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A Comprehensive Evaluation Model for Irrigation Districts Modernization Based on Variable Fuzzy Sets

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Abstract. The evaluation of irrigation district modernization is the basis of the construction of modern irrigation district and has an important reference for the irrigation district modernization.The indicators and evaluation index system were discussed and thresholds of irrigation districts indicators were analyzed.A mathematical model for the evaluation of modern irrigation districts was established based on variable fuzzy set theory.Taking the Panzhuang plain irrigation district in Shandong Province and the Tongziba plateau irrigation district in Gansu Province as an example, the situation of the irrigation district after modernization was evaluated. After the modernization of Panzhuang irrigation district and Tongziba irrigation district, the evaluation result is H=1.382, 1.448, respectively,which is all in full realization of modernization.Compared with the current status of irrigation district, it shows that the modernization measures of irrigation districts are reasonable and effective for irrigation district.

1. Preface

Irrigation district modernization and upgrading reconstruction is an important part of water conservancy modernization and socialism modernization. As the foundation of the construction of modern irrigation district, many scholars at home and abroad have studied the evaluation of irrigation district modernization.Charles [1] designed a set of special programs in which all the indicators were based on the comprehensive survey of irrigation districts and used for the comprehensive evaluation of the irrigation system that had been built. Raju K S,Vasan A[2] evaluated the irrigation system using multi-indicator utility theory and achieved good results. H.okada [3] used analytic hierarchy process to analyze and study the engineering transformation of irrigation district. Jing Xu[4] used an improved algorithm of additional momentum adaptive learning rate to establish an artificial neural network comprehensive evaluation model and evaluated two actual irrigation districts.WenChuan Wang[5] used the variable fuzzy set theory to establish a new and effective comprehensive evaluation method for water saving reform in irrigation district.ALi Zhao[6] applied the fuzzy comprehensive evaluation method to the Guanzhong irrigation district in Shanxi Province to comprehensively evaluate the irrigation district.Tao Ma[7] established the mathematical model of fuzzy comprehensive judgment to conduct a comprehensive evaluation of the operating conditions of the three irrigation districts in Donggang City. The evaluation results are in good agreement with the actual situation.This paper will establish a mathematical model of irrigation district modernization evaluation based on variable fuzzy set theory and takes the Panzhuang plain irrigation district in Shandong Province and the Tongziba plateau irrigation district in Gansu Province as an example to evaluate the modernization of irrigation districts.In the process of evaluation, the indicators are processed fuzziness, and the results obtained are of uniformity and accuracy.

2. Evaluation Index System of Modern Irrigation District

According to the connotation and characteristics of the modern irrigation district under the new era, the index evaluation system and threshold were set up, and the weights of indicators at all levels were calculated by binary contrast method. As shown in Table 1.

Table1. Evaluation index system of modernization irrigation district

A level of indicators	First level indicator weight	Secondary indicators	Threshold Value	Secondary indicator weight
Security A	0.271	The reaching standard rate of the irrigation dikes, water storage projects, pump stations and farmland flood control A1	90%	0.270
		The ratio of reaching standard area to village and town waterlogging area A2	100%	0.180
		The ratio of drought and flood disaster area to farmland area A3	5%	0.161
		Water supply guarantee rate A4	95%	0.220
		water qualifaication rate of water resource A5	90%	0.169
Constructio n B	0.187	serviceability rate of water source engineering B1	100%	0.169
		serviceability rate of water conveyance channel B2	95%	0.148
		serviceability rate of canal (ditch) building B3	95%	0.147
		Perfect degree of supporting facilities B4	100%	0.141
		Matching rate of water measuring facilities B5	95%	0.139
		Proportion of water saving irrigation project area B6	95%	0.136
		The rate of farmland irrigation B7	95%	0.120
Informatio n Manageme nt and Services C	0.164	The realistic degree of the data collection of the work situation, the water situation and the moisture content C1	90%	0.220
		Gate (pump station) remote monitoring rate C2	90%	0.184
		The realization rate of informational office C3	100%	0.200

		Percentage of technical personnel in water conservancy C4	90%	0.187
		Satisfaction degree of engineering maintenance cost C5	100%	0.230
Efficiency and benefit D	0.223	Effective utilization coefficient of irrigation water D1	0.75	0.290
		The amount of grain produced by consuming one cubic meter of water D2	3	0.332
		Water consumption by 10,000 yuan agricultural output value D3	800	0.378
Ecosystem E	0.155	Fertilizer utilization rate in farmland E1	43%	0.187
		Ecological slope protection ratio E2	95%	0.134
		Control rate of soil and water loss E3	95%	0.220
		Overexploitation rate of groundwater E4	1%	0.220
		Saline-alkali prevention and control meet standard rate E5	100%	0.238

Note: Based on Xu Xinran's "Study on Connotation and Comprehensive Evaluation of Modernization Irrigation District".

3. Variable fuzzy sets evaluation method

3.1. Evaluation method

Variable fuzzy set definition: Suppose a fuzzy concept *A* (a thing, a phenomenon) on the domain *U*, relative to any element *u* ($u \in U$) in *U*, on the continuous axis of the relative membership function.The relative membership degree of the attraction property *A* is $u_A(u)$, and the relative membership degree of the Repulsion property *A* is $u_A^c(u)$,The difference $D_A(u)$ between $u_A(u)$ and $u_A^c(u)$ is referred to as the relative degree of difference between *u* and *A*, and is between [-1,1].According to

$$\mu_A(u) + \mu_{A^c}(u) = 1 \quad (1)$$

$$u_A(u) = [1 + D_A(u)]/2 \quad (2)$$

Relative difference function model: *X* = [c, d], x is the magnitude of any point in the interval *X*, the interval (a, b) belongs to the interval [c, d], and *M* can be the midpoint of the interval [a, b] .

When *x* falls to the left of *M* point,the relative difference function model is:

$$D_A(u) = \left[\frac{x-a}{M-a}\right]^{\beta}; x \in [a, M] \quad (3)$$

$$D_A(u) = -\left[\frac{x-a}{c-a}\right]^{\beta}; x \in [c, a] \quad (4)$$

When *x* falls to the right of *M* point,the relative difference function model is:

$$D_A(u) = \left[\frac{x-b}{M-b}\right]^{\beta}; x \in [M, b] \quad (5)$$

$$D_A(u) = -\left[\frac{x-b}{d-b}\right]^{\beta}; x \in [b, d] \quad (6)$$

$$D_A(u) = -1; x \notin (c, d) \quad (7)$$

Where:β is a non-negative index, usually is 1. D_A *(u)* derived, according to equation (2) can be obtained relative membership u_A *(u)*.

Variable fuzzy evaluation model:

$$V'_{Ah} = \frac{1}{\left[1 + (d_g / d_b)^{\alpha}\right]} \quad (8)$$

$$d_b = \left\{ \sum_{i=1}^{m} \left[w_i u_A(x_{ij}) \right]^p \right\}^{\frac{1}{p}} \quad (9)$$

$$d_g = \left\{ \sum_{i=1}^{m} \left\{ w_i [1 - u_A(x_{ij})] \right\}^p \right\}^{\frac{1}{p}} \quad (10)$$

Where :α is the model optimization criterion parameter, $\alpha = 1$, $\alpha = 2$; w_i is the weight of the indicator; u_A *(xij)* is the relative membership degree of the indicator under each classification;P is distance parameter, P=1 is Haiming distance, p=2 is European distance.

According to Eq. (8), we can get the non-normalized comprehensive relative membership matrix V'_{Ah}, and get V_{Ah} after normalizing.

Grading evaluation using level eigenvalue H.

$$H = (1,2,\cdots c) \bullet V_{Ah} \quad (11)$$

3.2. Evaluation of the classification

The evaluation result of modern irrigation districts is divided into four levels according to the degree of modernization: I (full realization of modernization), II (partial realization of modernization), III (modernization of basic realization), IV (non-realization of modernization).According to "water-saving irrigation engineering specifications","flood control standards" and other water-related norms and research achievements, the two indicators of the level of classification.The level upper limit value is the threshold value of the index, and the lower limit of the grade is the average of the current poor irrigation districts..The standard division of modern irrigation is shown in Table 2. According to the classification of the standardization of modern irrigation district, the variable fuzzy set method is used to calculate the level of characteristic value H of modernized irrigation district.As shown in Table 3.

Table 2. index level division

Secondary indicators	I（Fully realized）	II（Basic realization）	III（Partially achieved）	IV（Unrealized）	Secondary indicators	I（Fully realized）	II（Basic realization）	III（Partially achieved）	IV（Unrealized）
A1	90%~80%	80%~65%	65%~50%	50%~35%	C2	90%~80%	80%~65%	65%~50%	50%~35%
A2	100%~90%	90%~75%	75%~60%	60%~45%	C3	100%~90%	90%~75%	75%~60%	60%~45%
A3	5%~10%	10%~20%	20%~30%	30%~35%	C4	90%~80%	80%~65%	65%~50%	50%~35%
A4	95%~85%	85%~75%	75%~60%	60%~50%	C5	100%~90%	90%~75%	75%~60%	60%~45%
A5	90%~80%	80%~65%	65%~50%	50%~35%	D1	0.75~0.70	0.70~0.60	0.60~0.50	0.50~0.40
B1	100%~90%	90%~75%	75%~60%	60%~45%	D2	3.0~2.5	2.5~2.0	2.0~1.0	1.0~0.5
B2	95%~85%	85%~70%	70%~55%	55%~40%	D3	800~950	950~1150	1150~1350	1350~1500
B3	95%~85%	85%~70%	70%~55%	55%~40%	E1	43%~40%	40%~35%	35%~30%	30%~20%
B4	100%~90%	90%~75%	75%~60%	60%~45%	E2	95%~85%	85%~70%	70%~55%	55%~40%

B5	95%~85%	85%~70%	70%~55%	55%~40%	E3	95%~85%	85%~70%	70%~55%	55%~40%
B6	95%~85%	85%~70%	70%~55%	55%~40%	E4	1%~3%	3%~5%	5%~8%	8%~10%
B7	95%~85%	85%~70%	70%~55%	55%~40%	E5	100%~90%	90%~75%	75%~60%	60%~45%
C1	90%~80%	80%~60%	60%~40%	40%~30%					

Table 3. Degree of modernization realization level characteristic value *H*

grade	H	Achieve the degree
I	1.0~1.5	Fully realize modernization
II	1.5~2.5	The basic realization of modernization
III	2.5~3.5	Part of the modernization
IV	3.5~4.0	Unrealized modernization

4. Example application

4.1. The basic situation of irrigation

Panzhuang irrigation district is located in the North China Plain, west of Dezhou City, Shandong Province, and is a national large-scale irrigation district.Irrigation district designed irrigation area of 33.33 million hectares, effective irrigated area 23.15 million hectares, planting wheat, corn and other crops.The annual irrigation water consumption is 869 million cubic meters, and the irrigation water utilization coefficient is 0.590. After years of operation, irrigation district have problems such as poor engineering support, low water use efficiency, poor ecological environment, and low management capacity. In 2014, the irrigation district district was rebuild supporting and water-saving renovation plans. Despite the overall improvement of irrigation district, compared with some of China's better irrigation districts, the overall situation is at a lower level.

Tongziba irrigation district is located in the north of Qilian Mountains on the Qinghai-Tibet Plateau and east of MinLe County in the middle section of the HeXi Corridor. It belongs to the national large-scale irrigation district.Irrigation district designed irrigation area of 2.02 million hectares, effective irrigated area 1.92 million hectares, planting wheat, corn and other crops. The annual irrigation water consumption in the irrigation district is 55.51 million cubic meters, and the irrigation water utilization coefficient is 0.494.The construction of irrigation district was limited by the economic and technical conditions at that time, and the construction standards were low. After years of operation, the irrigation district had problems such as poor engineering support, low water use efficiency, poor ecological environment, and low management capacity. Compared with other better irrigation districts in China, the irrigation district as a whole is a relatively poor irrigation district.

4.2. Data Processing

The realization rate of informationized office work in this index system is a qualitative index. It can be quantified by the expert scoring method from four aspects such as 3S technology application, irrigation district information management system, drought and flood disaster early warning and irrigation forecast, disaster prevention decision-making system and irrigation decision support system. This paper have dimensionless indicators, such as the amount of grain produced by consuming one cubic meters of water and water consumption by 10,000 yuan agricultural output value. It can be nondimensionalized by target value comparison method. The overexploitation rate of groundwater and ratio of drought and flood disaster area are the two reverse indexes. New indicator value by using 1 minus the index value is the positive index value

4.3. Irrigation District Evaluation Results and Analysis

The Panzhuang Plain irrigation district in Shandong Province and the Tongziba Plateau irrigation district in Gansu Province were taken as examples. According to the modern irrigation district planning, the target values of each index should be collected, which was evaluated in the condition after the modernization of the two irrigation districts, and the comprehensive evaluation of the modernization of the irrigation districts was carried out to evaluate modernization degree of two irrigation districts.The evaluation results are shown in Table 4.

Table 4. Result of Index Calculation after Reconstruction of Irrigation Districts

Secondary indicators	Panzhuang Plain irrigation district	Tongziba Plateau irrigation district	Secondary indicators	Panzhuang Plain irrigation district	Tongziba Plateau irrigation district
The reaching standard rate of the irrigation dikes, water storage projects, pump stations and farmland flood control A1	95%	90%	Gate (pump station) remote monitoring rate C2	100%	100%
The ratio of reaching standard area to village and town waterlogging area A2	100%	100%	The realization rate of informational office C3	100%	100%
The ratio of drought and flood disaster area to farmland area A3	5%	5%	Percentage of technical personnel in water conservancy C4	95%	90%
Water supply guarantee rate A4	95%	95%	Satisfaction degree of engineering maintenance cost C5	100%	100%
water qualifaication rate of water source A5	95%	90%	Effective utilization coefficient of irrigation water D1	0.690	0.767
serviceability rate of water source engineering B1	100%	95%	The amount of grain produced by consuming one cubic meter of water D2	4	4
serviceability rate of water conveyance channel B2	95%	95%	Water consumption by 10,000 yuan agricultural output value D3	690	700
serviceability rate of canal (ditch) building B3	95%	95%	Fertilizer utilization rate in farmland E1	43%	40%
Perfect degree of supporting facilities B4	100%	95%	Ecological slope protection ratio E2	100%	95%
Matching rate of water measuring facilities B5	95%	95%	Control rate of soil and water loss E3	100%	95%
Proportion of water saving irrigation project area B6	95%	80%	Overexploitation rate of groundwater E4	5%	3%
The rate of farmland irrigation B7	95%	100%	Saline-alkali prevention and control meet standard rate E5	85%	80%
The realistic degree of the data collection of the work situation, the water situation and the moisture content C1	100%	100%			

Using variable fuzzy set theory, we take α=1,p=2. Based on the fuzzy evaluation model, the relative membership degree of the two-level index of the two irrigation districts was obtained, and the comprehensive membership degree under the first-level index was obtained.After normalized treatment, the V_{ah1} and V_{ah2} after the water saving reform in the two irrigation districts were obtained respectively.

$$V_{Ah1} = [0.837, 0.223, 0.033, 0.000]$$

$$V_{Ah2} = [0.813, 0.222, 0.064, 0.000]$$

According to equation (11), the level eigenvalues of the two irrigation districts are obtained:

$$H_1 = 1.382 \;;\; H_2 = 1.448$$

According to Table 3, the evaluation results of the two irrigation districts are all at level I, and the level of modernization is fully modernized. Compared with the current status of the irrigation district, it shows that the implementation of the irrigation district modernization measures is feasible. At the same time, it shows that the evaluation index system and evaluation method of modern irrigation district established in this paper are feasible and reasonable, and can be used as the evaluation basis of modern irrigation district.

5. Conclusion

Through the evaluation system and threshold of irrigation district modernization established by the connotation and characteristics of modern irrigation district in the new era, the weights of each index were determined by using binary contrastive analysis method, and the mathematic model of irrigation district modernization evaluation was established based on variable fuzzy set theory. The status of the modernization of the Panzhuang Plain irrigation district in Shandong Province and the Tongziba Plateau irrigation district in Gansu Province was evaluated. The results show that the modernization level of the two irrigation districts is in full modernization degree. Compared with the present situation of the irrigation district, it shows the variable fuzzy Set theory adapts to the evaluation of the modernization of irrigation districts.

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