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RISK EVALUATION OF WATER CONSERVANCY IN A PUBLIC-PRIVATE PARTNERSHIP PROJECT BASED ON GREY FUZZY THEORY

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ABSTRACT

In this paper, a quantifiable method for risk evaluation of water conservancy ina public-private partnership (PP) PPP project is presented. Firstly, according to the characteristics of water conservancy PPP project, a risk evaluation index was determined by Delphi method and literature collection method; secondly, the weight of risk evaluation indexes were determined by rank correlation analysis; thirdly, based on grey fuzzy theory, a grey fuzzy comprehensive evaluation model was constructed, and uncertain grey and fuzzy contents were transformed into values that can be accurately measured, which provided a basis for managers to make decisions. Finally, the grey fuzzy comprehensive evaluation model was applied to Fendou Reservoir, a water conservancy PPP project, and it proved to be reasonable and scientific.

Palabras clave: teoría gris difusa, proyecto PPP, evaluación de riesgo, análisis de correlación de rangos, proyecto de conservación de agua

RESUMEN

En este trabajo se presenta un método de cuantificación para la evaluación de riesgo en un proyecto de colaboración pública y privada (PPP, por sus siglas en inglés) para conservación del agua. Primero, de acuerdo con las características del proyecto PPP para conservación del agua se determinó un índice de evaluación de riesgo por el método Delphi y una revisión de literatura; segundo, el peso de los índices de evaluación de riesgo se obtuvo por medio del análisis de correlación de rangos, y tercero, se construyó un modelo comprehensivo de evaluación gris difuso y los contenidos inciertos se transformaron en valores medibles con precisión para servir como fundamento a los tomadores de decisiones. Finalmente, el modelo comprehensivo gris disfuso se aplicó al embalse Fendou, un proyecto PPP de conservación del agua, y probó ser razonable y científico.

INTRODUCTION

Water conservancy project has huge investment, large scale, long construction period, changeable construction environment and complex construction technology. To reduce the cost, make government funds more efficient and get rid of the shackles of social development caused by the shortage of water conservancy project funds, PPP (Public-Private-Partnership), a new project financing model, has become more and more popular in the field of water conservancy project in China. Based on the experience of PPP model in Australia, Portugal, Spain and the UK, Garvin proved that PPP model has advantages in infrastructure development in North America (Garvin 2010, Nordin et al. 2017). It is reasonable and effective for the US to develop transportation facilities by the PPP model from the economic, legal and public point of view (Papajohn et al. 2010). A group researcher illustrated the positive effect of PPP model on the financial expenses of the provincial government in the project of Metro Line 4 in São Paulo, Brazil (Brandao et al. 2012, Roslan et al. 2017, Farooqi et al. 2017). Almassi tested the importance of Australian PPP concession contract setting and government guarantee mechanism to project performance using real option method (Ali et al. 2013, Toum et al. 2018).

PPP model is a new cooperation mode established by government and social capital through franchising. It has the characteristics of large investment, long operation cycle, complex contractual relationship and high social benefits. Shen et al. divided risks into internal, external and project-level risks by investigating the main risks in publicprojects and the management in the projects (Shen et al. 2006, Yun et al. 2018). Some researchers found that PPP project financing, especially capital market financing, plays an important role in the success of PPP projects (Regan et al. 2011, Arshadullah et al. 2017). In another study, scientists have constructed a PPP project performance index system with 5 kinds and 48 indexes by questionnaires (Yuan et al. 2011, Usman et al. 2017). Hwang et al. collected the risks that are common to PPP projects in Singapore and identified 23 key risks based on questionnaires (Hwang et al. 2013, Yasin and Usman 2017). A group researcher identified and counted 40 risks factors and selected the key risk factors of 20 water conservancy PPP projects in Ghana by Delphi method, mainly including exchange rate risk, corruption risk, theft risk, political risk, high cost operation and so on (Ameyaw and Chan, 2015). Other researchers investigated and revealed the risk and PPP feasibility of the local government, as well as the risks in the stages of procurement, construction, operation and transfer by questionnaires and interviews (Shrestha et al. 2017, Li et al. 2018). Because of the extension of the PPP project in space and time, and the specialization of the water conservancy project, the water conservancy PPP project will have different risks from other models in the process of implementation. Finding out the risk factorscomprehensively and reasonably and determining the risk evaluation index system of water conservancy PPP project are very important to the success of the project.

The early international risk evaluation method was single, and foreign scholars used qualitative and quantitative methods to analyze the risk of PPP project. For example, Kumaraswamy established a selection model of the project team in the concession agreement to meet the requirements of the sustainable development of PPP project (Kumaraswamy and Zhang 2001, Lu et al. 2018). Grimsey constructed a risk assessment model of PPP project from different perspectives based on Monte Carlo method, and evaluated the effectiveness of the model through sensitivity analysis; based on FTA and Delphi method, Thomas proposed an evaluation framework for risk probability and risk impact; Shen embedded the guiding strategies of benefit-sharing, multi-party satisfaction and risk-sharing in the key issue of concession period under PPP model with mathematical methods such as simulation and game theory, which has opened up a new idea for the research related to PPP project concession (Grimsey and Lewis 2002, Shen et al. 2007, Thomas et al. 2006). Xue constructed a well-organized and feasible framework model for automatic concession decision-making, which has played a significant role in reducing the risk of PPP project (Xue 2009). Iyer constructed a hierarchical structure and internal relationship of risks by using Interpretative Structural Modeling (ISM), and then determined the correlation and influence of the risks through MICMAC analysis (Iyer and Sagheer 2010). Xie constructed a PPP project decision model based on multi-party satisfaction using Bayesian network, which provides effective decision support information for stakeholders by using Monte Carlo simulation method, Carbonara determined and evaluated the franchise period of PPP project by constructing a win-win model of risk sharing between public and private parties based on Method of Moments (MoM), Aristeidis constructed a model to evaluate the financial risk of PPP project, and made a probabilistic analysis of the risk based on sensitivity analysis and scenario analysis (Xie and Ng, 2013; Carbonara et al. 2014; Pantelias and Zhang 2010). The above researches confirm the importance of PPP project risk evaluation (Basak and Gajbhiye 2018, Yang et al. 2018). The risk research of water conservancy PPP project is mainly of qualitative description. There is a certain gap between the existing evaluation model and the actual project operation application at the present stage (Shen et al. 2017, Xue et al. 2016). The calculation process is complicated, and the evaluation result is not clear, which makes the risk evaluation of water conservancy PPP project still immature. Therefore, in this paper, based on grey fuzzy theory, a grey fuzzy comprehensive evaluation model of water conservancy PPP project was constructed, and uncertain grey and fuzzy contents were transformed into values that can be accurately measured, which provided a basis for managers to make decisions (Albrecht and Shaffer 2016, Lu et al. 2017).

CONSTRUCTION OF THE RISK EVALUATION INDEX SYSTEM OF WATER CONSERVANCY PPP PROJECT

On the basis of summarizing the existing risks, according to the characteristics of water conservancy PPP project, a risk evaluation index system of water conservancy PPP project was determined by Delphi method and literature collection method. The risk evaluation index system of water conservancy PPP project is shown in **Fig. 1**.

DETERMINATION OF THE WEIGHT OF RISK EVALUATION INDEXES OF WATER CONSERVANCY PPP PROJECT BY RANK CORRELATION ANALYSIS

Rank Correlation Analysis is a subjective weighting method combining qualitative and quantitative methods. In determining the index weight, AHP needs to establish the judgment matrix by expert assignment, and to meet the consistency requirements, but when the sample data are large, it is difficult to meet the consistency requirements. The rank correlation analysis and consistency check need not to establish the judgment matrix and the calculation is reduced, which is suitable for the case of large sample data and difficult to make complete quantitative analysis.

Determination of the order relation of risk evaluation indexes

The experts ranked the risk evaluation indexes at the same level $U_1, U_2, \ldots, U_{n-1}$, Un from the most important to the least, namely, $U_1^* > U_2^* > \ldots > U_{n-1}^* > U_n^*$. Where $U_i^* > U_j^*$ showed that the risk evaluation index i was not inferior to the risk evaluation index j in importance, that is, the risk evaluation index i was superior to or equal to the risk evaluation index j in importance.

Assignment of the degree of importance between risk evaluation indexes

For the ratio of importance ri between adjacent risk evaluation indexes U*i-1andU*i at the same level, then:

$$r_i = \omega_{i-1}/\omega_i \quad (1)$$

Where $\omega_{i-1}$and ω_i were the weights of the i-1th and ith risk evaluation indexes, respectively, r_i was usually assigned with 1~2 values. The assignment and evaluation rules for r_i are shown in **Table I**.

Calculation of the weight of risk evaluation indexes

According to Formula (1), Formula (2) below was obtained:

$$\prod_{i=k}^{n} r_i = \frac{\omega_{k-1}}{\omega_k}\frac{\omega_k}{\omega_{k+1}}\cdots\frac{\omega_{n-2}}{\omega_{n-1}}\frac{\omega_{n-1}}{\omega_n} = \frac{\omega_{k-1}}{\omega_n}, \quad k \geq 2 \quad (2)$$

By finding the sum of k from 2 to n, Formula (3) below was obtained:

$$\sum_{k=2}^{n}\left(\prod_{i=k}^{n} r_i\right) = \sum_{k=2}^{n} \frac{\omega_{k-1}}{\omega_n} \quad (3)$$

Since the sum of the weights of all risk evaluation indexes was 1, Formula (4) below was obtained from Formula (3):

$$1 + \sum_{k=2}^{n}\left(\prod_{i=k}^{n} r_i\right) = 1 + \sum_{k=2}^{n} \frac{\omega_{k-1}}{\omega_n} = \frac{\omega_n}{\omega_n} + \sum_{k=2}^{n} \frac{\omega_{k-1}}{\omega_n} = \frac{1}{\omega_n}\sum_{k=1}^{n} \omega_k = \frac{1}{\omega_n} \quad (4)$$

By Formula (4), we know that the weight of other risk evaluation indexes can be deduced by calculating the weight of the last risk evaluation index ω_n. After deformation of Formula (4), Formula (5) below was obtained:

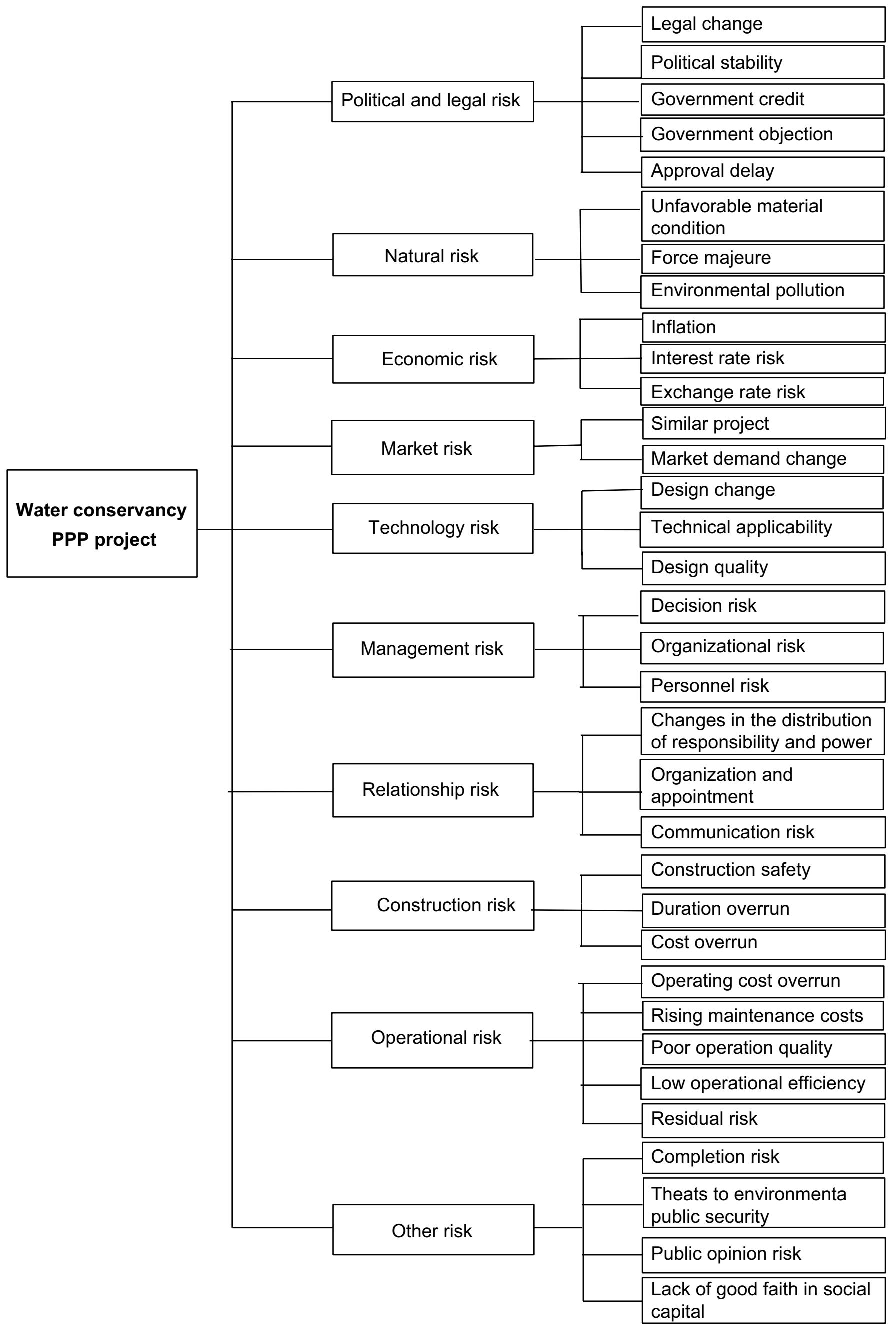

Fig. 1. A risk evaluation index system of water conservancy PPP project

$$\omega_n = \left[1 + \sum_{k=2}^{n} \left(\prod_{i=k}^{n} r_i\right)\right]^{-1} \quad (5)$$

The weight of other risk evaluation indexes can be deduced step by step by Formula (6) below:

$$\omega_{n-1} = rn\omega n \quad (6)$$

Determination of the weight of risk evaluation indexes

The weight of risk evaluation index U_i* was calculated by Rank Correlation Analysis. According to the corresponding relation between risk evaluation indexes and order relation evaluation indexes, the weight of risk evaluation indexes was determined.

TABLE I. THE ASSIGNMENT AND EVALUATION RULES FOR r_I

r_i	Evaluation instructions
1.0	U^*_{i-1} is as important as U^*_i
1.2	U^*_{i-1} and U^*_i are a little important
1.4	U^*_{i-1} and U^*_i are comparatively important
1.6	U^*_{i-1} and U^*_i are very important
1.8	U^*_{i-1} and U^*_i are particularly important

Note: 1.1, 1.3, 1.5, 1.7 and 1.9 are between two adjacent scales

CONSTRUCTION OF THE GREY FUZZY COMPREHENSIVE EVALUATION MODEL OF WATER CONSERVANCY PPP PROJECT

Determination of the risk evaluation index system and its weight

On the basis of risk analysis and risk identification, a risk evaluation index system of water conservancy PPP project was constructed, and the weight of risk evaluation indexes of water conservancy PPP project was calculated by Rank Correlation Analysis.

Establishment of the fuzzy evaluation set and evaluation sample matrix

Fuzzy evaluation set is a set composed of risk evaluation of risk indexes by experts, which is generally expressed as V, that is, V={V1, V2,…, Vh}, where h is the number of experts. In the risk evaluation of water conservancy PPP project, the risk was generally divided into five levels: smaller risk, small risk, general risk, large risk, larger risk, and the corresponding evaluation grade V was: 1, 3, 5, 7, 9, that is, V=(1, 3, 5, 7, 9). The risk between adjacent levels was 2, 4, 6, 8. According to the probability of risk occurrence in water conservancy PPP project, the experts evaluated the risk evaluation indexes and established an evaluation sample matrix.

$$D = (d_{ij}) \tag{7}$$

Where i=1,2, …,h; j=1,2, … ,m; h was the number of experts; m was the number of risk indexes.

Determination of the evaluation grey class and grey evaluation coefficient

In the risk evaluation of water conservancy PPP project, the risk was generally divided into five levels: smaller risk, small risk, general risk, large risk, larger risk, and the corresponding evaluation grey class e was: 1, 2, 3, 4, 5. The whitening weight function is the degree to which a certain grey number inclines to a certain value within a certain range, and it mainly describes the degree to which an evaluation object is subordinate to a certain grey class. Suppose all the whitening weight functions were linear functions, the grey number corresponding to the risk level and the whitening weight function are shown in **Table II**.

To determine the grey evaluation coefficient, it was necessary to calculate the whitening weight function of the evaluation value in the evaluation sample matrix according to **Table II**. Suppose the grey evaluation coefficient of the eth evaluation grey class of the risk evaluation index j by the ith expert was x_{ije}, the grey evaluation coefficient of the eth evaluation grey class of the risk evaluation index j by the experts was x_{je}, and the grey evaluation coefficient of the risk evaluation index j by the experts was x_j, then:

$$x_{ije} = fe(dij) \tag{8}$$

TABLE II. THE GREY NUMBER CORRESPONDING TO THE RISK LEVEL AND THE WHITENING WEIGHT FUNCTION

Risk level	The grey number	Whitening weight function
"small risk"(e=1)	$\otimes_1 \in[0,1,4]$	$f_1(d_{ij})=\begin{cases}0 & d_{ij}\notin[0,4]\\ 1 & d_{ij}\in[0,1]\\ 4/3-d_{ij}/3 & d_{ij}\in(1,4]\end{cases}$
"smaller risk"(e=2)	$\otimes_2 \in[0,3,6]$	$f_2(d_{ij})=\begin{cases}0 & d_{ij}\notin[0,6]\\ d_{ij}/3 & d_{ij}\in[0,3]\\ 2-d_{ij}/3 & d_{ij}\in(3,6]\end{cases}$
"general risk"(e=3)	$\otimes_3 \in[2,5,8]$	$f_3(d_{ij})=\begin{cases}0 & d_{ij}\notin[2,8]\\ d_{ij}/3-2/3 & d_{ij}\in[2,5]\\ 8/3-d_{ij}/3 & d_{ij}\in(5,8]\end{cases}$
"larger risk"(e=4)	$\otimes_4 \in[4,7,9]$	$f_4(d_{ij})=\begin{cases}0 & d_{ij}\notin[4,9]\\ d_{ij}/3-4/3 & d_{ij}\in[4,7]\\ 9/2-d_{ij}/2 & d_{ij}\in(7,9]\end{cases}$
"great risk"(e=5)	$\otimes_5 \in[5,8,9]$	$f_5(d_{ij})=\begin{cases}0 & d_{ij}\notin[5,9]\\ d_{ij}/3-5/3 & d_{ij}\in[5,8]\\ 1 & d_{ij}\in(8,9]\end{cases}$

$$x_{je} = \sum_{i=1}^{h} x_{ije} \quad (9)$$

$$x_{j} = \sum_{i=1}^{h} \sum_{e=1}^{5} x_{ije} \quad (10)$$

Where i=1, 2, …,h; j=1, 2, …,m; e=1, 2, 3, 4, 5.

Determination of the membership degree and membership matrix

The membership cje of the risk evaluation index j to the grey scale e was determined, that is, the grey evaluation coefficient of the risk evaluation index j was normalized, then:

$$c_{je} = \frac{\sum_{i=1}^{h} x_{ije}}{\sum_{i=1}^{h} \sum_{e=1}^{5} x_{ije}} \quad (11)$$

The first-order fuzzy membership matrix C_b was:

$$C_b = [c_{bje}] = [c_{b1e}, c_{b2e}, \ldots, c_{bu_b e}]^T \quad (12)$$

Where b=1, 2, …,s, s was the number of second-level risk evaluation indexes, and j=1, 2, …, u_b, u_b was the number of risk evaluation indexes corresponding to the second-level risk evaluation indexes in the first-level risk evaluation indexes.

Fuzzy comprehensive evaluation

The second-level fuzzy comprehensive evaluation was to convert the fuzzy vector Wb on the Ub to the fuzzy vector Bb on the V by fuzzy linear conversion, that is:

$$B_b = W_b C_b = [w_{b1}, w_{b2}, \ldots, w_{bu_b}][c_{b1e}, c_{b2e}, \ldots, c_{bu_b e}]^T \quad (13)$$

Then the judgment matrix was:

$$B = [B1, B2, \ldots, Bs] \quad (14)$$

Similarly, the first-level fuzzy comprehensive evaluation was to convert the fuzzy vector W on the U to the fuzzy vector R on the V by fuzzy linear conversion, that is:

$$R = WB = [w_1, w_2, \ldots, w_s][B_1, B_2, \ldots, B_s]^T \quad (15)$$

Analysis of the evaluation result

By multiplying the specific value R of fuzzy comprehensive evaluation by the quantitative evaluation index vector V= (1, 3, 5, 7, 9), the comprehensive evaluation result $Q=R \cdot V$ of project risk was obtained. By comparing the risk evaluation indexes with the result of calculation, the risk grade of water conservancy PPP project was finally determined.

CASE ANALYSIS

Project overview

Fendou Reservoir is a proposed water conservancy PPP project in Heilongjiang Province in recent years. The total investment is about 1,426 million yuan, of which, the government contribution is 800 million yuan, and the social capital is 626 million yuan, accounting for 43.9% of the total investment; the total construction period is 36 months. Fendou Reservoir, a major water conservancy project with social capital participating in its construction and operation, has greatly reduced the national financial burden and made up for the lack of government financial funds. Through investment in infrastructure, the social capital can also obtain long-term and steady returns.

Risk evaluation

Establishment of the risk evaluation index system

According to the characteristics of Fendou Reservoir, a risk evaluation index system of Fendou Reservoir PPP project was determined by Delphi method and literature collection method. The risk evaluation index system of Fendou Reservoir PPP project is shown in **Table III**.

Determination of the weight of risk evaluation indexes

Five experts in the field of water conservancy PPP project were invited to rank and assign the first-level risk evaluation indexes of Fendou Reservoir PPP project from the most important to the least. The order relation and ratio of importance of the first-level risk evaluation indexes are shown in **Table III**.

According to the order relation of the first-level risk evaluation indexes, the weight of each index was calculated by the Formulas (5) and (6). The calculation result of the weight of the second-level risk evaluation indexes is shown in **Table V**.

Similarly, the weight of the second-level risk evaluation indexes can be obtained. The calculation result of the weight of the second-level risk evaluation indexes is shown in **Table III**.

Establishment of the evaluation sample matrix and determination of the evaluation grey class

To evaluate the risk of Fendou Reservoir PPP project, five experts in the field of water conservancy PPP project were invited to rank the risk evaluation indexeson a scale of 1 to 9. According to the formula of whitening weight function and the result of expert scoring, the grey evaluation coefficient of the risk evaluation indexes was calculated. The scoring of

TABLE III. THE RISK EVALUATION INDEX SYSTEM OF FENDOU RESERVOIR PPP PROJECT

Target layer	Criterion layer	Weight	Index layer	Weight
Risk evaluation indexes of Fendou Reservoir PPP project	Political and legal risk U_1	0.208	Legal change U_{11}	0.201
			Political stability U_{12}	0.135
			Government credit U_{13}	0.283
			Government objection U_{14}	0.194
			Approval delay U_{15}	0.187
	Natural risk U_2	0.092	Unfavorable material condition U_{21}	0.306
			Force majeure U_{22}	0.358
			Environmental pollution U_{23}	0.336
	Economic risk U_3	0.173	Inflation U_{31}	0.263
			Interest rate risk U_{32}	0.190
			Exchange rate risk U_{33}	0.195
			Financing risk U_{34}	0.244
			Tax risk U_{35}	0.109
	Market risk U_4	0.062	Similar project competition U_{41}	0.437
			Market demand change U_{42}	0.529
	Technology risk U_5	0.031	Design change U_{51}	0.380
			Technical applicability U_{52}	0.345
			Design quality U_{53}	0.276
	Management risk U_6	0.109	Decision risk U_{61}	0.360
			Organizational risk U_{62}	0.338
			Personnel risk U_{63}	0.302
	Relationship risk U_7	0.07	Changes in the distribution of responsibility and power U_{71}	0.370
			Organization and appointment U_{72}	0.314
			Communication risk U_{73}	0.317
	Construction risk U_8	0.039	Construction safety U_{81}	0.298
			Duration overrun U_{82}	0.308
			Cost overrun U_{83}	0.394
	Operational risk U_9	0.117	Operating cost overrun U_{91}	0.299
			Rising maintenance costs U_{92}	0.169
			Poor operation quality U_{93}	0.148
			Low operational efficiency U_{94}	0.175
			Residual risk U_{95}	0.209
	Other risk U_{10}	0.098	Completion risk U101	0.185
			Threats to environmental public security U_{102}	0.222
			Public opinion risk U_{103}	0.297
			Lack of good faith in social capital U_{104}	0.295

TABLE IV. THE ORDER RELATION AND RATIO OF IMPORTANCE OF THE FIRST-LEVEL RISK EVALUATION INDEXES

No.	The order relation of indexes	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}
1	$U_1>U_3>U_9>U_4>U_7>U_2=U_{10}>U_6>U_8>U_5$	1.5	1.3	1.2	1.3	1.2	1	1.3	1.2	1.3
2	$U_3>U_6>U_2>U_7>U_{10}>U_4>U_8>U_9>U_1>U_5$	1.1	1.5	1.7	1.3	1.2	1.5	1.3	1.6	1.2
3	$U_4>U_3>U_1>U_9>U_7>U_6>U_2>U_{10}>U_8>U_5$	1.6	1.2	1.6	1.6	1.8	1.2	1.4	1.2	1.4
4	$U_1=U_5=U_9>U_8>U_{10}>U_4>U_7>U_6=U_3>U_2$	1	1	1.7	1.5	1.2	1.5	1.2	1	1.7
5	$U_1>U_9>U_2>U_4>U_{10}>U_3>U_7>U_8>U_6>U_5$	1.5	1.7	1.2	1.5	1.5	1.3	1.2	1.3	1.3

the risk evaluation indexes and the calculation result are shown in **Table VI**.

Fuzzy comprehensive evaluation

(1) Second-level fuzzy comprehensive evaluation

By Formula (13), the comprehensive risk evaluation under the risk index U_i was calculated:

Similarly, by Formula (11), the fuzzy variable on the second-level risk evaluation index was calculated:

$$B_1 = W_1 \times C_1 = \begin{bmatrix} 0.201 \\ 0.135 \\ 0.283 \\ 0.194 \\ 0.187 \end{bmatrix}^T \begin{bmatrix} 0.000 & 0.154 & 0.423 & 0.308 & 0.115 \\ 0.650 & 0.350 & 0.000 & 0.000 & 0.000 \\ 0.542 & 0.417 & 0.042 & 0.000 & 0.000 \\ 0.083 & 0.417 & 0.417 & 0.083 & 0.000 \\ 0.000 & 0.080 & 0.320 & 0.360 & 0.240 \end{bmatrix} = [0.257 \quad 0.292 \quad 0.238 \quad 0.145 \quad 0.068] \tag{16}$$

Similarly, the fuzzy variable Bon the second-level risk evaluation indexes was calculated by Formulas (11):

$$B = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \\ B_6 \\ B_7 \\ B_8 \\ B_9 \\ B_{10} \end{bmatrix} = \begin{bmatrix} 0.257 & 0.292 & 0.238 & 0.145 & 0.068 \\ 0.181 & 0.359 & 0.327 & 0.106 & 0.027 \\ 0.379 & 0.360 & 0.147 & 0.087 & 0.026 \\ 0.092 & 0.341 & 0.371 & 0.128 & 0.035 \\ 0.393 & 0.462 & 0.146 & 0.000 & 0.000 \\ 0.344 & 0.500 & 0.156 & 0.000 & 0.000 \\ 0.215 & 0.476 & 0.235 & 0.046 & 0.031 \\ 0.197 & 0.492 & 0.272 & 0.040 & 0.000 \\ 0.333 & 0.482 & 0.172 & 0.012 & 0.000 \\ 0.233 & 0.318 & 0.270 & 0.133 & 0.045 \end{bmatrix} \tag{17}$$

(2) First-level fuzzy comprehensive evaluation

By Formula (15), the calculation result of the first-level fuzzy comprehensive evaluation was $R=W\bullet B=[0.276\ 0.386\ 0.223\ 0.082\ 0.030]$, the grade vector of the evaluation grey class was $V=(1, 3, 5, 7, 9)^T$, and the comprehensive evaluation result was $Q=R\bullet V=3.398$.

Analysis of the evaluation result

The comprehensive evaluation value of Fendou Reservoir PPP project was 3.398, which belonged to small risk, thus it was feasible. The main risks of the PPP project were political and legal risks and economic risks, which will directly affect the smooth progress of the whole PPP project. Therefore, great importance should be attached to them and corresponding risk countermeasures should be worked out..

CONCLUSIONS

In this paper, a quantifiable method for risk evaluation of water conservancy PPP project was presented. Firstly, according to the characteristics of water conservancy PPP project, a risk evaluation index system of water conservancy PPP project was determined by Delphi method and literature collection method; secondly, the weight of risk evaluation indexes of water conservancy PPP project was determined by Rank Correlation Analysis; thirdly, based on grey fuzzy theory, a grey fuzzy comprehensive evaluation model of water conservancy PPP project was constructed. Finally, the grey fuzzy comprehensive evaluation model was applied to Fendou Reservoir, a water conservancy PPP project, and it proved to be reasonable and scientific because the evaluation results were more objective, impartial and scientific for it can effectively reduce the influence of human factors in the evaluation, thus making the decision-making more scientific.

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TABLE V. THE CALCULATION RESULT OF THE WEIGHT OF THE SECOND-LEVEL RISK EVALUATION INDEXES

number	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}
1	0.25	0.128	0.044	0.107	0.068	0.166	0.034	0.068	0.053	0.082
2	0.16	0.06	0.241	0.04	0.016	0.094	0.031	0.019	0.265	0.073
3	0.107	0.171	0.328	0.018	0.031	0.037	0.205	0.013	0.022	0.067
4	0.2	0.079	0.036	0.036	0.021	0.118	0.044	0.065	0.2	0.2
5	0.325	0.023	0.216	0.106	0.018	0.127	0.036	0.03	0.047	0.071
weight	0.208	0.092	0.173	0.062	0.031	0.109	0.07	0.039	0.117	0.098

TABLE VI. THE SCORING OF THE RISK EVALUATION INDEXES AND THE CALCULATION RESULT

Risk index	d_{1j}	d_{2j}	d_{3j}	d_{4j}	d_{5j}	x_{j1}	x_{j2}	x_{j3}	x_{j4}	x_{j5}	x_{ij}	c_{j1}	c_{j2}	c_{j3}	c_{j4}	c_{j5}
U_{11}	7	5	4	5	6	0	1.333	3.667	2.667	1.000	8.667	0	0.154	0.423	0.308	0.115
U_{12}	1	2	2	1	1	4.333	2.333	0	0	0	6.667	0.650	0.350	0	0	0
U_{13}	2	3	2	2	1	4.333	3.333	0.333	0	0	8.000	0.542	0.417	0.042	0	0
U_{14}	5	5	4	3	3	0.667	3.333	3.333	0.667	0	8.000	0.083	0.417	0.417	0.083	0
U_{15}	8	7	4	6	5	0	0.667	2.667	3.000	2.000	8.333	0	0.080	0.320	0.360	0.240
U_{21}	4	3	3	2	5	1.333	3.667	2.333	0.333	0	7.667	0.174	0.478	0.304	0.043	0
U_{22}	5	7	5	5	5	0	1.333	4.667	2.333	0.667	9.000	0	0.148	0.519	0.259	0.074
U_{23}	2	3	1	2	4	2.667	3.333	1.000	0	0	7.000	0.381	0.476	0.143	0	0
U_{31}	1	2	2	3	1	3.667	3.000	0.333	0	0	7.000	0.524	0.429	0.048	0	0
U_{32}	1	3	2	3	2	3.000	3.667	0.667	0	0	7.333	0.409	0.500	0.091	0	0
U_{33}	2	1	2	3	2	4.333	3.333	0.333	0	0	8.000	0.542	0.417	0.042	0	0
U_{34}	7	5	6	5	5	0	1.000	4.000	3.333	1.000	9.333	0	0.107	0.429	0.357	0.107
U_{35}	2	3	1	2	2	4.333	3.333	0.333	0	0	8.000	0.542	0.417	0.042	0	0
U_{41}	7	5	5	5	4	0	1.667	4.000	2	0.667	8.333	0	0.200	0.480	0.240	0.080
U_{42}	5	3	4	2	3	1.333	3.667	2.333	0.333	0	7.667	0.174	0.478	0.304	0.043	0
U_{51}	3	4	3	2	4	1.333	4.000	1.667	0	0	7.000	0.190	0.571	0.238	0	0
U_{52}	1	2	2	1	1	4.333	2.333	0	0	0	6.667	0.650	0.350	0	0	0
U_{53}	4	1	2	2	4	2.333	3.000	1.333	0	0	6.667	0.350	0.450	0.200	0	0
U_{61}	3	2	4	1	2	2.667	3.333	1.000	0	0	7.000	0.381	0.476	0.143	0	0
U_{62}	3	4	2	2	3	2.000	4.000	1.333	0	0	7.333	0.273	0.545	0.182	0	0
U_{63}	4	3	1	2	2	2.667	3.333	1.000	0	0	7.000	0.381	0.476	0.143	0	0
U_{71}	7	4	4	3	3	0.667	3.333	2.333	1.000	0.667	8.000	0.083	0.417	0.292	0.125	0.083
U_{72}	3	2	1	1	3	3.333	3.333	0.667	0	0	7.333	0.455	0.455	0.091	0	0
U_{73}	4	3	4	3	3	1.000	4.333	2.333	0	0	7.667	0.130	0.565	0.304	0	0
U_{81}	3	3	3	3	3	1.667	5.000	1.667	0	0	8.333	0.200	0.600	0.200	0	0
U_{82}	5	4	4	5	4	0	2.667	4.000	1.000	0	7.667	0	0.348	0.522	0.130	0
U_{83}	3	1	3	2	3	2.667	4.000	1.000	0	0	7.667	0.348	0.522	0.130	0	0
U_{91}	3	2	2	3	2	2.667	4.000	1.000	0	0	7.667	0.348	0.522	0.130	0	0
U_{92}	3	1	2	1	3	3.333	3.333	0.667	0	0	7.333	0.455	0.455	0.091	0	0
U_{93}	4	5	3	5	3	0.667	3.333	3.333	0.667	0	8.000	0.083	0.417	0.417	0.083	0
U_{94}	4	2	1	2	3	2.667	3.333	1.000	0	0	7.000	0.381	0.476	0.143	0	0
U_{95}	3	2	2	3	3	2.333	3.333	1.000	0	0	6.667	0.350	0.500	0.150	0	0
U_{101}	5	3	2	5	1	2.000	2.667	1.667	0.667	0	7.000	0.286	0.381	0.238	0.095	0
U_{102}	1	2	2	1	2	4.333	2.333	0	0	0	6.667	0.650	0.350	0	0	0
U_{103}	5	3	4	2	5	0.667	3.333	3.333	0.667	0	8.000	0.083	0.417	0.417	0.083	0
U_{104}	6	7	6	5	3	0.333	1.333	3.000	2.667	1.333	8.667	0.038	0.154	0.346	0.308	0.154

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