

## Research Article

# Risk Assessment of Water Environment Treatment PPP Projects Based on a Cloud Model

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Risk assessment of public-private partnership projects has been recently acknowledged as a crucial issue in infrastructure projects. Objective assessment of risk status is conducive to the establishment of scientific and reasonable management measures. The particularity of evaluating water environment treatment PPP projects means that random errors in the evaluation index and the threshold fuzziness of evaluation degrees are issues that require attention. This paper uses the Pythagorean fuzzy cloud model to process the randomness and fuzziness of the indicators. This study assessed the risks of an iconic water environment treatment PPP project in mid-China. The risk ranks were evaluated in terms of five dimensions: political, economic, construction completion, operational, and ecological. Moreover, the results of the evaluation were compared with results derived using a regular cloud model. It was found that the Pythagorean fuzzy cloud model produced results consistent with the regular method, while also having the advantage of reflecting the randomness and fuzziness of the evaluation indicators. According to the evaluation data in this case, the project risks were ranked as follows: political > construction completion > operational > ecological > economic. The overall project risk was medium. This study's results could provide technical support for water treatment PPP project risk assessment, indicator measurement, and statistical error control.

## 1. Introduction

Water is an indispensable resource for the development of societies, both naturally and economically [1]. The pollution of water environments and the shortage of water resources are universal problems in the world, which hinder the sustainable development of both societies and economies. Nowadays, people are paying more attention to the improvement of the natural environment rather than to economic growth; hence, the demand for water environment improvement is increasing rapidly. Such improvements require continued investment in water infrastructure projects, especially water environment treatment projects [2]. However, financial funds alone cannot meet the demands of

water environment treatment projects' investment and construction [3], which has precipitated the rapid growth of PPPs (Public-Private Partnerships) in the water sector [4]. More and more countries and regions are encouraging the use of the PPP model for water environment treatment in order to attract private investors and relieve financial pressure on the government [5]. The involvement of the private sector can bring not only a large amount of capital but also advanced management expertise and innovative technologies, effectively improving the performance of water environmental treatment PPP projects [6]. As the world's largest developing country, China is also the most active PPP markets, especially in its water infrastructure. According to the China Public-Private Partnerships Center (CPPPC),

China invested in 267 water PPP projects from 2008 to 2018, accounting for one third of the global total [7]. After 2018, there was a significant decline in the PPP market after many failed projects created a huge burden that the Chinese government had to shoulder. Many PPP projects fail when private enterprises take too many risks due to inaccurate risk assessment. To maintain sustainable development of water environmental treatment PPP projects, it is of great significance to assess the project risk scientifically and accurately [8].

Water environment treatment PPP projects are involved in ecologic, economic, and hydraulic engineering theory and knowledge. The purpose of these projects is to reduce the pollution of river basins, protect aquatic animals and plants, improve the landscape around water bodies, and create a good natural environment. These kinds of projects require significant investment and expertise as they greatly influence the surrounding environment and urban residents. Thus, as a principal investor and responsible party, the Chinese government cannot guarantee the construction and operational efficiency of the projects [9]. Moreover, water environment treatment PPP projects are very different from other infrastructure projects. First, water environment treatment PPP projects involve more stakeholders than other infrastructure projects, leading to a more complex relationship system. For example, if residents' dump sewage into the watershed and obstruct water treatment, the progress of a project will be greatly affected. Second, the performance evaluation of water environment treatment PPP projects is usually based more on qualitative than on quantitative indicators. The scoring standards and language expressions of experts have more influence on project risk assessment than quantitative indicators do. Finally, the current method of risk assessment is mainly used in projects with clear outputs, such as highway projects and sewage treatment projects. However, water environment treatment PPP projects with no clear outputs rely on government fees or package peripheral fees rather than user fees, which randomly generate more risks and require more suitable risk assessment methods. Therefore, it is necessary to comprehensively consider the relationship between stakeholders and the risks generated from these relationships while also considering the fuzziness and randomness of risk indicators at the same time.

Most researchers focus on the identification of risk factors, risk distribution, and the impact of risk on project performance of water environment treatment PPP projects. Xu and Yang [10] identified 11 key risk factors in China's water environment treatment PPP projects using a case study and developed a risk distribution mechanism. Nguyen et al. [11] identified 22 key risk factors affecting the sustainability of highway PPP projects from the perspective of stakeholders and evaluated project risks. Shrestha et al. [5] introduced a general risk distribution method based on the literature on 25 kinds of risk factors and the comments of 32 experts in China's water infrastructure industry. Sobiei [12] adopted the neural network and a framework for quantitatively identifying, evaluating, and responding to risk in construction. Ameyaw [13–15] used fuzzy set approach in

the Delphi method to deal with the ambiguity of linguistic terms to minimize the fuzziness of qualitative expert examination in water infrastructure PPP projects. Above all, the methods used in these studies are usually the analytic hierarchy process (AHP) [16], fuzzy comprehensive evaluation [17], and Monte Carlo simulation [18]. The results of different methods vary greatly mainly due to the large proportion of qualitative evaluation indicators in the evaluation index system [19]. Both the fuzziness and randomness of risk indicators have an impact on the evaluation results, but the existing studies usually consider only fuzziness [13–17] or randomness [18], rather than both aspects at the same time. Moreover, few scholars have paid attention to the impact of inaccurate qualitative indicators of risk assessment for water environment treatment PPP projects. All these issues provide research space for this study.

To bridge the research gap, this paper adopts the cloud model to simultaneously consider the fuzziness and randomness of the risk indicators by its eigenvalues of expectation ( $E_x$ ), entropy ( $E_n$ ), and hyperentropy ( $H_e$ ). When determining indicator's weight, the Pythagorean fuzzy set was used to process the fuzziness of expert ratings in the cloud model. So, the cloud model with the Pythagorean fuzzy set is the right choice for studying two kinds of uncertainty. The rest of this paper is organized as follows. In Section 2, a literature review is conducted. Section 3 explains the cloud model and the Pythagorean fuzzy AHP method. In Section 4, a case study of water environment treatment PPP project is analyzed to demonstrate the application of the proposed method and validate it. Section 5 discusses the risk factors influencing water environment treatment PPP projects and compares the results with those of a regular cloud model. Finally, conclusions are drawn and limitations are discussed in Section 6.

## 2. Literature Review

*2.1. Risk Evaluation Methods for PPP Projects.* PPP projects are more complex than any other infrastructure PPP projects due to their massive investment scale and the multiple stakeholders that are involved in their extremely long life cycle. Therefore, insufficient or improper risk management measures may cause severe problems during the long project lifecycle, which could lead the failure to the project. [13]. Thus, PPP risk management is still one of the most common topics in PPP academic research in China and the worldwide [20].

Previous studies on PPP project risk mainly focused on risk identification, risk assessment, and risk allocation [21]. (i) *Risk identification:* Xu et al. [22] identified 17 key risk factors in PPP projects, among which government intervention seemed to be the most critical. Chan et al. [23] found 34 major risks affecting PPP projects in China. (ii) *Risk assessment:* Thomas et al. [24] evaluated risk probability and its impact based on fuzzy fault tree analysis and the Delphi method and applied it to PPP projects. Wu et al. [25] combined 2-dimensional language information with a cloud model to evaluate risk in a waste incineration power generation project. (iii) *Risk allocation:* Ameyaw and Chan

[13] adopted a fuzzy method and found 13 modes of risk allocation in water PPP projects. In the context of the increasingly complex structure of PPP projects, scholars are constantly developing new risk assessment methods to ensure the smooth operation of the projects. For example, Valipour et al. [26] introduced new risk assessment criteria by using stepwise weighting assessment ratio analysis and complex ratio. Wu et al. [27] adopted a 3-dimensional model, including probability, loss, and uncontrollability, to conduct risk assessment and then used AHP and the gray fuzzy method to evaluate project risks. Li and Wang [28] proposed a systematic and practical risk assessment method by combining the ISM method and network process. Although these studies provide insight into PPP project risk, additional attention should be given to risk assessment because it is to the success of the PPP projects [5].

The above scholars adopted the analytic hierarchy process (AHP) [16], the fuzzy comprehensive evaluation method [17], or Monte Carlo simulation [18] when assessing project risk, but some obvious disadvantages exist for each of these methods. First, AHP is too general and subjective. Second, in the fuzzy comprehensive evaluation method, the value of the membership function is used to replace the fuzzy number, so the uncertainty of the evaluation cannot be well reflected [29]. Finally, Monte Carlo simulation cannot determine the probability distribution of each risk variable. Filling all these research gaps, the cloud model uses three eigenvalues to realize the transformation from qualitative indicators to quantitative data; it can not only reflect fuzziness in the evaluation results but also account for randomness and fuzziness while the model is being built.

**2.2. Risk Factors of Water Environment Treatment PPP Projects.** The first step of risk assessment is risk identification, which is an elementary and important step for risk management [30]. Most risk factors and their evaluations are influenced by the characteristics of the target industry [13]. Compared with other types of infrastructure PPP projects, water environment treatment PPP projects have more stakeholders, which form a more complex relationship structure [5] and bring more conflict. First of all, different interest demands will affect the behavior of stakeholders, which in turn will affect project performance. Whereas the government pursues the maximization of public interests and the private sector pursues the maximization of investment returns. Second, water environment treatment PPP projects have more significant social and economic impacts than other types of infrastructure PPP projects. Water security is a fundamental condition for socio-economic development and urbanization, and it has a strong causal relationship with economic growth and social progress [31]. However, in the process of project risk evaluation, many indicators are difficult to quantitatively evaluate, and scientific methods are needed to transform qualitative data into quantitative data. Finally, water environment treatment PPP projects usually have a strong

external effect. The composition of PPP projects' profit is a simplex of social and external benefits, which greatly changes the proportion of risk allocation in PPP projects. Thus, more refined risk identification and evaluation methods are needed to make the whole process more scientific and effective in water environment treatment PPP projects.

There are a few studies on risk identification in water environment treatment PPP projects. Choi et al. [4] analyzed a PPP project in China's water utilities' market and determined the risk factors faced by foreign companies entering the Chinese market. Ameyaw and Chan [13] used the fuzzy comprehensive evaluation method to assess and rank risk factors in a water supply PPP project in a developing country. However, many risk identification methods are not effective when applied to water environment treatment PPP projects because of their unique industrial background. Therefore, this paper mainly focuses on developing an indicator system and assessing the fuzziness, randomness, and uncertainty of indicators in project risk identification and evaluation to make the risk evaluation of water environment treatment PPP projects more scientific and reasonable.

It is generally accepted that the key risk categories of PPP projects include political risk [13], economic risk [32], operational risk [5], environment risk [33], and construction risk [2]. Based on research on these risk categories, this paper adopted the method of literature reviews and a questionnaire survey to construct a risk evaluation index system for water environment treatment PPP projects. Accordingly, 35 critical factors are identified, as shown in Table 1.

To build a 2-level indicator system from previous list, questionnaires (shown in Supplementary material (available here)) were distributed to 150 recipients between September 2018 to June 2019, which was in the first year after this project was built, and 122 were returned. For previous research studies of infrastructure projects [57, 58], this sample size was enough for this research. The recipients were selected from six departments of the water environment treatment PPP project team and three research institutes. In order to fully consider stakeholders on all sides, we selected sample groups from the local government, the private sector, the contracting industry, a research institution, the water resource department, and a pool of experienced PPP experts from various institutions.

Using a combination of the literature review and the questionnaire responses, five first-level indicators were screened: political risk, economic risk, construction completion risk, operational risk, and ecological risk; 25 second-level indicators were also evaluated. Based on the data from the questionnaires and the accumulated risk factors, this research identified a risk assessment indicator system, as shown in Table 2.

### 3. Methodology

**3.1. Understanding the Cloud Model.** The cloud model can transform an evaluation indicator from a qualitative concept into a quantitative description [59]. On the

TABLE 1: Risk identification.

Risk factor	Risk category	Source
Corruption	Political	[34, 35]
Government's intervention	Political	[34–38]
Expropriation by government	Political	[36–39]
Government's reliability	Political	[35, 38, 40–42]
Political/public's conflict	Political	[34, 38, 40]
Legislative changes	Political	[36, 38, 43]
Change in interest rate	Economic	[34–36, 38, 40, 42]
Foreign exchange and convertibility	Economic	[34, 36, 38]
Inflation	Economic	[34, 35, 38, 40]
Delay by government's decision-making	Political	[34, 40, 44, 45]
Delay by complex approval process	Political	[36, 38, 40]
Conflict or uncomplete contract	Operation	[34, 35, 38, 40]
Financial crises	Financial	[34, 38, 40]
Project completion risk	Construction	[35, 36, 38]
Technology risk	Construction	[36, 38]
Change in market demand	Economic	[34, 38, 40, 43]
Change in market price	Economic	[35, 36]
Force majeure	Political	[34, 36, 40, 46]
Coordination and management risk	Operation	[36, 40, 43]
Environmental protection	Construction	[40, 47]
Regime stability	Political	[43]
Flawed legal system	Political	[43]
Delay in construction	Construction	[34, 38, 43]
Credit risk	Construction	[38, 48]
Profit share risk	Operation	[49–51]
Cost over run	Operation/construction	[43, 50, 52, 53]
Project quality risk	Construction	[34, 43, 50, 52]
Project design risk	Economic	[34, 49, 50]
Landscaping risk	Ecological	[39, 48, 54]
Soil erosion	Ecological	[55]
Biological chain destruction	Ecological	[48, 49, 54]
Solid waste pollution	Ecological	[43, 48, 49, 52, 53, 56]
Public perception and satisfaction	Ecological	[43, 49–51, 53]
Water resource utilization	Ecological	[48, 49, 54]
Land acquisition	Political	Interview

contrary, the comprehensive index assessment method does not consider the uncertainty of the index, and the fuzzy assessment method only considers the fuzziness of the index but neglects the randomness. At present, the cloud model has been widely applied in data mining [60], evaluating air/water quality [61], evaluating the capacity of water environments [62], etc. In this paper, the cloud model approach is adopted to deal with the fuzziness and randomness of indicators in project risk evaluation. Moreover, the cloud model also considers the cognitive aspect of experts' rating of weight determinations using Pythagorean fuzzy numbers (PFNs), to reduce their randomness and fuzziness.

In a cloud model, a set of precise numbers of the values of  $U$  represents the quantitative domain.  $C$  is the set of qualitative concepts in set  $U$ . Let  $\forall x \in U$ , where  $x$  is a random implementation of the qualitative concept  $C$ . The degree of certainty of  $x$  for concept  $C_\mu(x) \in [0, 1]$ , which is noted as "membership," is a set of random numbers that tend to be stable [40], where  $\mu: U \rightarrow [0, 1]$ ,  $\forall x \in U$ ,  $x \rightarrow \mu(x)$ ; the final form composed by all  $x$ s in domain  $U$  is called a cloud, in which each  $x$  is a cloud drop of the cloud

[63]. A cloud model can transform the qualitative concepts of an index system into quantitative representations. One cloud drop represents a random event, which can be understood as a probability distribution function that represents the randomness of a qualitative concept. The certainty of a cloud drop represents the fuzziness of a qualitative concept, which can be understood as membership based on the fuzzy set theory.

The eigenvalues of the cloud model are usually composed of 3 digits ( $E_x, E_n, H_e$ ): expectation ( $E_x$ ), entropy ( $E_n$ ), and hyperentropy ( $H_e$ ). Expectation measures the certainty of the qualitative concept; entropy measures the scope of uncertainty by its fuzziness and randomness; hyperentropy measures the uncertainty of entropy. An illustration of a standard cloud is shown in Figure 1. The larger ( $E_n$ ) is, the larger the acceptance range of the qualitative description will be. The larger ( $H_e$ ) is, the more dispersed the cloud will be; the greater the number of the clouds, the clearer the shape of the cloud.

The forward cloud generator obtains a series of cloud drops by inputting three digits eigenvalues, and the specific steps for calculating the three digits as follows:

TABLE 2: Evaluation indicators in water environment treatment PPP project risks.

1 <sup>st</sup> -level indicator of risk	2 <sup>nd</sup> -level risk indicator of risk
$U_1$ Political	$U_{11}$ Legislative changes
	$U_{12}$ Government intervention
	$U_{13}$ Land acquisition
	$U_{14}$ Unstable law or rules
$U_2$ Economic	$U_{21}$ Interest rate
	$U_{22}$ Financial/exchange rate risk
	$U_{23}$ Inflation risk
	$U_{24}$ Land compensation standard
$U_3$ Construction completion	$U_{31}$ Technology risk
	$U_{32}$ Construction cost overrun
	$U_{33}$ Delay in supply
	$U_{34}$ Project quality risk
$U_4$ Operational	$U_{41}$ Profit risk
	$U_{42}$ Operation management risk
	$U_{43}$ Default risk
	$U_{44}$ Supporting facilities
	$U_{45}$ Operator change
	$U_{46}$ Operation cost overrun
$U_5$ Ecological	$U_{51}$ Landscaping risk
	$U_{52}$ Soil erosion
	$U_{53}$ Biological chain destruction
	$U_{54}$ Water pollution
	$U_{55}$ Solid waste pollution
	$U_{56}$ Public perception and involvement

- (1) Generate standard random numbers  $E_{n_i} = \text{NORM}(E_n, H_e^2)$  by using Python, where  $E_n$  is the expectation and  $H_e$  is the standard deviation
- (2) Generate standard random numbers  $x_i$ , where  $H_e$  is the expectation and  $E_{n_i}$  is the standard deviation, here  $x_i$  is the cloud drops
- (3) Calculate  $\mu_i$ , the membership of  $x_i$ , to obtain the coordinator of the cloud drop  $(x_i, \mu_i)$  by using  $\mu_i = \exp[-(x_i - E_x)^2 / 2E_n^2]$

$$L = \{L_1, L_2, L_3, L_4, L_5\} = \{\text{really low risk, low risk, medium risk, medium high risk, high risk}\} \\ = \{(0, 30); [30, 50]; [50, 70]; [70, 90]; [90, 100)\}. \quad (3)$$

To value a unilateral boundary value of  $[C_{\min}, +\infty)$  or  $(-\infty, C_{\max}]$ , it is necessary to verify the parameters or expectations of the default boundary before transforming the data into cloud eigenvalues. A cloud model can then be built to describe the risks of the project based on this grade threshold. Function (4) is used to transform the qualitative data into the 3-digit qualitative eigenvalues of the cloud model.  $k$  is constant.

- (4) Repeat Steps 1–3 until there are  $n$  drops in the cloud model

Unlike the forward cloud generator, the backward cloud generator transmits the qualitative data into quantitative data noted by  $(E_x, E_n, H_e)$ . To calculate  $N$  given numbers of cloud drops  $x_j$ , the steps are as follows:

- (1) Calculate the mean  $\bar{X}$  (or  $E_x$ ) by cloud drops  $x_j$ :

$$\bar{X} = \frac{1}{N} \sum_{j=1}^N x_j, \quad (1)$$

$$E_x = \bar{X}.$$

- (2) Calculate  $E_n$  through  $x_j$  and  $E_x$ :

$$E_n = \sqrt{\frac{\pi}{2}} \frac{1}{N} \sum_{j=1}^N |x_j - \bar{X}|. \quad (2)$$

- (3) Let  $H = k$  (where  $k$  is a norm, which can be adjusted as needed).

**3.2. The Process of Pythagorean Cloud Model.** In a cloud model, a standard cloud graph represents the risk ranks of five risk levels, from the lowest to the highest, as a reference object. After determining an indicator's weight, the eigenvalues of the cloud model can be calculated to draw an indicator specific cloud. This specific cloud represents the eigenvalues of one first-level indicator rank. Ultimately, locating each of the indicator specific clouds in the standard cloud shows the risk level assessment of the five first-level indicators. Here, Python was chosen to achieve such an evaluation based on the cloud model, see steps in Figure 2.

**3.2.1. Ensure Indicator Grade Threshold.** According to the overview of water environment treatment PPP projects in China, the evaluation grade threshold can be divided into five categories:

$$\begin{cases} E_x = \frac{C_{\max} + C_{\min}}{2}, \\ E_n = \frac{C_{\max} - C_{\min}}{6}, \\ H_e = k. \end{cases} \quad (4)$$

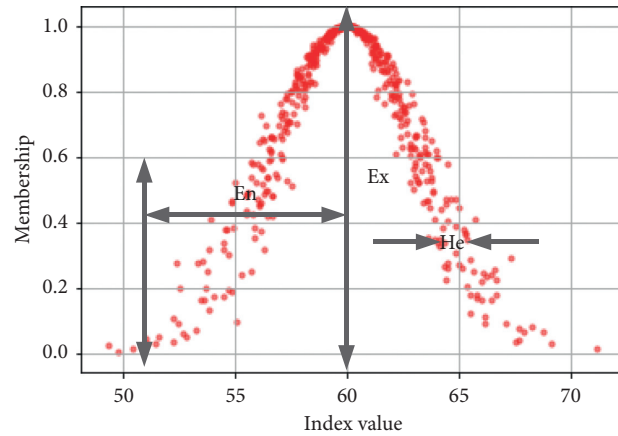


FIGURE 1: Illustration of a standard cloud model by its eigenvalues ( $E_x, E_n, H_e$ ).

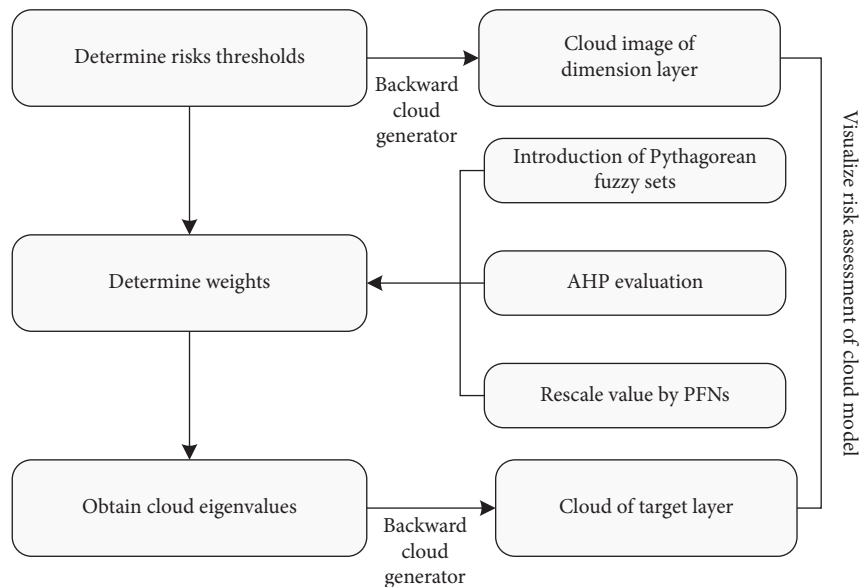


FIGURE 2: Flowchart of project risk assessment using a cloud model.

Based on previous research, let  $k = 0.5$ , so the thresholds for the indicator standard cloud would be as follows: really low risk, indicated in the color of dark blue (0, 10, 0.5), low risk, indicated in green (40, 10/3, 0.5), medium risk, indicated in light blue (60, 10/3, 0.5), medium-high risk, indicated in black (80, 10/3, 0.5), and high risk, indicated in purple (100, 10/3, 0.5). Figure 3 graphically shows these thresholds.

**3.2.2. Determination of Indicator Weight.** The analytic hierarchy process (AHP) method was widely used in determining indicator's weight [64]. However, the component of project stakeholders is so complicated that their activities are unpredictable. Additionally, the linguistic comment set for risk evaluation contains fuzziness and randomness. Thus, the Pythagorean fuzzy set (PFS) is used to determine the weight of indicators and extend the AHP method. As the information solicited requires the participants to have in-depth knowledge and empirical experience about risks, the

participants needed to meet at least one of the following criteria [42, 57]: (i) extensive working experience in water PPP projects in China; (ii) current/recent working experience on infrastructure risk management; (iii) in-depth understanding of the concept of PPP risks.

- (1) Understanding the Pythagorean fuzzy AHP: AHP, which was first proposed by Saaty, is one of the most popular multicriteria decision-making methods. The classical AHP method takes decision makers and their opinions into consideration in order to make a multiple criteria evaluation. To deal with the fuzziness and randomness of indicators, the classic fuzzy set and the intuitionistic fuzzy set have been widely used. However, intuitionistic fuzzy sets have certain limitations. The sum of membership and non-membership of the scheme satisfying the attributes cannot be greater than 1. In the case of such a limitation, Pythagorean fuzzy numbers (PFNs) can rectify the problems [65–67]. PFNs can reallocate the

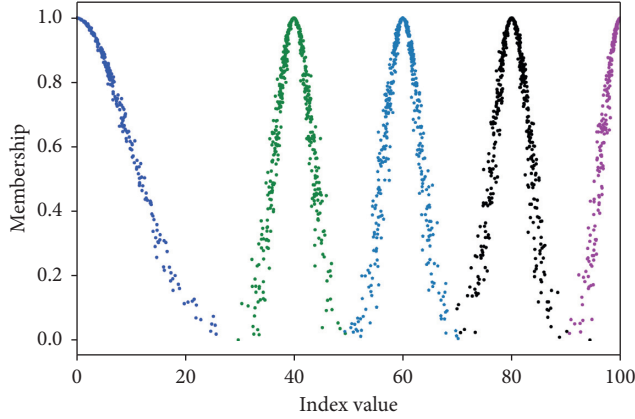


FIGURE 3: Standard cloud map of risks evaluation grade thresholds.

scale set of the judgement matrix in the AHP. The new matrix with PFNs is obtained to finish the process of determining the weights. Thus, Pythagorean fuzzy AHP can be an appropriate method for building a cloud model because of its weight determination step.

- (2) Rescaling the judgement matrix using Pythagorean fuzzy AHP: let  $X$  be the domain so that  $A = \{x, \mu_A(x), \nu_A(x) \mid x \in X\}$  is the PFS, with  $\mu_A: X \rightarrow [0, 1]$  and  $\nu_A: X \rightarrow [0, 1]$  being the membership and nonmembership of  $A$  in domain  $X$ . For every  $x \in X$  satisfying  $\mu_A^2(x) + \nu_A^2(x) \leq 1$ ,  $\pi_A(x) = \sqrt{1 - \mu_A^2(x) - \nu_A^2(x)}$  represents the hesitation or uncertainty of  $X$  on  $A$ .  $\beta = \mu_\beta, \nu_\beta$  is called the set of Pythagorean fuzzy numbers, or the PFNs [68]. Use  $i$  and  $j$  to define the risk indicators.

By rescaling the AHP judgement matrix with PFNs, a new matrix scale is obtained. A comparison of the newly obtained scores to the regular AHP scores is clearly shown in Table 3 [69].

- Step 1: create a pairwise comparison matrix  $\bar{A}$  as given in Table 2:

$$\bar{A} = \begin{pmatrix} A & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & A \end{pmatrix}. \quad (5)$$

where  $A$  is  $([0.4, 0.55], [0.4, 0.55])$ , while  $a$  is  $([\mu_L, \mu_U], [\nu_L, \nu_U])$ .

- Step 2: obtain differences of the matrix between risk indicator  $i$  and  $j$  by using (6) and (7):

$$d_{iKL} = \mu_{iKL}^2 - \nu_{iKL}^2, \quad (6)$$

$$d_{iKU} = \mu_{iKU}^2 - \nu_{iKU}^2. \quad (7)$$

- Step 3: obtain the interval multiplicative matrix using equations (8) and (9):

TABLE 3: Evaluation scores for weight vectors in AHP and PFNs.

Linguistic terms (from $i$ to $j$ )	AHP score	PFNs	
		$\mu_L \mu_U$	$\nu_L \nu_U$
Equally important	1	[0.4, 0.55]	[0.4, 0.55]
Slightly important	3	[0.5, 0.65]	[0.3, 0.45]
Obviously important	5	[0.6, 0.75]	[0.2, 0.35]
Very important	7	[0.7, 0.85]	[0.1, 0.25]
Extremely important	9	[0.8, 0.95]	[0.0, 0.15]
Slightly unimportant	1/3	[0.3, 0.45]	[0.5, 0.65]
Obviously unimportant	1/5	[0.2, 0.35]	[0.6, 0.75]
Very unimportant	1/7	[0.1, 0.25]	[0.7, 0.85]
Extremely unimportant	1/9	[0.0, 0.15]	[0.8, 0.95]

$$S_{iKL} = \sqrt{1000^{d_{iKL}}}, \quad (8)$$

$$S_{iKU} = \sqrt{1000^{d_{iKU}}}. \quad (9)$$

- Step 4: calculate the determinacy value of matrix  $\bar{A}$ :

$$\tau_{iK} = 1 - (\mu_{iKU}^2 - \mu_{iKL}^2) - (\nu_{iKU}^2 - \nu_{iKL}^2). \quad (10)$$

- Step 5: multiply the determinacy value of matrix  $\bar{A}$  to obtain the weights' matrix  $t_{iK}$ :

$$t_{iK} = \left( \frac{S_{iKL} + S_{iKU}}{2} \right) * \tau_{iK}. \quad (11)$$

- Step 6: compute the normalized priority weights:

$$\omega_i = \frac{\sum_{k=1}^m t_{iK}}{\sum_{i=1}^m \sum_{k=1}^m t_{iK}}. \quad (12)$$

- Step 7: perform a consistency test of the judgement matrix:

$$\lambda_{\max}(\bar{A}) = \sum_{i=1}^n \frac{(\bar{A}\omega)_i}{n\omega_i}, \quad (13)$$

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad (14)$$

$$CR = \frac{CI}{RI}, \quad (15)$$

where  $\bar{A}$  is the judgement matrix,  $(\bar{A}\omega)_i$  is the  $i^{\text{th}}$  element in the matrix,  $\lambda_{\max}(\bar{A})$  is the maximum eigenvalue of the judgement matrix  $(\bar{A})$ , and  $CI$  is the consistency test index. If  $CI = 0$ ,  $(\bar{A})$  is absolutely consistent, and  $RI$  is the average random consistency index of  $(\bar{A})$ . When  $CR \leq 0.1$ , the judgement matrix passes the consistency test. As per common knowledge, if  $CR > 0.1$ , then  $(\bar{A})$  has failed the consistency test. In that case, the matrix needs to be reconstructed; steps are as shown in Figure 4.

The Pythagorean fuzzy AHP interval matrix scalar is built up in Table 4.



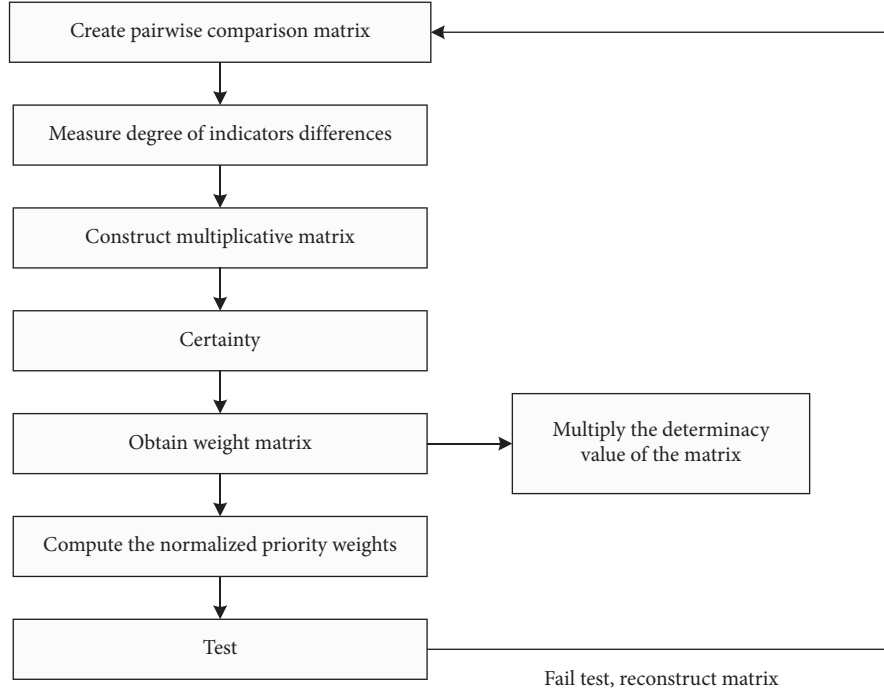


FIGURE 4: Steps to obtain weight by using Pythagorean fuzzy AHP.

TABLE 4: Pythagorean fuzzy scale set interval weight matrix.

No.	PFNs		$\tau_{iK}$	$t_{iK}$
	$\mu_L \mu_U$	$\nu_L \nu_U$		
A	[0.4, 0.55]	[0.4, 0.55]	0.715	0.7150
B	[0.5, 0.65]	[0.3, 0.45]	0.715	1.3856
C	[0.6, 0.75]	[0.2, 0.35]	0.715	2.7137
D	[0.7, 0.85]	[0.1, 0.25]	0.715	5.3698
E	[0.8, 0.95]	[0, 0.15]	0.715	10.7297
F	[0.3, 0.45]	[0.5, 0.65]	0.715	0.3729
G	[0.2, 0.35]	[0.6, 0.75]	0.715	0.1966
H	[0.1, 0.25]	[0.7, 0.85]	0.715	0.1047
I	[0.0, 0.15]	[0.8, 0.95]	0.715	0.0563

3.2.3. *Calculation of the Eigenvalues of the Cloud Model.* Ratings from experts,  $E_{x1} \cdots E_{xn}$ , and their weights,  $\omega_1 \cdots \omega_n$ , are obtained in the first two steps using equations (1) and (2). Then, the floating cloud algorithm [70] is used to calculate the eigenvalues ( $E_x, E_n, H_e$ ) of the second-level indicators of the cloud model, for there is a small correlation and each element is basically independent:

$$\begin{cases} E_x = \frac{E_{x1}\omega_1 + E_{x2}\omega_2 + \cdots + E_{xn}\omega_n}{\omega_1 + \omega_2 + \cdots + \omega_n}, \\ E_n = \frac{E_{n1}\omega_1^2 + E_{n2}\omega_2^2 + \cdots + E_{nn}\omega_n^2}{\omega_1^2 + \omega_2^2 + \cdots + \omega_n^2}, \\ H_e = \frac{H_{e1}\omega_1^2 + H_{e2}\omega_2^2 + \cdots + H_{en}\omega_n^2}{\omega_1^2 + \omega_2^2 + \cdots + \omega_n^2}, \end{cases} \quad (16)$$

where  $E_{xn}$  is expectation/mean of the experts' ratings,  $E_{n1}$  is the entropy,  $H_{en}$  is the hyperentropy,  $\omega$  is the weights of the ratings, and  $n$  is the number of second-level elements.

To compute the eigenvalues of the first-level indicators, it is necessary to integrate the second-level indicators. This is a conceptual upgrade that combines two or more clouds into a generalized one. Here, we adopted the virtual cloud comprehensive algorithm [70] to figure out cloud eigenvalues for the whole project risk evaluation:

$$\begin{cases} E_x = \frac{E_{x1}E_{n1}\omega_1 + E_{x2}E_{n2}\omega_2 + \cdots + E_{xn}E_{nn}\omega_n}{E_{n1}\omega_1 + E_{n2}\omega_2 + \cdots + E_{nn}\omega_n}, \\ E_n = E_{n1}\omega_1 + E_{n2}\omega_2 + \cdots + E_{nn}\omega_n, \\ H_e = \frac{H_{e1}E_{n1}\omega_1 + H_{e2}E_{n2}\omega_2 + \cdots + H_{en}E_{nn}\omega_n}{E_{n1}\omega_1^2 + E_{n2}\omega_2^2 + \cdots + E_{nn}\omega_n^2}, \end{cases} \quad (17)$$

where  $E_{xn}$  is the eigenvalues of the second-level indicators, which are from equation (16). Similarly,  $E_{n1}$  is the entropy.  $H_{en}$  is the hyperentropy.  $\omega$  is the weight calculated by the Pythagorean fuzzy AHP method.  $n$  is the number of second-level elements.

#### 4. Case Study

Case study analysis is used to consider "how" and "why" problems in a real-life context [71]. In this case, an actual ecological water PPP project called the Yinma River project in Xuchang, China, was adopted. This case addresses a "how" question in order to understand how a cloud model can be used scientifically in a water environment treatment PPP project. This project was not randomly selected, but was



chosen because it is a typical case. As one of the first PPP projects for water environment treatment, the Yinma River project is located in a disadvantaged city in central China with a scarcity of water. This project was built to maintain the surface soil, underground water, and fish habitat, as well as the area's biodiversity. Therefore, it has been highly supported by the local government using the PPP model for financing and managing. The investment in the project has been massive for the city, costing about 82,816,420 RMB, and it has been financially supported by China Development Bank. Because the cooperation procedure between the public and private sectors is immature, the risk assessment of water environment treatment PPP projects is even more meaningful.

Working with the government, the private sector participant in the project is the Xuchang Water Ecology Investment Development Co., Ltd., which was jointly established by the Henan Water Resources Investment Group Co., Ltd. and the Xuchang City Investment Corporation. The private sector is responsible for the project construction, financial management, project quality control, and safety supervision. The project's construction period was two years; thereafter, its operational period is up to 30 years. According to the contract, this is a quasi-profit project whose purpose is to implement the overall plan of Xuchang City. The content of the project includes the construction of riverside landscaping and the protection and restoration of water ecosystems in order to improve citizens' happiness index. Moreover, the project stimulates the tourism industry and economy due to its unique urban river landscape.

According to the Pythagorean fuzzy AHP process, as shown in Figure 4, and the principles of interviewing experts, the index weight is evaluated. Then, equations (5)–(12) are used to determine the weights, and equations (13)–(15) are used to do the consistency test. Results are displayed in Tables 5–9.

Furthermore, a backward cloud generator is used to get the eigenvalues of the first-level index using equation (16). Finally, equation (17) is used to obtain the total project risk. Eigenvalues of indicators represent the significance of the risks, as shown in Table 10. The more significant the indicator, the more critical the risk. As mentioned before,  $H_e = 0.5$ .

The first-level index in Table 10 are defined as a red cloud, in which every eigenvalue is visualized by Python through the backward cloud generator. Then, the indicator specific cloud is located in the standard cloud, as mentioned in 3.2.1. The risk assessment results of each level and of the whole project are clearly shown in Figures 5–10.

### 5. Discussion

The results show that the total risk of the Yinma River project is rated as medium, see Figure 10. With regard to the efficiency of the method to measure the water environment treatment PPP project risk, the results obtained by both the Pythagorean fuzzy cloud model and the traditional cloud model yielded similar conclusions, as shown in Table 11.

TABLE 5: Indicator judgement matrix and the weights of the political risk.

$U_1$	$U_{11}$	$U_{12}$	$U_{13}$	$U_{14}$	$\omega$
$U_{11}$	0.715	1.3856	2.7137	5.3698	0.5210
$U_{12}$	0.3729	0.715	1.3856	2.7137	0.2675
$U_{13}$	0.1966	0.3729	0.715	1.3856	0.1388
$U_{14}$	0.1047	0.1966	0.3729	0.715	0.0728
$\lambda$	4.05402	CI	0.018007	CR	0.020007

TABLE 6: Indicator judgement matrix and the weights of the economic risk.

$U_2$	$U_{21}$	$U_{22}$	$U_{23}$	$U_{24}$	$\omega$
$U_{21}$	0.715	1.3856	5.3698	0.3729	0.3228
$U_{22}$	0.3729	0.715	1.3856	0.3729	0.1657
$U_{23}$	0.1047	0.3729	0.715	0.1047	0.0632
$U_{24}$	1.3856	1.3856	5.3698	0.715	0.4482
$\lambda$	4.17004	CI	0.05681	CR	0.062979

TABLE 7: Indicator judgement matrix and the weights of the construction completion risk.

$U_3$	$U_{31}$	$U_{32}$	$U_{33}$	$U_{34}$	$\omega$
$U_{31}$	0.715	1.3856	2.7137	0.3729	0.2835
$U_{32}$	0.3729	0.715	1.3856	0.3729	0.1726
$U_{33}$	0.1966	0.3729	0.715	0.1047	0.0771
$U_{34}$	1.3856	1.3856	5.398	0.715	0.4668
$\lambda$	4.10067	CI	0.033557	CR	0.037285

TABLE 8: Indicator judgement matrix and the weights of the operational risk.

$U_4$	$U_{41}$	$U_{42}$	$U_{43}$	$U_{44}$	$U_{45}$	$U_{46}$	$\omega$
$U_{41}$	0.715	1.3856	2.7137	5.3698	1.3856	2.7137	0.3559
$U_{42}$	0.3729	0.715	1.3856	1.3856	0.3729	2.7137	0.1639
$U_{43}$	0.1966	0.3729	0.715	1.3856	0.3729	1.3856	0.1059
$U_{44}$	0.1047	0.3729	0.3729	0.715	0.1966	1.3856	0.0688
$U_{45}$	0.3729	1.3856	1.3856	2.7137	0.715	5.3698	0.2558
$U_{46}$	0.1966	0.1966	0.3729	0.3729	0.1047	0.715	0.0497
$\lambda$	6.27597	CI	0.055195	CR	0.04451		

TABLE 9: Indicator judgement matrix and the weights of the ecological risk.

$U_5$	$U_{51}$	$U_{52}$	$U_{53}$	$U_{54}$	$U_{55}$	$U_{56}$	$\omega$
$U_{51}$	0.715	0.1966	0.1966	0.0563	0.0563	0.1047	0.0230
$U_{52}$	2.7137	0.715	0.3729	0.1966	0.1966	0.3729	0.0743
$U_{53}$	2.7137	1.3856	0.715	0.1966	0.1966	0.3729	0.0924
$U_{54}$	10.7297	2.7137	2.7137	0.715	1.3856	2.7137	0.3771
$U_{55}$	10.7297	2.7137	2.7137	0.3729	0.715	1.3856	0.2788
$U_{56}$	5.3698	1.3856	1.3856	0.1966	0.3729	0.715	0.1434
$\lambda$	6.25713	CI	0.05142	CR	0.04147		

The classic risk assessment method for PPP projects is concerned with sequencing and scope of project risks [33], and the advantages of the cloud model are highlighted. The Pythagorean fuzzy cloud model not only determines the level of project risk but also can generate risk in the form of a

TABLE 10: Cloud eigenvalues of the indicator system.

1 <sup>st</sup> -level risk indicator	Eigenvalue	2 <sup>nd</sup> -level risk indicator	Eigenvalue
$U_1$ Political risk	(72.56, 4.27, 0.5)	$U_{11}$ Legislative changes	(80.20, 4.81, 0.5)
		$U_{12}$ Government intervention	(65.40, 2.41, 0.5)
		$U_{13}$ Land acquisition	(82.00, 4.01, 0.5)
		$U_{14}$ Unstable law or rules	(26.20, 2.81, 0.5)
$U_2$ Economic risk	(40.55, 1.36, 0.5)	$U_{21}$ Interest rate	(34.40, 1.10, 0.5)
		$U_{22}$ Financial/exchange rate risk	(80.00, 4.01, 0.5)
		$U_{23}$ Inflation risk	(33.40, 3.11, 0.5)
		$U_{24}$ Land compensation standard	(31.40, 1.10, 0.5)
$U_3$ Construction completion risk	(64.75, 2.80, 0.5)	$U_{31}$ Technology risk	(65.40, 1.40, 0.5)
		$U_{32}$ Construction cost overrun	(79.80, 5.21, 0.5)
		$U_{33}$ Delay in supply	(27.20, 1.70, 0.5)
		$U_{34}$ Project quality risk	(65.00, 3.01, 0.5)
$U_4$ Operational risk	(61.23, 1.70, 0.5)	$U_{41}$ Profit risk	(65.00, 1.50, 0.5)
		$U_{42}$ Operation management risk	(64.40, 3.11, 0.5)
		$U_{43}$ Default risk	(26.60, 1.41, 0.5)
		$U_{44}$ Supporting facilities	(65.40, 2.41, 0.5)
		$U_{45}$ Operator change	(66.00, 1.50, 0.5)
		$U_{46}$ Operation cost overrun	(67.20, 1.70, 0.5)
$U_5$ Ecological risk	(53.08, 2.71, 0.5)	$U_{51}$ Landscaping risk	(32.80, 1.80, 0.5)
		$U_{52}$ Soil erosion	(33.40, 1.91, 0.5)
		$U_{53}$ Biological chain destruction	(31.20, 1.30, 0.5)
		$U_{54}$ Water pollution	(64.60, 3.11, 0.5)
		$U_{55}$ Solid waste pollution	(65.20, 2.31, 0.5)
		$U_{56}$ Public perception and involvement	(26.80, 2.31, 0.5)
<b>Project risk</b>	<b>(65.52, 4.12, 0.5)</b>		

cloud. This model blurs the boundary of the risk and makes the assessment no longer a simple list. The following analysis will discuss the results that combine the eigenvalues of the second-level index in Table 10 and their figures (Figures 4–8). The analysis below is ordered from the highest

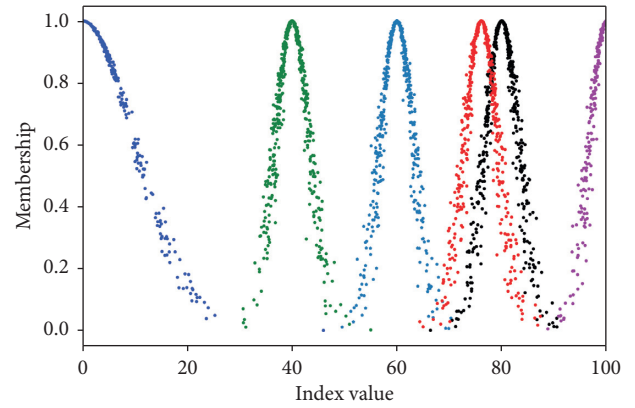


FIGURE 5: Cloud map of political risk.

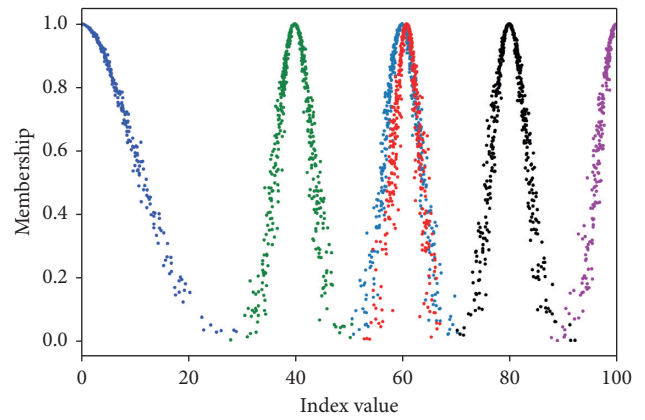


FIGURE 6: Cloud map of economic risk.

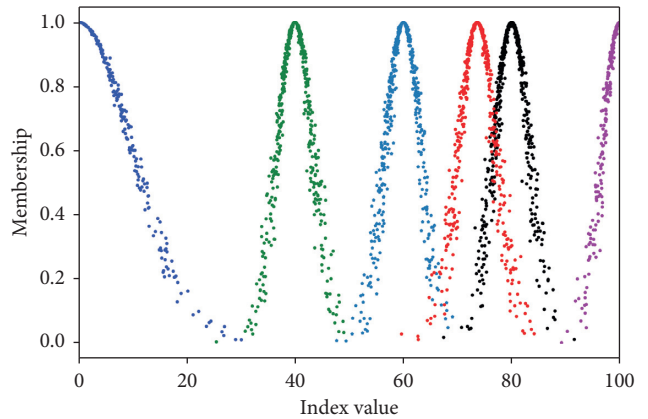


FIGURE 7: Cloud map of construction completion risk.

risk level to the lowest according to the eigenvalues of the indicators. The higher the value of  $E_x$ , the more critical the factor.

For the political risk aspect, its risk cloud falls between the medium and medium-high risk thresholds, as shown in Figure 5. The cloud crosses the medium risk cloud below the membership of 0.2; then, it crosses the medium-high risk cloud with a membership over 0.8. Comparing the

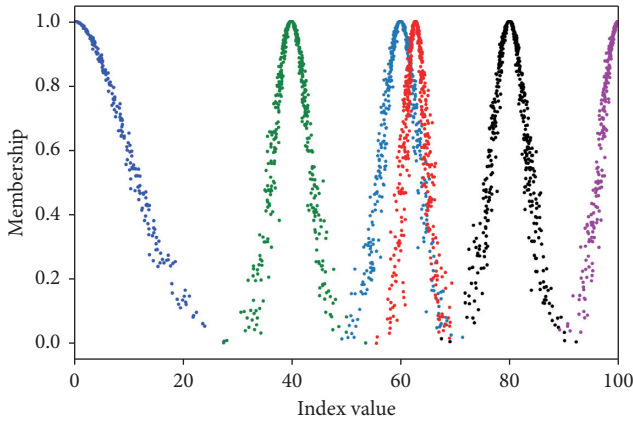


FIGURE 8: Cloud map of operational risk.

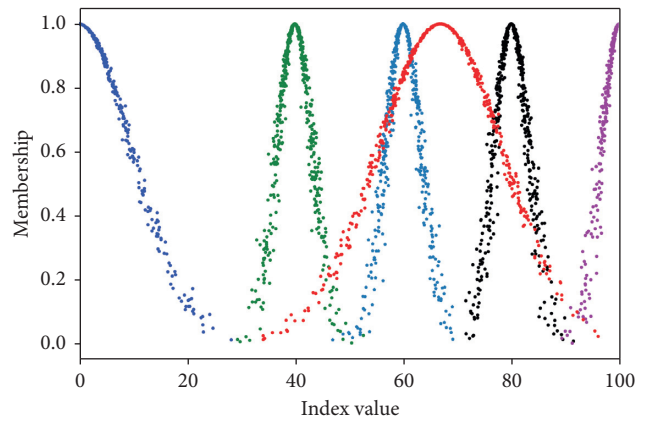


FIGURE 10: Cloud map of total project risk.

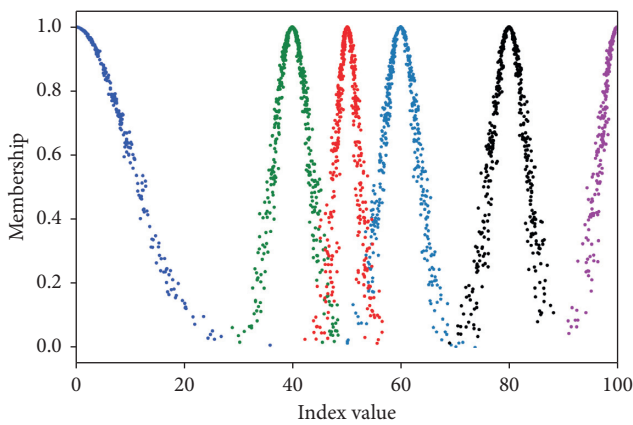


FIGURE 9: Cloud map of ecological risk.

eigenvalues of the secondary index in Table 10, legislative change (80.20, 4.81, 0.5), land compensation (82.00, 4.01, 0.5), and government intervention (65.40, 2.41, 0.5) were found to be critical. As public welfare projects, water environment treatment projects have a simple rate of return, and they are usually funded by the Chinese government. Therefore, government compensation and policy changes have a great impact on PPP projects. Like China’s Olympic Stadium, the “Bird’s Nest” [72] and “Citong Bridge” [73] are typical PPP projects that have been unsuccessful due to policy implications and inadequate incentives. For the government, it is recommended to participate in a subordinate role and to introduce a third-party regulatory agent to assist with the project. For research institutes, scholars may focus more on the optimization of the compensation mechanism. For the private sector, to avoid risk from the government, a long-term legislative contract is indispensable. More importantly, a sound legal mechanism can make the contract more resistant to risks.

With regard to the construction completion risk aspect, see Figure 7, its cloud intersects with the medium risk below the membership of 0.2, and it crosses the medium-high risk standard cloud between the memberships of 0.6 and 0.8, which means that the construction completion risk is almost in the medium-high risk rank. Comparing the eigenvalues of

the secondary index in Table 10, construction cost overrun (79.80, 5.21, 0.5) was found to pose the most critical risk. Therefore, contractors should declare the budget and sign a “turn-key contract” with the private consortium. In that case, the private consortium would no longer be responsible for any additional payments during the construction period. In addition, a clear settlement date should be specified in the contract with a detailed list of costs and reasonable incentives. In order to avoid loss from technology risk (65.40, 1.40, 0.5), choosing an experienced and reliable contractor is necessary. Furthermore, the contractor needs to ensure the effectiveness of current technology for the duration of the project and not experiment with nascent technologies. To ensure construction quality, private consortiums should choose a reliable contractor with a good reputation.

Operational risk is assessed as a medium risk level, see Figure 8. Its cloud crosses the medium cloud with a membership between 0.6 and 0.8, and it intersects with the medium-high cloud below 0.2, in which the eigenvalue is (61.23, 1.70, 0.5). Comparing the eigenvalues of the secondary index in Table 10, five  $E_x$  values for the second-level indicators are over 60. They are the following: cost overrun (67.20, 1.70, 0.5), operator change (66.00, 1.50, 0.5), supporting facilities (65.40, 2.41, 0.5), profit risk (65.00, 1.50, 0.5), and operation management risk (64.40, 3.11, 0.5). First, in the context of China’s rapid economic development, the risk of exceeding the budget will occur during a long operating period. The private sector may win the bid for a PPP project by reducing their cost. Postponed construction is another cause of an overrun budget. Second, after the project is designed, the contract between the government and the private sector will identify the operating sector. The operating company may offer to withdraw from the project due to its own financial problems or because of conflicts with the builder in the previous phase. Third, inadequate and unmatched facilities often are an issue in Chinese infrastructure projects. This requires the project management company to focus on the links between each department. Fourth, profit sharing is a big topic in PPP research, and a fair benefit distribution agreement can effectively alleviate the cooperation contradiction between the public and private sectors. If this is not done, it will cause risks. Finally, the

TABLE 11: Comparison of the AHP cloud model and the PFAHP cloud model: assessment.

	Cloud model with AHP	Cloud model with PFAHP
Total risk level	MEDIUM	MEDIUM

PPP mode in China is, in fact, still in the exploration stage. Nonetheless, PPP projects need highly talented personnel with operation and management skills. Thus, universities could expand related faculty to cultivate synthesized talent. The operation period is the longest one in a PPP project's life cycle, and all stakeholders need to strengthen their legal awareness of the key risks identified when formulating the contract.

From the ecological perspective, see Figure 9, the cloud is primarily located in the low risk rank, with a membership of below 0.2, though a small amount of it is in the medium risk rank, with a membership between 0.2 and 0.4. Comparing the eigenvalues of the secondary index in Table 10, we found that water pollution (64.60, 3.11, 0.5) and solid waste risks (65.20, 2.31, 0.5) are the most significant. In our case study, Xuchang, China, was denoted as a fourth-tier city, with pollution coming mostly from citizens. For example, the nearby factories dump unqualified products directly into the river, which has led to serious pollution for a long time. Additionally, it was reported that residents often do laundry and wash their cars in the river, which has led to chemical pollution of the river. The local government and media should work together to spread knowledge to local residents and visitors about sustainable human behaviors and how they affect our living environment. At the same time, NGOs could take on the responsibility of monitoring the pollution. From the technology perspective, the government is recommended to provide more funding to academic institutions for innovative sewage and solid waste treatment technologies.

For the economic risk dimension, the cloud is basically within the medium risk rank and has a small distribution, as shown in Figure 6, with an eigenvalue of (40.55, 1.36, 0.5). Comparing the eigenvalues of the second-level indicators in Table 10, we found that financing risk (80.00, 4.01, 0.5) is the most critical factor. Equity financing and debt financing are two options in project financing. Equity financing is derived from a company's capital, and its purpose is to enhance the ability of the operating company to mitigate risk and expand project scale. On the contrary, debt financing is mainly aimed at expanding project scale and obtaining cash flow during a project's operating period. Water environment treatment projects were mostly funded by the Chinese government in the earliest days of the nation. It was not until the early 1980s that PPP projects were developed in China, and such projects have accumulated experience in equity investment. However, China's bond market is still immature. A PPP project is likely to be refinanced or debt financed, during its long operating period. With regard to debt financing, syndicated loans are flexible and efficient. They can customize relevant terms to various private

investors. Ke [38] mentioned the usage of syndicated loans in PPP financing early on, but they are still not the main force in the Chinese credit market. In the meanwhile, the government has suggested providing incentives, tax reductions, and exemptions to lower the entry barriers for private enterprises.

## 6. Conclusion

Water environment treatment PPP projects have been acknowledged as a crucial aspect of China's infrastructure projects. With the rapid development of the economy and society, the problem of water environment pollution in China has increased in severity. Water environment treatment PPP projects have fully received the attention of the Chinese government. The application of the PPP model has brought significant funds to such projects. Therefore, a scientific assessment method of the risks of water environment treatment PPP projects can reduce the losses to all stakeholders.

Due to problems caused by the fuzziness and randomness of the index and evaluation language set in traditional risk assessment, the cloud model was adopted to deal with the above problems for the index system. This paper first constructed a risk evaluation indicator system for water environment treatment PPP projects. After collecting risk ratings from experts and decision makers about the risks of PPP projects in water environment governance, the weights of these risks were calculated using a Pythagorean fuzzy AHP. Later, the cloud model eigenvalues of the first- and second-level indexes were calculated using the floating cloud algorithm and the comprehensive cloud algorithm. Moreover, some visual cloud maps were obtained according to the backward cloud generator. Finally, some suggestions were developed to evaluate the risks of the Yinma River water environment treatment PPP project. The results show that the project is considered to be a "Medium" risk, with an eigenvalue of (65.52, 4.12, 0.5), and Political risk > Construction completion risk > Operational risk > Ecological risk > Economic risk. Based on these results, the factors under each first-level indicator were discussed.

This paper makes two important contributions. First, it identifies unique risk factors of water environment treatment PPP projects, which make up for the lack of industry background in current risk assessment research. Secondly, a new risk assessment cloud model was constructed by using PFS, in which it was found that ecological risk was more critical than economic risk, providing a new approach for risk assessment in PPP projects. First-level risk indicators, when using regular AHP in a cloud model, are ordered as  $U_1 > U_3 > U_4 > U_2 > U_5$ , while the order is  $U_1 > U_3 > U_4 > U_5 > U_2$  when using PFAHP. Such results reflect the advantages of using the PFS in the cloud model in water environment treatment projects, for its ecological risk ( $U_5$ ) might have been ignored in the classic methods. Thus, the results of this study are conducive to creating a more accurate and scientific risk assessment method. The detailed eigenvalues are listed in Supplementary material. Finally,

this paper provides a new angle for the theory and empirical study of risk assessment in water environment treatment PPP projects, which has both theoretical and practical value. Meanwhile, this paper also has some limitations. In the process of gathering expert ratings, the membership function of the language variables depended on the perception of experts, which entails a certain degree of subjectivity. In future studies, multigranularity linguistics could be considered to expand the evaluation linguistic set.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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## Supplementary Materials

Appendix 1. Questionnaire of risk identification Part I: Background of interviewees. Appendix 2. Comparison of AHP cloud model and PFAHP cloud model: eigenvalues. (*Supplementary Materials*)

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