which penetrates into the groundwater and replenishes it. At the same time, during non-rainfall periods, groundwater will replenish surface water. This is the operating mechanism of the water environment in nature. Due to the construction of urban asphalt pavement, and the existence of a large number of concrete buildings. As a result of this, its mechanism is different from the natural water environment operation mechanism. Firstly, urban surface water is dominated by urban water landscape (lakes and rivers in some cities), but water landscapes are generally less, and most water landscapes often have no other water supply except rainwater replenishment. This has caused most water landscapes to consider anti-seepage measures. This has mixed a lot of artificial measures and human factors. At the same time, due to the construction of asphalt pavements and a large number of concrete buildings, the soil surface is hardened, and the water cycle cannot be performed effectively. In normal urban water cycle, surface water (mainly refers to temporary surface water formed by rainfall) is drained underground through the urban pipe network. Therefore, it is often necessary to comprehensively consider the degree of urban pipe network construction and pipe network bearing capacity when a water-saving model is constructed.

At the same time, urban operation cannot be separated from economic production, and industrial production. Both of them will consume a lot of water resources. In industrial production, it is measured by the water consumption per unit of output value. So in industrial production, it is often measured by the water consumption level of 10,000 yuan GDP (Gross Domestic Production) in industrial production.

2. Overview of Henan Province

Henan Province spans the Yangtze River Basin, Huaihe River Basin, Yellow River Basin, and Haihe River Basin.

Most of the rivers in the province originate from the mountain areas in the west, northwest, and southeast. There are 493 rivers with a basin area of more than 100 km^2. The province's average water resources totalled 40.5 billion m^3, ranking 19th in China, and its per capita water resources were <420 m^3. This is equivalent to one-fifth of China's average.

Henan Province is the only province in China that flows through four major river basins. It is also the largest province in China with a long history and has bred Chinese civilization. Currently, under the strategy of the rise of the Central Plains, the water environment in Henan Province is relatively complicated, and so it is particularly important to evaluate urban water conservation.

2.1. Evaluation index selection and system construction

The index screening is conducted from the perspective of urban water conservation, including the urban area and the surrounding environment, fully reflecting the urban operation and ecological cycle and the interaction between them. The indicators should fully reflect the state of urban development and the state of the natural environment in a region. The indicators are selected from the aspects of the city's economic development status, social progress, and surrounding environment status.

In terms of urban operation, the selected indicators should reflect the city's water-saving capacity and efficiency. This is done by selecting indicators from the perspectives of people's lives, industrial and commercial production, and economic construction. At the same time, the policy of a region is also an indicator of water-saving capacity. In terms of natural environment, selected indicators included in the operation of the water environment were, agricultural farming, ecological environment, etc. The selection of the secondary indicators is the refinement of the primary indicators, and at the same time it can explain the interaction between urban operation and natural ecology.

The following indicators were screened by studying the selection criteria of water-saving evaluation indicators at home and abroad, combining with the definition of water environment from a new perspective in this article, based on the policy of giving priority to water conservation and the characteristics of Henan Province, and combining frequency statistics with theoretical analysis. Target layer *O*: evaluation of urban water-saving; rule level *C*: city operation *C*1 and ecological cycle *C*2. The second-level indicator layers under *C*1 are: *A* domestic water-saving, *B* production water-saving, *C* economic development status, and *D* management water-saving. The subordinates of *C*2 are: ecological environment *E* and agricultural water-saving *F*. As shown in Table 1.

After establishing the target layer *O*, the criterion layer *C*, and the indicator layer *P*, we select specific evaluation factors to comprehensively reflect the comprehensive status of each indicator layer. From the research perspective of this article, the most representative evaluation factors are selected following scientific, comprehensive, systematic, purposeful, and practical principle: *C*1 = {*A*, *B*, *C*, *D*} and *C*2 = {*E*, *F*}. Each *C* layer has specific evaluation factors, as shown in Table 2.

The evaluation index is constructed under the full reflection of urban operation and ecological cycle and their interaction, which is combining existing research at home and abroad. The actual situation of Henan Province in the study area is finally determined, specific selection of urban water-saving indicators, and ecological water-saving indicators fully reflects the evaluation of the water-saving status of the research area under the new concept.

3. Water-saving evaluation calculation

In this study, AHP and TOPSIS were used to construct a water-saving state evaluation model for Henan Province under the concept of new water environment. AHP may, according to the evaluation factors of the importance of empowerment. But due to the factors important degree, there are no clear standards, it is often easy to cause error caused by major factors. However, because of the factor important degree, there are no clear standards. Therefore, TOPSIS is used to empower evaluation factors that contain dat. This will mean that the relationship between evaluation factor data is scientifically and effectively reflected. To some extent, errors caused by subjective empowerment are avoided. At the same time, it also guarantees the standardization and scientificity of the evaluation system.

3.1. AHP determines indicator weight

Analytic hierarchy process was proposed by American operations researcher Saaty in the 1970s, referred to as AHP. AHP is the decomposition of elements related to decision into target layer, criterion layer, and index layer. When making a decisional analysis, you can evaluate a complex system that is composed of many factors. These factors are interrelated and mutually restrictive from different perspectives, hierarchical, and organized issues according to the system's decision goals. A hierarchical structure is established and a multi-level analysis structure model is formed.

3.1.1. Comparison scale

According to the scale and judgment principle of pairwise comparison, related indicators at the same level are

Table 1
Target layer-criteria layer-indicator layer relationship

O	Urban water conservation estimation					
C	City operation				Ecological cycle	
P	Domestic water-saving	Production water-saving	Economic development	Management water-saving	Natural ecosystems	Agricultural water-saving

Table 2
Comprehensive evaluation system of water environment and water-saving status

P	*C*		Specific evaluation factors	Analytical calculation method
City operation saves water	Domestic water-saving (*A*)	*A*1	Water consumption norm for residential area	(Water consumption per capita in the previous year – water consumption per capita this year)/water consumption per capita this year × 100%
		*A*2	Promotion rate of water-saving appliances	Number of users installing water-saving appliances/total number of households × 100%
		*A*3	Per capita water resources	Water loss from the pipe network/total pipeline water delivery × 100%
	Production Water-saving (*B*)	*B*1	Total industrial water use	Extracted by China National Data Network
		*B*2	Leakage rate of urban pipe network	Reuse of industrial wastewater/total amount of industrial wastewater × 100%
		*B*3	Increased water consumption per unit of industrial output	Amount of water reused/(fresh water used in production + amount of water reused) × 100%
	Economic development (*C*)	*C*1	GDP growth rate	(Current GDP – total GDP in the previous year)/current GDP × 100%
		*C*2	Water consumption per 10,000 yuan of GDP	(Water consumption per 10,000 yuan of industrial output value in the previous year – water consumption per 10,000 yuan of industrial output value)/water consumption per 10,000 yuan of industrial output value × 100%
		*C*3	Per capita income	Extracted from the annual report of the study area
	Management Water-saving (D)	*D*1	Water-saving management systems and institutions	Qualitative analysis
		*D*2	Water-saving society construction plan	Qualitative analysis
		*D*3	Water-saving legal system publicity and education	Qualitative analysis
		*D*4	Water-saving investment guarantee	Qualitative analysis
Ecological operation saves water	Natural ecosystems (E)	*E*1	Total water resources	Coverage of water-saving irrigation projects/total farmland irrigation area × 100%
		*E*2	Ecological water use rate	Ecological water/total water consumption × 100%
		*E*3	Water functional zone compliance rate	Number of water functional zones/total number of water functional areas × 100%
	Agricultural water-saving (F)	*F*1	Guarantee rate of water for agriculture, forestry, and fishery	Effective irrigation water/total irrigation water × 100%
		*F*2	Agricultural unit water efficiency	Recycled water for agriculture/total agricultural water use × 100% (including water for agriculture, forestry, animal husbandry, and fishing)
		*F*3	Average irrigation water per mu	Total irrigation water/irrigated acres

compared and assigned using the binary comparison method. Psychology usually ranks the importance of one thing into nine scales. As shown in Table 3, standard values of 2, 4, 6, and 8 indicate that the importance of the comparison factor is between two levels. If $W_{ij} = r_i/r_j$, then $1/W_{ij} = r_j/r_i$.

3.1.2. Constructing a judgment matrix

The judgment matrix should be R, because each layer of index factors is based on the index factors of the adjacent previous layer. A judgment matrix can be constructed according to the pairwise comparison scaling method:

$$R = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix} = \begin{bmatrix} \frac{A_1}{A_1} & \frac{A_1}{A_2} & \cdots & \frac{A_1}{A_n} \\ \frac{A_2}{A_1} & \frac{A_2}{A_2} & \cdots & \frac{A_2}{A_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{A_n}{A_1} & \frac{A_n}{A_2} & \cdots & \frac{A_n}{A_n} \end{bmatrix} \quad (1)$$

where R is a positive definite reciprocal matrix, or a positive definite reciprocal matrix, its eigenvalue λ_{max} exists and is unique. In fact, the exact eigenvalue and eigenvector W of the judgment matrix R are very difficult to solve. Generally, the method of obtaining an approximate value is adopted.

Methods for calculating eigenvalue λ_{max} and eigenvector W include geometric mean, method of arithmetic average, and eigenvector method. The principle of the geometric average method is to use the geometric average to find the development speed of the predicted target, that is, the feature vector. This method is commonly used in statistical research. The principle of the arithmetic average method is a method to obtain the arithmetic average of the predicted target in a certain observation period as the characteristic value of the next period. The eigenvector method uses the weight vector and the weight ratio matrix to multiply to get the result. The advantages and disadvantages of the three methods are the three methods are used to solve the eigenvalues at the same time so as to ensure the stability of the model, and take the average value as the final characteristic value. The three methods are listed as follows.

3.1.2.1. Geometric mean

The elements in the judgment matrix are multiplied first by rows to get a new vector. The new vector is the n-th power. Finally, the resulting vector is normalized into a weight vector. The Eq. (2) is as follows:

$$w_i = \frac{\left(\prod_{j=1}^{h} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{h} a_{ij}\right)^{\frac{1}{n}}}, i = 1, 2, \cdots n \quad (2)$$

3.1.2.2. Method of arithmetic average

Since each column in the judgment matrix approximately reflects the distribution of weights, the arithmetic mean of all column vectors is used to estimate the weight vector. The elements of A are normalized by columns, that is, $a_{ij} / \sum_{k=1}^{n} a_{kj}$. Add the normalized columns and divide by n to get the weight vector. The formula is as follows:

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, i = 1, 2, \cdots n \quad (3)$$

3.1.2.3. Eigenvector method

Multiply the weight vector W by the weight ratio matrix A, $AW = \lambda_{max}W$, repeat the same steps, that is, λ_{max} is the maximum eigenvalue of the judgment matrix, and it is the only one. Finally, it is normalized.

3.1.3. Consistency check

When comparing scales, if there are too many evaluation factors (generally no more than nine). It is easy to produce logical errors, and therefore, a consistency check is required. The Eqs. (4) and (5) is as follows:

$$\text{CI} = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \quad (5)$$

where consistency index (CI) is the calculation consistency index, RI is the consistency index, RI can query the specific

Table 3
Graded assignment criteria for index importance

Standard value	Definition	Description
1	Equally important	r_i and r_j are equally important
3	Slightly important	Factor r_i is slightly more important than r_j
5	More important	Factor r_i is more important than r_j
7	Obviously important	Factor r_i is significantly more important than r_j
9	Absolutely important	Factor r_i is absolutely more important than r_j

value through the form. If CR < 0.1, then the consistency check is satisfied. It is considered that the consistency of the judgment matrix is acceptable. If it is not satisfied, the scale judgment should be readjusted to make it logical.

3.2. TOPSIS comprehensive evaluation model

Hwang and Yoon first proposed TOPSIS in 1981. TOPSIS method is also known as the superior and inferior distance solution or the approximate ideal solution ranking method. The basic principle is to use the positive and negative indicators in the multi-objective decision problem to sort the evaluation objects. Through its forward processing, the indicator types are consistent, and then the standardized processing is performed to eliminate the dimensional impact. Then the optimal solution and the worst solution in the finite solution are found. Finally, the direct distance between each scheme and the best and worst solutions is compared. The TOPSIS method can perform weight analysis on a large number of indicator groups. It can reflect the mutual contrast between the data in the indicator group, it accurately reflects the relationship between the various schemes, and effectively avoids the error caused by subjectivity. TOPSIS method is a commonly used and effective method in multi-objective decision making.

3.2.1. Initial judgement matrix

Let scheme set $P = \{P_1, P_2, \ldots, P_m\}$, each program evaluation index set $r = \{r_1, r_2, r_3, \ldots, r_n\}$, evaluation index r_{ij} indicates the j evaluation index of the i plan, $i \in [1, m]$, $j \in [1, n]$. The initial evaluation matrix can be expressed as:

$$P = \left(r_{ij}\right)_{m\times n} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{6}$$

3.2.2. Initial indicator forward

For very large indicators (benefit-based indicators), the larger the value of the evaluation index, the better it is, such as GDP. The evaluation means that the smaller the better, such as 10,000 yuan of GDP water consumption, and small indicators (cost-based indicators). Some indicators are best near a certain value. For example, the PH value in river water is an intermediate indicator. Therefore, the evaluation targets can be divided into three facts: positive indicators, negative indicators, and intermediate indicators. As shown in Table 4.

The conversion formulas for different types of indicators are as follows:

Minimal type → very large index:

$$M = \max - x \tag{7}$$

where M is the value after the minimal type I's transformed into very large index.

Very large index → minimal type:

$$M = \min - x \tag{8}$$

where M is the value after the very large index is transformed into a minimal type.

Intermediate type index → very large index:

$$M = \max\left\{\left|x_i - x_{\text{best}}\right|\right\},\ x_i = 1 - \frac{x_i - x_{\text{best}}}{M} \tag{9}$$

where x_{best} is the best value, M is the value after the intermediate type index is transformed into a very large index.

Interval index → very large index:

$$M = \max\left\{a - \min\left\{x_i\right\}, \max\left\{x_i\right\} - b\right\},\ x_i = \begin{cases} 1 - \dfrac{\alpha - x}{M}, x < a \\ 1, a \le x \le b \\ 1 - \dfrac{x - b}{M}, x > b \end{cases} \tag{10}$$

Table 4
Indicator types

Indicator name	Index characteristics	Example
Very large (benefit) index	Bigger (more) the better	GDP, total water resources
Minimal type (cost type)	Smaller (less) the better	Water consumption per 10,000 yuan GDP
Intermediate type index	Closer to a certain value, the better	PH in river
Interval index	Better it falls in a certain range	COD, BOD content in river

Table 5
Weight coefficients and eigenvalues of the judgment matrix *O* of the water-saving state evaluation factors in Henan province

Calculation method	City operation	Ecological cycle	CI	CR
Geometric mean	0.6667	0.3333	0	0
Method of arithmetic average	0.6667	0.3333	0	0
Eigenvector method	0.6667	0.3333	0	0

Table 6
*C*1 weight coefficients and eigenvalues of urban water-saving evaluation factor judgment matrix

Calculation method	Domestic water-saving	Production Water-saving	Management Water-saving	Economic development	CI	CR
Geometric mean	0.1256	0.5411	0.0686	0.2647	0.0040	0.0045
Method of arithmetic average	0.1252	0.5416	0.0684	0.2648	0.0043	0.0048
Eigenvector method	0.1253	0.5423	0.0684	0.2648	0.0041	0.0046

Table 7
Weighting coefficients and eigenvalues of the judgment matrix *C*2 for ecological water-saving evaluation factors

Calculation method	Natural ecosystems	Agricultural water-saving	CI	CR
Geometric mean	0.75	0.25	0	0
Method of arithmetic average	0.75	0.25	0	0
Eigenvector method	0.75	0.25	0	0

Table 8
Weight coefficients and eigenvalues of water-saving management evaluation factor judgment matrix *P*4

Calculation method	Water-saving management systems and institutions	Water-saving society construction plan	Water-saving legal system publicity and education	Water-saving investment guarantee	CI	CR
Geometric mean	0.3349	0.1386	0.0817	0.4448	0.0322	0.0362
Method of arithmetic average	0.3342	0.1386	0.0803	0.4469	0.0318	0.0358
Eigenvector method	0.3336	0.136	0.0799	0.4505	0.0320	0.0360

Table 9
Data classification of various indicators

Specific evaluation factors		Indicator type
*A*1	Water consumption norm for residential area	Positive indicator
*A*2	Promotion rate of water-saving appliances	Positive indicator
*A*3	Per capita water resources	Negative indicator
*B*1	Total industrial water use	Negative indicator
*B*2	Leakage rate of urban pipe network	Positive indicator
*B*3	Increased water consumption per unit of industrial output	Positive indicator
*C*1	GDP growth rate	Positive indicator
*C*2	Water consumption per 10,000 yuan of GDP	Positive indicator
*C*3	Per capita income	Positive indicator
*D*1	Water-saving management systems and institutions	Qualitative index
*D*2	Water-saving society construction plan	Qualitative index
*D*3	Water-saving legal system publicity and education	Qualitative index
*D*4	Water-saving investment guarantee	Qualitative index
*E*1	Total water resources	Positive indicator
*E*2	Ecological water use rate	Positive indicator
*E*3	Water functional zone compliance rate	Positive indicator
*F*1	Guarantee rate of water for agriculture, forestry, and fishery	Positive indicator
*F*2	Agricultural unit water efficiency	Positive indicator
*F*3	Average irrigation water per mu	Negative indicator

Table 10
Final scores of water-saving evaluation in Henan Province

Years	2008	2009	2010	2011	2012
Final score	0.24407	0.1816	0.2729	0.2774	0.2298
Years	2013	2014	2015	2016	2017
Final score	0.2079	0.3421	0.3294	0.352	0.4051

The best interval is [*a*,*b*]. *M* is the value after the interval index is transformed into a very large index.

Generally, the indicator processing is unified conversion into a type of indicator, and this study uniformly transforms into a very large (benefit) indicator.

3.2.3. Standardized decision matrix

Because each evaluation index has different dimensions and dimensional units, and there is no contrast, in order to eliminate the incommensurability of the index, the evaluation index is needed to be dimensionally normalized. For a standardized decision matrix $B = (b_{ij})_{m\times n}$, the calculation is as follows:

$$b_{ij} = \frac{r_{ij} - \min\left(r_{ij}\right)}{\max_j\left(r_{ij}\right) - \min_j\left(r_{ij}\right)} \quad (11)$$

$$b_{ij} = \frac{\max\left(r_{ij}\right) - r_{ij}}{\max_j\left(r_{ij}\right) - \min_j\left(r_{ij}\right)} \quad (12)$$

In Eqs. (11) and (12), b_{ij} is the items after the standardized decision matrix, r_{ij} is the first item of the standardized decision matrix.

3.2.4. Weighted standardized decision matrix

To multiply the column vector of matrix *B* by the total ranking weights of each index level determined in AHP, the weighted normalization can be obtained. The decision matrix is as follows:

$$R = \left(r_{ij}\right)_{m\times n} = \begin{bmatrix} w_1 b_{11} & w_2 b_{12} & \cdots & w_n b_{1n} \\ w_1 b_{21} & w_2 b_{22} & \cdots & w_n b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 b_{m1} & w_2 b_{m2} & \cdots & w_n b_{mn} \end{bmatrix} \quad (13)$$

3.2.5. Normalization processing

The positive ideal solution of the positive indicator J_1 is the maximum value of the row vector. The negative ideal solution is the minimum value of the row vector, and the value of the negative indicator set J_2 is the opposite. The formula is as follows:

Table 11
Water-saving status evaluation table

Level	Interval	Level description
1	0.8–1	High degree of water-saving
2	0.6–0.8	Relatively high water-saving
3	0.4–0.6	Average water-saving
4	0.2–0.4	Poor water-saving
5	0–0.2	Waste of water

$$\left.\begin{aligned} R^+ &= \left\{\left(\max_n w_n b_{mn} \middle| m \in J_1\right), \left(\min_n w_n b_{mn} \middle| m \in J_2\right)\right\} \\ R^- &= \left\{\left(\min_n w_n b_{mn} \middle| m \in J_1\right), \left(\max_n w_n b_{mn} \middle| m \in J_2\right)\right\} \end{aligned}\right\} \quad (14)$$

In Eq. (14), R^+ and R^- are positive ideal solution and negative ideal solution, respectively. The distance between the judgment object and the ideal solution is:

$$\left.\begin{aligned} D_i^+ &= \sqrt{\sum_{j=1}^{n}\left(r_{ij} - r_j^+\right)^2} \\ D_j^- &= \sqrt{\sum_{j=1}^{n}\left(r_{ij} - r_j^-\right)^2} \end{aligned}\right\} \quad (15)$$

In Eq. (15), D_i^+ and D_i^- are the distance between the evaluation object and the positive and negative ideal solutions respectively; r_j^+ and r_j^- are the specific evaluation indexes corresponding to R^+ and R^-, respectively.

The calculation formula for the comprehensive evaluation index is as follows:

$$C_i^+ = \frac{D_i^-}{\left(D_i + +D_i^-\right)\left(0 \le C_i^+ \le 1\right)} \quad (16)$$

When the judgment object is a positive index, $C_i^+ = 1$. When the evaluation object is a negative indicator, $C_i^+ = 0$. In general, the value of the closeness of the judgment object C_i^+ is (0,1), which reflects how close the evaluation object is to the positive ideal solution.

3.3. AHP-TOPSIS coupling evaluation model

The evaluation matrix *P* is constructed from the closeness analysis of the TOPSIS method, combined with the initial weight obtained by AHP analysis of *O–P*. The comprehensive judgment result vector *Q* of the evaluation object is as follows:

$$Q = W \times C \quad (17)$$

In Eq. (17), *C* is the judgment matrix formed by the closeness of each evaluation index to the positive ideal solution, and *W* is the initial weight obtained by AHP.

3.4. AHP-TOPSIS evaluation model

The *O–P* layer, *P–C* layer and urban water-saving management in the evaluation of urban water-saving are analyzed by AHP.

A judgment matrix is built first. The judgment matrix of water-saving evaluation in Henan Province is O, the evaluation matrices of the evaluation factors of urban operation and ecological cycle are $C1$ and $C2$, and the judgment matrix of water conservation management in $C1$ city operation is $P4$.

In order to ensure the robustness of the results, three methods of geometric mean, method of arithmetic average, and eigenvector method are used in this evaluation to solve simultaneously. The judgment matrices O, $C1$, $C2$, and $P4$ are as follows:

$$O = \begin{bmatrix} 1 & 1/2 \\ 2 & 1 \end{bmatrix}$$

$$C1 = \begin{bmatrix} 1 & 1/5 & 2 & 1/2 \\ 5 & 1 & 7 & 2 \\ 1/2 & 1/7 & 1 & 1/4 \\ 2 & 1/2 & 4 & 1 \end{bmatrix}$$

$$C2 = \begin{bmatrix} 1 & 1/3 \\ 3 & 1 \end{bmatrix}$$

$$P4 = \begin{bmatrix} 1 & 3 & 5 & 1/2 \\ 1/3 & 1 & 2 & 1/3 \\ 1/5 & 1/2 & 1 & 1/4 \\ 2 & 3 & 4 & 1 \end{bmatrix}$$

Considering the robustness of the results, each judgment matrix is calculated using three eigenvalues, and the results are as follows:

In summary, judgment matrices O, $C1$, $C2$, and $P4$ satisfy $CR < 0.10$ through all three algorithms, therefore, consistency check passed.

After calculating the weighting using AHP analytic hierarchy process, the remaining data are processed positively. After data classification and selection, positive processing is performed by Eqs. (7)–(9). The data classification is as follows:

After processing of each indicator, the matrix $P1$ of domestic water-saving, $P2$ of water-saving in production, $P3$ of economic development, $P5$ of natural ecology, and $P6$ of agricultural water are produced by using Eqs. (10) and (11) for standardization.

$$P1 = \begin{bmatrix} 0.311 & 0.3548 & 0.3801 \\ 0.3505 & 0.3461 & 0.3039 \\ 0.3078 & 0.3389 & 0.2602 \\ 0.2666 & 0.3244 & 0.2579 \\ 0.2831 & 0.3186 & 0.1964 \\ 0.3341 & 0.3114 & 0.2424 \\ 0.339 & 0.2998 & 0.3 \\ 0.3028 & 0.2896 & 0.2977 \\ 0.311 & 0.2868 & 0.2977 \\ 0.3456 & 0.2824 & 0.3382 \end{bmatrix}$$

$$P2 = \begin{bmatrix} 0.4285 & 0.5275 & 0.4702 \\ 0.4601 & 0.4943 & 0.4198 \\ 0.3605 & 0.3397 & 0.4047 \\ 0.3564 & 0.2955 & 0.403 \\ 0.0478 & 0.1629 & 0.361 \\ 0 & 0.1464 & 0.2519 \\ 0.1667 & 0.1878 & 0.2519 \\ 0.2226 & 0 & 0.1343 \\ 0.3154 & 0.1408 & 0.0336 \\ 0.4105 & 0.4143 & 0 \end{bmatrix}$$

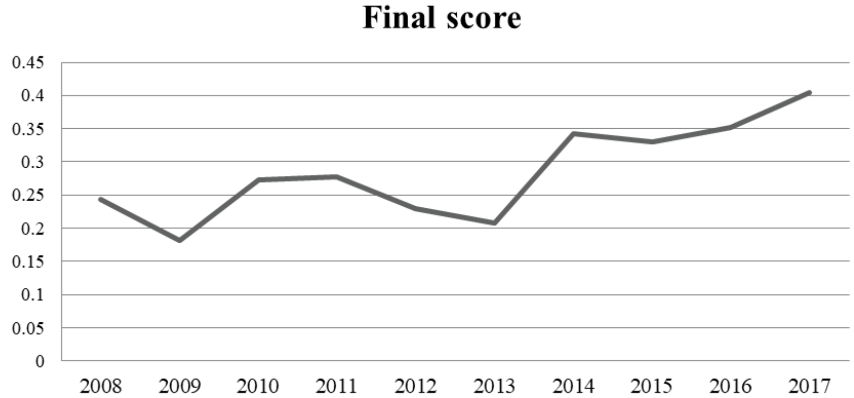

Fig. 1. Schematic diagram of water-saving status of Henan Province.

$$P3=\begin{bmatrix} 0.2558 & 0.4713 & 0.4396 \\ 0.2379 & 0.4333 & 0.4005 \\ 0.1499 & 0.4181 & 0.3681 \\ 0.2165 & 0.4105 & 0.3492 \\ 0.2222 & 0.2273 & 0.3225 \\ 0.2442 & 0.2813 & 0.2968 \\ 0.4217 & 0.2889 & 0.2706 \\ 0.4704 & 0.1748 & 0.2316 \\ 0.2058 & 0.0456 & 0.1937 \\ 0.508 & 0 & 0.1802 \end{bmatrix}$$

$$P5=\begin{bmatrix} 0.3843 & 0.3616 & 0.4634 \\ 0.3064 & 0.2954 & 0.3933 \\ 0.2609 & 0.4257 & 0.3816 \\ 0.2574 & 0.6005 & 0.3622 \\ 0.1955 & 0.0542 & 0.2765 \\ 0.2412 & 0.1906 & 0.3076 \\ 0.2979 & 0.3188 & 0.2882 \\ 0.4859 & 0.2956 & 0.2765 \\ 0.2987 & 0 & 0.1168 \\ 0.3373 & 0.1088 & 0.0974 \end{bmatrix}$$

$$P6=\begin{bmatrix} 0.3616 & 0.3852 & 0.4054 \\ 0.2954 & 0.3799 & 0.3266 \\ 0.4257 & 0.3894 & 0.3378 \\ 0.6005 & 0.3952 & 0.4392 \\ 0.0542 & 0.3046 & 0 \\ 0.1906 & 0.2964 & 0.3153 \\ 0.3188 & 0.2869 & 0.3491 \\ 0.2956 & 0.2419 & 0.3041 \\ 0 & 0.2113 & 0.2027 \\ 0.1088 & 0.1823 & 0.259 \end{bmatrix}$$

After standardization, Eqs. (12)–(15) for weighting and normalization are applied to get the final score, which is as follows:

3.5. Result analysis

The final score is shown in Fig. 1. The water-saving status of Henan Province rose generally from 2008 to 2017, and declined in 2009 and 2013.

The indicators of the *P*-layer from 2008 to 2017 are shown in Figs. 2–7. Among them, water-saving in production contributed the most to the water-saving evaluation of Henan Province, followed by ecological water-saving, economic development, domestic water-saving, and agricultural water-saving.

The degree of conservation is an indicator to the water-saving status of the study area. The degree of conservation Y is between 0 and 1, and it is divided into five levels. The levels are divided as follows:

In summary, the current final score of water-saving in Henan province is 0.4051, which belongs to the general level of water-saving. From the perspective of trend, the development trend of urban water-saving is very good, with the trend increasing from 2008 to 2017 and decreasing in 2009 and 2013. According to the analysis of the specific evaluation indicators in Figs. 1–7, it can be concluded that the *p*-level indicators increase from 2008 to 2017, but decrease in 2009 and 2013. The specific reasons are caused by the major national strategies such as cutting overcapacity and shifting of economic gear in 2009 and 2013 in Henan Province, among which the economic development has the greatest impact.

4. Conclusion

- This paper analyzed the operation mechanism of water environment from the macro perspective, and expounded the relationship between water environment and each other. Based on the research on water-saving evaluation at home and abroad, the concept of urban water-saving evaluation under a new perspective was proposed, which was a water-saving evaluation including social production economy and ecological nature from a macro perspective.
- The AHP-TOPSIS is used to construct the urban water-saving evaluation model under the new concept. Based on the conversation priority under the big background of water-saving, weight the upper index by AHP, coupling TOPSIS evaluation index for specific analysis at the same time, ensure the relative relation between the data. Therefore, it not only eliminates the dimensional influence, but also ensures that the results conform to the actual data and the general background of the current water-saving priority policy, which provides a new way to water-saving evaluation model and a theoretical basis for guiding practice.
- By analyzing the state of water-saving in Henan province from 2008 to 2017, it is concluded that water-saving score is 0.4051 in Henan province at present, which belongs to a general degree of water-saving. The overall growth trend is good, but there exists a decreasing trend in 2009 and 2013. The direct reason is that each index decreased in 2009 and 2013. The specific reason is caused by the major national strategies of Henan Province, such as cutting overcapacity and shifting economic gear in 2009 and 2013, among which economic development has the greatest impact on water-saving state.
- The overall water resources in Henan Province are relatively scarce. The water-saving capacity barely reached a good level in 2017, however, due to related economic and water-saving policies in 2009 and 2013, it shows a

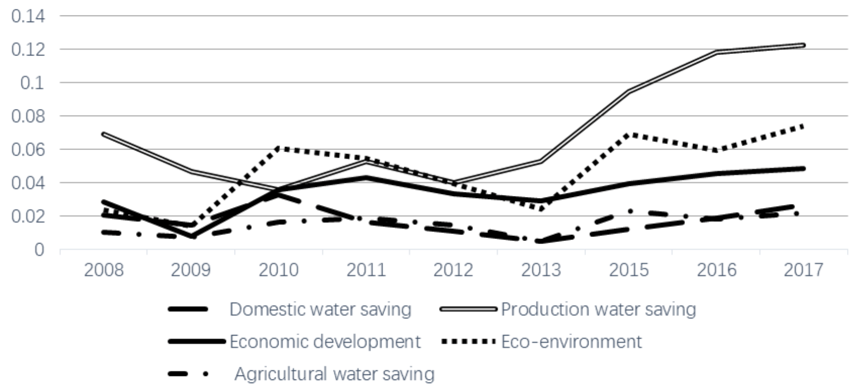

Fig. 2. *P*-Layer score of water-saving state in Henan Province.

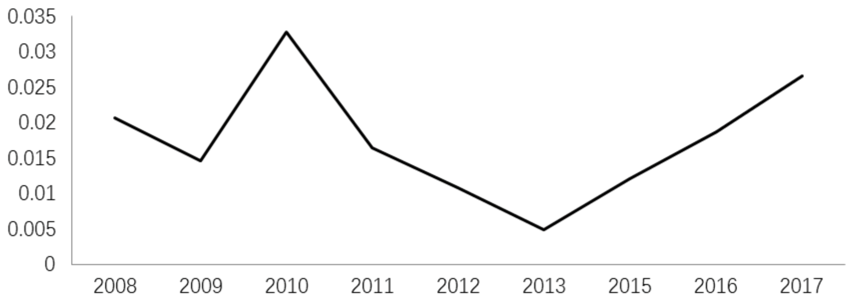

Fig. 3. Domestic water-saving score.

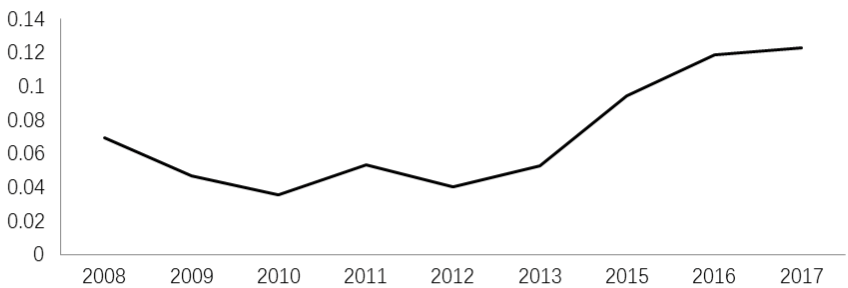

Fig. 4. Production water-saving score.

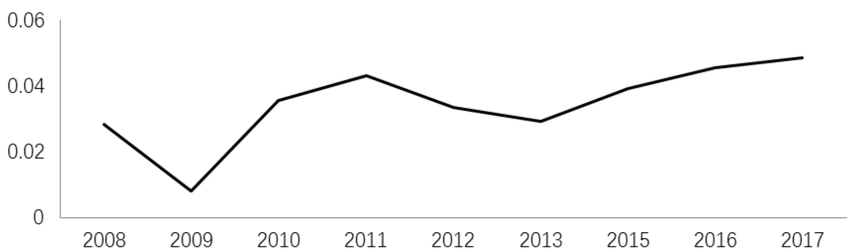

Fig. 5. Economic development score.

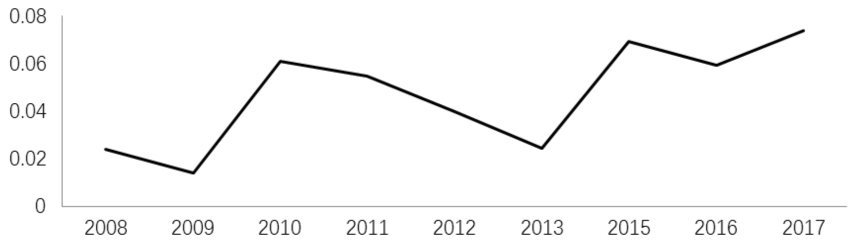

Fig. 6. Eco-environment score.

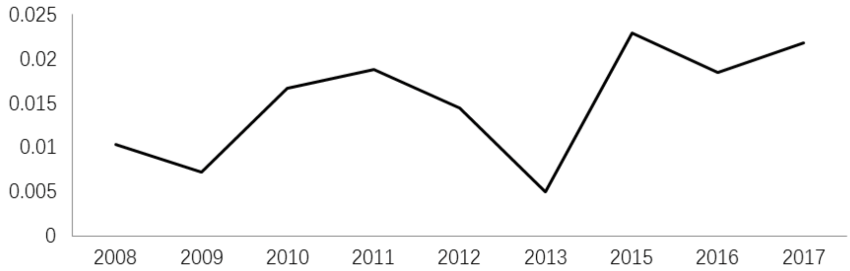

Fig. 7. Agricultural water-saving score.

slight fluctuation in water-saving capacity. In regions where water resources are scarce and water-saving capacity is relatively weak, the impact of policy regulation is deep and the water-saving capacity fluctuates greatly. Therefore, the factors above should be taken into account when formulating relevant policies in the future and relatively moderate economic and water-saving policies should be formulated.

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