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ORIGINAL RESEARCH ARTICLE

Study on health evaluation model of modern irrigation district project based on AHP-FCE

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ABSTRACT

Objective: The modernization of irrigation areas is an important guarantee of national food security. Make clear the health status of irrigation projects, put forward the renovation plan for modern irrigation areas, guide the construction of modern irrigation areas, and promote agricultural modernization. Method: Taking Lailong Irrigation District in Jiangsu Province as an example, the health evaluation index system of key projects in the irrigation district was constructed, and the weight of each evaluation index was calculated by AHP and a fuzzy comprehensive evaluation model (AHP-FCE) to evaluate the health status of key projects. Results: The proportions of "good", "medium" and "poor" in the comprehensive evaluation of the health status of the pump station project and the sluice project in Lailong Irrigation District were 16.72%, 53.33%, 30%, 13.51%, 48.65%, and 37.84%, respectively. In the evaluation of the criterion level, the proportion of "poor" information level evaluation level reached 63.33% and 64.86%. This paper analyzes the key problems and weak links of the modernization of the irrigation project in the Lailong irrigation area and puts forward the requirements for the modernization of the Lailong irrigation area according to the basic characteristics of the modern irrigation area. Conclusion: Water-saving reconstruction projects in irrigated areas basically meet the requirements of irrigation and drainage, but information technology has not been applied in the reconstruction of irrigated areas, and the construction of modern irrigated areas should pay more attention to information construction. This paper provides a theoretical basis and technical support for the modernization of irrigation areas in Jiangsu Province.

Keywords: modern irrigation area; AHP-FCE evaluation model; assessment of health status; retrofit scheme

1. Introduction

Irrigated areas play a pivotal role in the development of agriculture and the rural economy. They are the important foundation for ensuring national food security, the main base for the development of modern agriculture, the important support for regional economic development, the basic support for ecological environment protection, and the construction of beautiful countryside. In recent years, the No. 1 Central

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document and the Strategic Plan for Rural Revitalization have proposed to implement the renewal of supporting facilities and the modernization of large and medium-sized irrigated areas. The modernization of irrigated areas is a dynamic concept. The Ministry of Water Resources clearly puts forward the characteristics of modern irrigated areas in the Guiding Opinions on the Standardized Management of Large and Medium-sized Irrigated Areas: water-saving and efficient, perfect facilities, scientific management, and good ecology. The construction of modern irrigation areas is a complex and huge system engineering project involving society, economy, water conservancy, agriculture, ecological environment, meteorology, and other fields. The irrigation project is the foundation and core of the construction of modern irrigation areas. Aiming at the requirement of building a higher-level, well-off society in an all-round way, the evaluation index system of irrigation projects in irrigated areas is constructed, the problems and weak links of irrigation projects are found, the modernization of irrigated areas is reasonably promoted, and basic support is provided for improving the comprehensive agricultural production capacity and ensuring food security in irrigated areas.

American operational research scholars proposed and applied the analytic hierarchy process[1] for the first time to construct the evaluation system of irrigation areas, quantifying the factors that are difficult to quantify by assigning values and realizing the visualization of evaluation objectives. Li et al.[2] selected four criteria indicators reflecting the sustainable development ability of the irrigated area and constructed an evaluation system with a total of 30 indicators. By using the analytic hierarchy process and fuzzy comprehensive evaluation method, they conducted a comprehensive quantitative evaluation of the sustainable development of the Baojixia irrigated area after water-saving transformation. Yang et al.[3] selected the criterion layer reflecting the ecological environment of the irrigated area, constructed the ecological environment evaluation index system of the irrigated area with 31 indicators, and used an analytic hierarchy process to screen out the indicators for evaluating the ecological environment of the irrigated area. However, the previous evaluation system of irrigation area is mainly based on the hardware, operation management, and benefit of irrigation area, which cannot reflect the connotation of modern irrigation area. Based on this, according to the construction standards of modern irrigation areas, this paper constructed the health evaluation index system of key projects in irrigation areas, used the analytic hierarchy process and fuzzy comprehensive evaluation model (AHP-FCE) to calculate the weight of each evaluation index to evaluate the health status of key projects, and took Lailong Irrigation District in Jiangsu Province as an example to put forward its modernization program.

2. Materials and methods

2.1. Model selection

For the evaluation of the current situation of irrigated areas, single evaluation methods such as the analytic hierarchy process, the entropy method, the fuzzy comprehensive evaluation method, and the gray correlation method are widely used at present, which are easily affected by subjective judgment. Therefore, this paper combines the analytic hierarchy process with the fuzzy comprehensive evaluation method to mostly reduce the interference of subjective factors and improve the scientificity and accuracy of conclusions.

The analytical hierarchy process (AHP) is a weight analysis method that reasonably compiles people’s subjective feelings through mathematical models so as to form clear and orderly logical relations[4]. The principle of the AHP method is to decompose the target problem into more specific, different levels step by step and calculate and rank the weights through mathematical operations.

Fuzzy comprehensive evaluation (FCE) is a multi-factor and multi-level evaluation method for fuzzy objects based on the concept of fuzzy mathematics[5]. The principle of the FCE method is to make a scientific overall evaluation of fuzzy objects by quantitative means according to user evaluation. The principle of the

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The construction of the evaluation system based on AHP-FCE is divided into two steps: Firstly, the hierarchy process is used to build the ladder structure and calculate the respective weight vectors. Secondly, fuzzy comprehensive evaluation combined with hierarchical analysis is used to evaluate the current situation of the irrigation area.

2.2. Model construction

For the evaluation of the current situation of irrigated areas, single evaluation methods such as the analytic hierarchy process, the entropy method, the fuzzy comprehensive evaluation method, and the gray correlation method are widely used at present, which are easily affected by subjective judgment. Therefore, this paper combines the analytic hierarchy process with the fuzzy comprehensive evaluation method to reduce the interference of subjective factors as much as possible and improve the scientificity and accuracy of conclusions.

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The construction of an evaluation system based on AHP and FCE is divided into two steps: The first-step structure was established based on the analytic hierarchy process (AHP) to calculate the weight of the respective modern irrigation area around the "water-saving efficiency, facilities, management science, ecological good" characteristics from the backbone engineering, field engineering, ecological engineering, and construction of informatization and standardization management. The transformation and upgrading of the backbone project is an important link in the modernization and construction of the irrigation area. The contents and construction scale of the transformation of the backbone project will have an important impact on the layout of the irrigation and drainage systems. In order to clarify the health status of the key engineering facilities and maximize the investment benefit of the project, the health status evaluation system of the key irrigation and drainage projects (pumping station project and sluice project) in Long irrigation District was established by consulting the evaluation literature of the irrigation area[6,7] and listening to the opinions of relevant experts.

The evaluation system constructed in this paper is divided into three layers: the consolidation and upgrading standard of the backbone irrigation and drainage project is taken as the target layer, and the functional status, ecological environment, and information level are taken as the criterion layer of the index system. Fourteen evaluation indexes are obtained by decomposition of the criterion layer as the indicator layer, and all evaluation indexes are independent and closely related to each other. Under the construction of the evaluation index system, the 1–5 scale scoring method is used to determine its relative importance or good or bad degree[1], and the scoring method is shown in **Table 1**.

Table 1. Scale criterion.

Scale	Meaning
1	Both factors are of equal importance
2	There was only a slight difference in importance between the two factors
3	There are significant differences in the importance of the two factors
4	The importance of the two factors is quite different
5	The importance of the two factors varies greatly
The bottom	If the ratio of the importance of factor I to factor j is aij, then the ratio of the importance of factor j to factor I is $a_{ji}=1/a_{ij}$

The judgment matrix is constructed according to the constructed scaling criterion. Taking N elements as an example, the judgment matrix obtained is $\boldsymbol{A}= (a_{ij})_{n\times n}$. Matlab is used to calculate the maximum eigenroot λ_{max} of the judgment matrix $\boldsymbol{A}$ and its corresponding eigenvectors, and the eigenvectors are normalized to the weights in the index system. The calculation formula is:

$$AW = \lambda_{\max} W \tag{1}$$

In order to avoid unreasonable results, the consistency index *CI* of the matrix and the average random consistency index *CR* value are used for consistency tests to determine the rationality of the judgment. The calculation method is as follows:

$$CI = (\lambda_{\max} - \mathrm{n})/(\mathrm{n} - 1) \tag{2}$$

$$CR = CI/RI \tag{3}$$

where: When $CR < 0.1$, the consistency requirements are met; when $CR \geq 0.1$, the consistency does not meet the basic requirements, and the modification matrix is returned.

According to the actual situation of the irrigation area and the Evaluation Standard of Irrigation and Drainage Project, the evaluation set of health factors of the irrigation area project (a excellent; b good; c medium; d is poor), the corresponding quantization values of each result were 1, 0.75, 0.5, 0.25, and then the fuzzy judgment matrix *R* was obtained according to the weight of each factor and its membership vector. Finally, the fuzzy evaluation matrix *R* and the factor weight vector *W* are fuzzy operations and normalized, and the fuzzy evaluation result is obtained.

3. Results and analysis

3.1. Basic situation of irrigation area

Lailong Irrigation District is located in the lower reaches of the Yishusi River system in the Huaihe River basin. According to the second national land survey data (2013), the total land area of Lailong Irrigation District is 73,100 hm^2, the designed irrigation area of the irrigation district is 35,000 hm^2, and the effective irrigation area is 31,900 hm^2. After years of continuous construction and water-saving transformation in the irrigated area, the key irrigation and drainage system has been basically improved, but there are still some problems, such as the aging of key projects, damage to supporting equipment, and poor operation conditions in the irrigated area. According to the Standardized Construction Measures for the Management of Large-scale Irrigation Areas in Jiangsu Province (Trial) and the Construction Specifications for Modern Irrigation Areas, the layout and adjustment of the backbone irrigation and drainage projects in the irrigation areas are planned to be carried out in combination with the actual situation of the irrigation areas, so as to build them into modern irrigation areas. Now the health status of the irrigation areas is evaluated. The evaluation index grade table is shown in **Tables 2** and **3**.

Table 2. Basic grade division of evaluation indicators.

Index level	Good	A good medium	Poor
Foundation	The settlement material 0	Settlement <50 mm settlement ≤80 mm	Settlement of > 80 mm
Structural deformation	No effect	Minor Impact General impact	The serious influence
Structural failure	There is no erosion	Local denudation penetrating cracks	Penetrating cracks
Hydraulic conditions	Flow smoothly	The flow pattern is stable non penetrating vortex	Through the vortex of sex
Metal structure	There is no deformation	Slight deformation and general damage	Severe damage to

Table 3. Grade division of evaluation indicators.

Index level		Good	Good	Medium	Poor
Functional status	Mechanical and electrical equipment	Normal mechanical operation Good electrical equipment	Normal mechanical operation Electrical equipment General	Abnormal of machinery Electrical equipment General	Abnormal of machinery No guarantee of electricity
	Safety protection	A place	Basic perfect	Is not yet perfect	There are security flaws
The ecological environment	The water environment	Clean and pollution-free	No obvious pollutants	Presence of contaminants	Accumulation of pollutants
	The work environment	Optimal	Good	In the	Poor
	The surrounding environment	Optimal	Good	In the	Poor
Level of informatization	Information monitoring	Equipment perfect information collection Timely and correct	The equipment is basically perfect and the information is effective	Equipment is not perfect	No monitoring equipment or information is invalid
	Automatic control	Instruction receives automatic operation Timely and correct	Automatic control is basically effective	The automatic control equipment is not working well	No automatic control
	Application level	Optimal	Good	In the	Poor
	Information technology guarantee	System consummation Money is enough	Basic institutional and financial guarantees	Inadequate protection	The system and capital are not guaranteed

3.2. Determine the indicator weight

According to the scale scoring method, several experts in the research of modern irrigation area construction were invited to form an expert group to judge the importance of indicators at all levels, and then the analytic hierarchy process was used to calculate the judgment matrix to get the final weight of each indicator.

According to the expert evaluation results, in the evaluation process of the target level relative to the criterion level, the functional status criterion is slightly more important than the ecological environment criterion and the informatization level criterion, and the ecological environment criterion and the informatization level criterion are equally important. The judgment matrix constructed thus is shown in **Table 4**.

Table 4. Judgment matrix A-B and its eigenvalues.

A	B_1	B_2	B_3	Weights w_1
B_1	1	2	2	0.4905
B_2	1/2	1	2	0.3119
B_3	1/2	1/2	1	0.1976

Note: λ_{max} = 3.054, CI = 0.027, RI = 0.52, CR = 0.052 < 0.1, meeting the consistency test.

The weights of indicators at all levels are calculated in turn, and the results are shown in **Table 5**. Therefore, the final weight of 14 indicators can be calculated. The final weight of a node is equal to the product of its own relative weight and the relative weight of all its superiors. For example, the final weight of water environment C_8 is 0.5571 × 0.3119 = 0.1738.

Table 5. Total order of A-C.

Rule layer B	B_1	B_2	B_3	Total sorting W_1
	0.4905	0.3119	0.1976	
Index layer C				
C_1	0.2730			0.1339
C_2	0.2730			0.1339
C_3	0.1716			0.0842
C_4	0.1083			0.0531
C_5	0.0660			0.0324
C_6	0.0660			0.0324
C_7	0.0421			0.0207
C_8		0.5571		0.1738
C_9		0.1226		0.0382
C_{10}		0.3203		0.0999
C_{11}			0.4715	0.0932
C_{12}			0.1653	0.0327
C_{13}			0.2550	0.0504
C_{14}			0.1082	0.2140

3.3. Fuzzy comprehensive evaluation

Taking Luji Station in Long Irrigation District as an example to carry out a fuzzy comprehensive evaluation of backbone projects, the membership matrix of project condition factor evaluation, ecological environment factor evaluation, and information level factor evaluation of Luji station were set as R_{B11}, R_{B12} and R_{B13}, respectively. The members of the expert group were invited to construct the membership matrix of each index of the backbone project, and the health status of Luji Station project was calculated according to the comprehensive fuzzy evaluation Equations (4)–(6). The membership matrix of each factor evaluation index of Luji station is:

$$R_{B11} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0.1 & 0.6 & 0.3 & 0 \\ 0.1 & 0.6 & 0.3 & 0 \\ 0 & 0.1 & 0.1 & 0.8 \\ 0.1 & 0.2 & 0.7 & 0 \\ 0 & 0.3 & 0.7 & 0 \\ 0.2 & 0.7 & 0.1 & 0 \end{bmatrix} \quad (4)$$

$$R_{\mathrm{B12}} = \begin{bmatrix} 0.1 & 0.6 & 0.3 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \\ 0.1 & 0.5 & 0.4 & 0 \end{bmatrix} \quad (5)$$

$$R_{\mathrm{B13}} = \begin{bmatrix} 0 & 0.6 & 0.4 & 0 \\ 0 & 0.2 & 0.7 & 0.1 \\ 0 & 0.1 & 0.7 & 0.2 \\ 0 & 0 & 0.1 & 0.9 \end{bmatrix} \quad (6)$$

The evaluation results of project status, ecological environment, and informatization level of Luji Station are as Equations (7)–(9):

$$E_{11} = {w_{11}^{1}}^{\mathrm{T}} R_{\mathrm{B11}} = [0.059, 0.340, 0.514, 0.087] \quad (7)$$

$$E_{12} = {w_{12}}^{\mathrm{T}} R_{\mathrm{B12}} = [0.149, 0.543, 0.308, 0.000] \quad (8)$$

$$E_{13} = {w_{13}}^{\mathrm{T}} R_{\mathrm{B13}} = [0.000, 0.341, 0.494, 0.165] \quad (9)$$

E_{11}, E_{12} and E_{13} constitute the membership matrix P_1 of the comprehensive evaluation of pump station engineering, and the comprehensive evaluation result is shown in Equation (10):

$$E_1 = {w_1}^{\mathrm{T}} P_1 = [0.076, 0.404, 0.445, 0.075] \quad (10)$$

According to the principle of maximum membership degree, the comprehensive evaluation level of Luji Station is "medium", in which the engineering condition is "medium", the ecological environment is "good", and the informatization level is "medium".

Using the above method, the membership matrix of all backbone projects selected from field investigation is constructed, and a fuzzy comprehensive evaluation is carried out. The evaluation results are shown in **Tables 6** and **7**. The proportion of "good" status is 16.72% and 13.51% respectively; the proportion of "medium" status is 53.33% and 48.65% respectively; the proportion of "poor" status is 30% and 37.84% respectively. Among them, in the projects with "poor" comprehensive evaluation levels, most of the evaluation results of engineering, ecological environment, and informatization level are also "poor".

Table 6. Comprehensive evaluation status of pump station engineering.

Index grade	Excellent	Good	Medium	Discrepancy
Engineering status/%	0	13	57	30
Ecological environment/%	10	17	46	27
Informatization level/%	0	13	63	24
Comprehensive evaluation grade/%	0	17	53	30

Therefore, the engineering condition, ecological environment, and comprehensive evaluation grade of most projects in Lailong Irrigation District are "medium", which is still far from the requirements of modern irrigation districts. The informatization level of the project is generally at a "poor" level, and the irrigation area project has not yet realized informatization and intelligence. This shows that the water-saving renovation project of the irrigation area has basically ensured the irrigation and drainage requirements, but the information technology has not been applied to the renovation of the irrigation area, so the construction of modern irrigation areas should pay more attention to the information construction.

Table 7. Comprehensive evaluation status of sluice engineering.

Index grade	Excellent	Good	Medium	Discrepancy
Engineering status/%	8	16	51	25
Ecological environment/%	11	22	32	25
Informatization level/%	0	5	20	65
Comprehensive evaluation grade/%	0	13	49	38

According to the evaluation results of AHP-FCE, the irrigation and drainage capacity, water safety, and water ecological guarantee capacity of Lailong Irrigation District have been improved to some extent, but there is still a certain gap between the requirements of modern agricultural development in irrigation districts and the construction of the Huaihe River ecological economic belt. In addition, there is still room for improvement in information construction and management facilities in irrigation districts. Therefore, Lailong Irrigation District should further improve irrigation and drainage projects, popularize and apply agricultural water-saving technologies, and improve the informational level of irrigation districts in the modernization of irrigation districts.

1) Consolidation and upgrading of irrigation and drainage projects According to the evaluation results of the health status of the backbone, the project facilities are carried out separately.

Maintenance and renovation, demolition and reconstruction of engineering facilities, and upgrading of the ecological environment and information technology. If the comprehensive evaluation grade is "good", part of the projects shall be upgraded according to their degree of importance. For projects with a comprehensive evaluation grade of "medium", repair and transform the parts with hidden dangers, and upgrade some projects according to their importance. The project with the comprehensive evaluation grade of "poor" is difficult to repair and rebuild on the original basis, so part of the project should be dismantled and rebuilt directly.

2) Water saving, emission reduction, and water environment protection Lailong Irrigation District should vigorously promote water saving in collection projects, water saving in agriculture, and water conservation.

Comprehensive water-saving technology integrated with water-saving, supporting water source transformation projects, strengthening anti-seepage lining, and standardized construction of channels[8] In combination with the construction of high-standard farmland, comprehensive management of drought, waterlogging, and waterlogging, rational utilization of soil and water resources, supporting irrigation and drainage channel systems (pipe networks) and management facilities, rational setting of water distribution and measurement devices in the field, and improving irrigation management means and capacity, Strengthen backbone canal system and rural river river regulation, improve liable to waterlogging bottomland easily stained by farmland soil environment, increase the storage capacity of river network and the self-purification ability, drainage (water) in reusing and rivers water storage ditches, ecological transformation, increase the pits wetland water area, play the rivers ditch wetland purification function, improve irrigation capacity of water environment carrying capacity.

3) Information construction and standardized management Lailong Irrigation District manages water according to the local economic basis, rigid conditions, and

Ping systematically studied the contents of modern irrigation information system construction and standardized management reform; a database of basic data, water condition, meteorology, and moisture in the irrigation area was constructed. Develop an intelligent control system vigorously to realize automatic control of key engineering elements of irrigation and drainage systems; Rationally reform the management system of the irrigation area to ensure a clear division of responsibilities and perfect working procedures; Establish an information disclosure website or public account, timely release of irrigation area-related information, and open and transparent management.

4. Conclusion

Based on the study of modern irrigation evaluation methods and index content and induction on the basis of the dragon irrigation area since the backbone project (station) as a case study, building the appraisal model of AHP-FEC from a functional condition and ecological environment, the rule of information level 3 layer selects 14 factors as the index of evaluation of backbone project health. According to the calculation of the evaluation model, the proportions of "good", "medium" and "poor" in the comprehensive evaluation of the health status of the pump station project and the sluice project in the Lailong Irrigation District were 16.72%, 53.33%, and 30%, and 13.51%, 48.65%, and 37.84%, respectively. The proportion of "poor" information level evaluation reached 63.33% and 64.86%. Based on the evaluation results, the key problems and weak links of the modernization of the irrigation project in the Lailong irrigation area are clarified, and the requirements of the modernization of the Lailong irrigation area are put forward according to the basic characteristics of the modern irrigation area.

Conflict of interest

The authors declare no conflict of interest.

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