Evaluation of Economic Operation Effect of Rural Small Water-lifting Irrigation Pumping Station Based on Fuzzy Comprehensive Evaluation Model

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Abstract: With the continuous advancement of the comprehensive reform of agricultural water prices across the country, various water management units across the country have strengthened the management and protection of irrigation facilities such as irrigation pumping stations, improved the operating efficiency of irrigation pumping stations, and saved agricultural irrigation costs; There is still an imbalance in the management and protection of water-lifting irrigation pumping stations, especially in the evaluation of the economic operation effect of the pumping station. For this reason, this paper uses the fuzzy comprehensive evaluation method to evaluate the economic operation of small-scale rural water-lifting irrigation pumping stations. The effect was quantitatively evaluated, providing new and reliable ideas and methods for water management related management departments to evaluate the economic operation of pumping stations; through empirical research on City G, it was also found that City G is still in the economic operation of small irrigation pumping stations. There are some shortcomings, and some technical and economic measures can be used to further improve the economic operation and management efficiency of the pumping station, and further reduce the cost of agricultural irrigation.

Key words: irrigation pumping station; economic operation; fuzzy comprehensive evaluation model; effect
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INTRODUCTION

At present, China attaches great importance to agricultural water-saving work and invests a lot of funds in agricultural water-saving irrigation every year, which strengthens the implementation construction of farmland irrigation infrastructure, improves irrigation efficiency and improves the effective utilization coefficient of farmland irrigation water in provinces, cities and counties (districts) year by year. After a comprehensive study of relevant research literature at home and abroad, there were many relevant studies on the high-efficient water saving techniques and management such as those on economic operation of irrigation facilities (pumping stations) focusing on large pumping stations, adjustable vane pumping stations, cascade pumping stations, well group pumping stations and so on[1-5]. Some scholars have also studied the optimization of single-stage and multi-stage pump stations by modern scientific methods[6-8] However, there are very few researches on evaluating the economic operation effect of small pumping stations, especially on quantitative evaluation. Therefore, in this paper, the economic operation effect of rural small water-lifting irrigation pumping stations is evaluated quantitatively. With the help of fuzzy mathematics theory, a fuzzy comprehensive evaluation method is constructed to quantify some qualitative evaluation indexes as much as possible, in order to obtain more credible evaluation results so that relevant departments can take relevant measures according to the evaluation results, further consolidate and optimize the economic operation effect of the pumping station, and further reduce the cost of agricultural water. It is of great significance to continuously strengthen the management of agricultural water, promote the water management units to strengthen the management and protection of irrigation pumping stations, improve their operation efficiency and save the operation cost of agricultural irrigation.

DEFINITION OF RELATED CONCEPTS OF FUZZY COMPREHENSIVE EVALUATION METHOD

Fuzzy comprehensive evaluation, as an evaluation method based on fuzzy mathematics, applying the principle of fuzzy relation synthesis, quantifying some factors with unclear boundaries and difficulty in quantification, so as to make a relatively objective, correct and practical evaluation, can effectively solve the problems caused by multifactor, fuzziness and subjective judgment, and is a better method for comprehensive consideration of various attributes and related factors[9]. The following five steps are usually required to establish a fuzzy comprehensive evaluation model: establishing an evaluation indicator set, determining the weight of each indicator, establishing an evaluation grade set, establishing a membership relationship and establishing a fuzzy matrix and fuzzy comprehensive evaluation[10].

MODELING AND EMPIRICAL RESEARCH

In this study, the economic operation effect of typical small pumping stations in rural areas of City G was evaluated. City G is located in the lower reaches of the Huaihe River, the Lixiahe Plain in the central part of Jiangsu Province, with a total area of 1,963km², including 1,175km² of land and 788km² of water. There are complex water systems in the territory, and three river basins, namely, the River Estuary, the Beijing-Hangzhou Grand Canal and the Sanyang River passing through, which divide the whole city into the hills in the west of the lake and the polder area along the lake, the gravity irrigation area in the east of canal and the polder area of Lixia River. The city has jurisdiction over 13 townships (parks) and 175 administrative villages, with an existing cultivated land area of 1,151,100 mu and an effective irrigated area of 1,083,000 mu. Rice is the main food crop, and the irrigated area of rice accounts for over 90%. As there is a solid foundation for water-saving irrigation and comprehensive reform of agricultural water price in City G, 48 typical small pumping stations of 24 types (2 for each type) in City G were selected as samples, which basically represent small pumping stations of various types, models, years and heads in all irrigation districts of City G. Based on the relevant technical basis, operation and other data of the 24 types of small water pumping irrigation stations, and in combination with the management status information of each irrigation pumping station, an evaluation group mainly composed of the leaders in charge of the water resources department, experts, grass-roots management personnel and water users' representatives was formed to evaluate the economic operation of the small water pumping irrigation stations. A questionnaire survey was conducted on the relevant indicators of the economic operation of these 24 typical irrigation pumping stations in this evaluation. A total of 260 questionnaires were distributed to the evaluation group and 235 were collected. After the questionnaires were sorted out, 198 were considered to be valid. According to the results of 198 valid questionnaires and the steps of the fuzzy comprehensive evaluation model mentioned above in this paper, the economic operation effect of typical small water-lifting irrigation pumping station in rural area of City G was evaluated in the following steps:

Establishing an Evaluation Indicator System

In this paper, the related indicator set U for the economic operation effect evaluation of small water-lifting irrigation pumping station includes three evaluation indicators of technology, economy and management. Among them, the technical subset can be divided into five sub-level indicators, pump station type suitability rate, pump station service life, pump station head matching, power matching, and the proportion of actual flow; the economic subset can be further divided into three sub-level indicators, i.e., the proportion of service fees paid to the unit water-lifting dispatcher, the proportion of energy consumption and the proportion of maintenance fees; and the management subset can be further divided into three sub-level indicators, management organization, management system and intelligent management[11]. Therefore, an evaluation indicator system was established according to the above main evaluation indexes, as shown in Table 1.

Table 1
Evaluation Indicator System for Economic Operation of Typical Small Irrigation Pumping Stations in City G

Evaluation objectives	First-level evaluation indicators	Second-level evaluation indicators
		Pump station type suitability rate U_{11}
		Pump station service life U_{12}
	Technology U_1	Pump station head matching U_{13}
Evaluation on		Power matching U_{14}
economic operation of		Proportion of actual flow U_{15}
small water-lifting		Proportion of dispatching labor cost U_{21}
irrigation pumping	Economy U_2	Proportion of energy consumption U_{22}
stations *U*		Proportion of maintenance fees U_{23}
		Management organization U_{31}
	Management U_3	Management system U_{32}
		Intelligent management U_{33}

Determining the weight of each indicator

The adjacent index comparison method was adopted to determine the weight. In this case, 10 experts from water conservancy, agriculture, finance and other industries in the region were selected to rank the importance on the basis of full deliberation, then the importance ratio of adjacent indicators was given, and the weight result was calculated by simple weighted average. For example, the importance of the first-level evaluation indicators was $U_1 > U_2 > U_3$, and its weight was calculated as shown in Table 2.

Table 2
Weights of First-level Evaluation Indicators

S/N	vis-a-vis	Relative importance ratio	Weights	Normalized weights
0	U_1: U_1	1	W_1=1.0	W_1=0.36
1	U_3: U_1	0.8	W_3=0.8 W_1=1.0	W_3=0.29
2	U_2: U_3	1.2	W_2=0.96 W_3=0.8	W_2=0.35
			$\sum W$=2.76	$\sum W$=1

According to Table 2, the weight of the first-level evaluation indicators can be recorded as W = (0.36, 0.35, 0.29).

In the same way, the weights of the second-level evaluation indicators determined after full deliberation by 10 experts are respectively recorded as follows:

$$W_1 = (0.20, 0.19, 0.20, 0.18, 0.23)$$

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$W_2 = (0.20, 0.70, 0.10)$

$W_3 = (0.30, 0.20, 0.50)$

Establishing an Evaluation Grade Set

According to the actual situation of the project in combination with the opinions of the experts at the same time, the evaluation indicators at all levels were identified as 5 evaluation levels, and the evaluation level set $V = (V_k)$= (better, good, general, bad, worse) was established (k =1-5).

Establishing a Membership Relation and a Fuzzy Matrix Bi (i=1,2,3)

According to the actual economic operation effect of the small water-lifting irrigation pumping station in City G, the indicator U_{ij} under $U_i(i=1,2,3)$ was comprehensively considered to evaluate its degree r_{ijk} belonging to the k-th evaluation level, and the fuzzy evaluation matrix R_i of U_i can be obtained as follows:

$$R_i = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1m} \\ r_{i21} & r_{i21} & \cdots & r_{i2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{in1} & r_{in2} & \cdots & r_{inm} \end{bmatrix}$$

The following algorithms were introduced in this paper:

$$B_i = W_i * R_i$$

A fuzzy evaluation matrix $B_i = (b_{i1}, b_{i2}, \ldots, b_{im})$is obtained, in which $b_{it} = \sum_{j=1}^{n} w_{ij} r_{ijk}$. Similarly, since $B_i\ (i=1, 2, 3)$, the fuzzy evaluation matrix at layer B is $R = (B_1, B_2, B_3)^T$. According to the questionnaire survey statistics, it is calculated as follows:

First, the statistics of 198 evaluation questionnaires are shown in Table 3.

Table 3 Statistical Table of Economic Operation Evaluation Survey of Typical Small Irrigation Pumping Stations In City G (198 Copies)

First-level evaluation indicators	Second-level evaluation indicators	Grade Better	Good	General	Bad	Worse
Technology U_1	Pump station type suitability rate U_{11}	30	130	38	0	0
	Pump station service life U_{12}	20	135	36	7	0
	Pump station head matching U_{13}	28	132	33	5	0
	Power matching U_{14}	15	125	40	18	0
	Proportion of actual flow U_{15}	16	140	28	14	0
Economy U_2	Proportion of dispatching labor cost U_{21}	26	133	27	12	0
	Proportion of energy consumption U_{22}	33	135	30	0	0
	Proportion of maintenance fees U_{23}	30	136	32	0	0
Management U_3	Management organization U_{31}	35	136	27	0	0
	Management system U_{32}	25	135	29	9	0
	Intelligent management U_{33}	28	144	26	0	0

Secondly, according to the statistical data in Table 3, the fuzzy evaluation matrix $R_i\ (i=1,2,3)$of U_i can be obtained by comprehensively calculating the evaluation values of each factor in the judgment set. Meanwhile, $B_i\ (i=1,2,3)$ is calculated according to the formula $B_i = W_i * R_i$;

$$R_1 = \begin{bmatrix} 0.151 & 0.657 & 0.192 & 0.000 & 0.000 \\ 0.101 & 0.682 & 0.182 & 0.035 & 0.000 \\ 0.141 & 0.667 & 0.167 & 0.025 & 0.000 \\ 0.076 & 0.631 & 0.202 & 0.091 & 0.000 \\ 0.081 & 0.707 & 0.141 & 0.071 & 0.000 \end{bmatrix}$$

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$$R_2 = \begin{bmatrix} 0.131 & 0.672 & 0.136 & 0.061 & 0.000 \\ 0.167 & 0.682 & 0.151 & 0.000 & 0.000 \\ 0.151 & 0.687 & 0.162 & 0.000 & 0.000 \end{bmatrix}.$$

$$R_3 = \begin{bmatrix} 0.177 & 0.687 & 0.136 & 0.000 & 0.000 \\ 0.126 & 0.682 & 0.146 & 0.046 & 0.000 \\ 0.142 & 0.727 & 0.131 & 0.000 & 0.000 \end{bmatrix}$$

$$B_1 = W_{1*} R_1 = (0.20, 0.19, 0.20, 0.18, 0.23)* \begin{bmatrix} 0.151 & 0.657 & 0.192 & 0.000 & 0.000 \\ 0.101 & 0.682 & 0.182 & 0.035 & 0.000 \\ 0.141 & 0.667 & 0.167 & 0.025 & 0.000 \\ 0.076 & 0.631 & 0.202 & 0.091 & 0.000 \\ 0.081 & 0.707 & 0.141 & 0.071 & 0.000 \end{bmatrix}$$

$$= (0.1099, 0.6706, 0.1752, 0.0443, 0.0000)$$

Similarly, the calculation results of B_2 and B_3 are:

$$B_2 = W_{2*} R_2 = (0.1582, 0.6805, 0.1491, 0.0122, 0.0000)$$

$$B_3 = W_{3*} R_3 = (0.1493, 0.7060, 0.1355, 0.0092, 0.0000)$$

At last, B_i is integrated to form the fuzzy evaluation matrix $R = (B_1, B_2, B_3)^T$ of the upper level, namely.

$$R = \begin{bmatrix} 0.1099 & 0.6706 & 0.1752 & 0.0443 & 0.0000 \\ 0.1582 & 0.6805 & 0.1491 & 0.0122 & 0.0000 \\ 0.1493 & 0.7060 & 0.1355 & 0.0092 & 0.0000 \end{bmatrix}$$

Fuzzy Comprehensive Evaluation

The comprehensive evaluation on the impact evaluation U of the post-evaluation of the project results in the comprehensive evaluation result $B = W*R$ of U, i.e.

$$B = (0.36, 0.35, 0.29)* \begin{bmatrix} 0.1099 & 0.6706 & 0.1752 & 0.0443 & 0.0000 \\ 0.1582 & 0.6805 & 0.1491 & 0.0122 & 0.0000 \\ 0.1493 & 0.7060 & 0.1355 & 0.0092 & 0.0000 \end{bmatrix}$$

$$= (0.1382, 0.6843, 0.1546, 0.0229, 0.0000)$$

According to the principle of maximum membership degree, the calculation results show that the second indicator value in fuzzy comprehensive evaluation set B is the largest, and its corresponding evaluation grade is "better". Therefore, the evaluation result of the economic operation effect of the typical small water-lifting irri\
gation pumping station in rural areas of City G is the second grade, i.e. better, indicating that there is still room for further optimization and improvement in the economic operation of the small water-lifting irrigation pumping station in City G.

OPTIMIZATION MEASURES FOR ECONOMIC OPERATION OF SMALL WATER-LIFTING IRRIGATION PUMPING STATION IN CITY G

According to the relevant technical basis and operation data of 24 types of typical small water-lifting irrigation pumping stations in City G, and in combination with the management status data of pumping stations in various irrigation districts, there are still some problems in technology, economy and management, such as the mismatch between the selection of individual pumping stations and the actual engineering needs, the high proportion of pumping stations that have been used for more than 10 years, the high operating cost of pumping stations and the insufficient implementation of intelligent management. Therefore, it is necessary for City G to take optimization measures from the aspects of technology, economy and management: (1) Technical measures: updating individual pump stations with mismatched model selection, and phasing out pump stations with long service life and poor maintenance[12]; (2) Economic measures: scientifically calculating the service fees of dispatching personnel, scientifically dispatching the operation time of the pumping station, and timely maintaining to make the pumping station in good operation state; (3) Management measures: strengthening the construction of management and protection organizations and systems, and gradually increasing the implementation of intelligent management to improve the efficiency of pump station operation management, thus further saving costs[13].

CONCLUSIONS

In this paper, the principle of fuzzy mathematics is applied to the construction of the evaluation model, and the model is used to evaluate the economic operation effect of typical small water-lifting irrigation pumping stations in rural areas of

City G, and the expected evaluation results are obtained. The application of fuzzy comprehensive evaluation method to evaluate the economic operation effect of small water-lifting irrigation pumping stations has the advantages of simple operation and convenient calculation, which avoids many human factors in the subjective evaluation in the past, and provides a new and reliable idea and method for the relevant management departments of water-saving irrigation to evaluate the economic operation of pumping stations. Moreover, the evaluation of the economic operation effect of small water-lifting irrigation pumping stations also reveals that City G can further improve the operation and management efficiency of pumping stations and further reduce the agricultural irrigation cost by means of some technical and economic measures.

Author Declaration

The authors declare no sponsored financial sources by any organization related to tobacco production for the undertaken study.

References

1. Li XL. Starting condition and safe and economic operation of large double suction centrifugal pump. *China Rural Water and Hydropower*. 2013;(06):88-90.
2. Cao R, Fang GH, Sun HB, Wu XW, Liu Q. Sensitivity analysis of daily optimal operation of adjustable blade pumping stations. *China Rural Water and Hydropower*. 2015;(05):167-171.
3. Zheng HZ, Zhang Z, Wu HM, Lei XH. Daily optimal dispatching and economic operation of water conveyance system for cascade pumping stations. *Journal of Hydraulic Engineering*. 2016;47(12):1558-1565.
4. Li KL, Zhu ML, Li XZ, Xing M, Hui ZG. Economic operation scheme of well group pumping stations. *Journal of Water Resources and Water Engineering*. 2017;28(06):173-176.
5. Zhang YH, Fang GH, Wen X, Tian Y. Daily optimum operation of full adjustment of cascade pump station blades. *Journal of Water Resources and Water Engineering*. 2017;28(06):123-128.
6. Guo YL, Zhang HC, Zhu XL. Daily economic operation optimization model of single-stage pump station based on dynamic programming. *China Rural Water and Hydropower*. 2020;(01):192-196.
7. Deng YF. Operation, Dispatching and Modernization Management Analysis of Pump Stations for Small and Medium-sized Water Conservancy Projects. *Value Engineering*. 2020;39(12):16-18.
8. Tao D, Li N, Xiao RF, Fu ZM, Zhang KQ. Optimum operation of multi-stage water pumping station. *China Rural Water and Hydropower*. 2020;(05):123-127.
9. Ma HQ, Kan J. Post-impact Assessment of Water-saving Irrigation Project Based on Fuzzy Comprehensive Assessment Model. *China Water Power & Electrification*. 2020;(4):65-68.
10. Peng ZZ, Sun YY. Fuzzy Mathematics and Its Application, Wuhan: Wuhan University Press. 2002.
11. Liu JC. Selection of economic operation scheme for small and medium-sized axial flow pump drainage pump station. *Pump Technology*. 2020;(2):46-49.
12. Wen BL, Li P. Economic Operation of Pump Station Based on Genetic Particle Swarm Fusion Algorithm. *Harnessing the Huaihe River*. 2018;(7)21-23.
13. Yue YX. Brief introduction to economic operation measures of pumping station of high-lift electric power irrigation project. *China Building Materials Science and Technology*. 2019(1):142-143.

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