Research Article

Application of the Cloud Model Synthesis Method in Ecological Evaluation of Waterways

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The cloud model synthesis method based on the membership cloud theory combines the fuzziness and randomness of uncertain problems in reality and is a model that can realize the transformation between qualitative concepts and quantitative data compared with the traditional fuzzy theory system. The theory and method are relatively lacking in the research work of waterway ecological evaluation. In view of the abovementioned characteristics and the advantages of wide applications of the membership cloud model, this paper takes the ecological evaluation of the Jingjiang River waterway as an example and applies the cloud model synthesis method to the comprehensive evaluation of waterway ecology. The cloud generator MATLAB code is used as a tool to combine the expert scoring data of the Jingjiang ecological waterway comprehensive evaluation system, and the clouding principle of human scoring variables is applied to conduct a comprehensive evaluation of the ecological nature of the Jingjiang waterway from 2011 to 2015. The results show that the cloud model synthesis method is applicable to the ecological evaluation of waterways and has the advantages of being applicable to subjective and objective data as well as retaining the uncertainty of each element in the evaluation system in the calculation process. This research can play a supplementary and perfect role for the method of waterway ecological evaluation.

1. Introduction

Exploring the method and connection of mutual transformation between the uncertainty and certainty in knowledge are the direction of the efforts of many scientific researchers in related fields. In order to continuously adapt to the needs of practical applications, a series of theoretical results such as fuzzy random variables [1–3], hesitant fuzzy linguistic term sets [4, 5], and membership functions [6] have been derived based on the theories of random variables, fuzzy set theory [7], and possibility distributions [8, 9]. These theoretical results have been widely used in many fields such as economy, transportation, engineering, and service satisfaction.

In order to continuously improve the theoretical system of transformation from uncertainty to certainty, academician Deyi Li proposed the cloud theory [6] and the concept of membership cloud based on the abovementioned two parameters after an in-depth investigation of the irrationality of fuzzy set theory and probability theory in the study of certain problems in reality. The theory effectively transforms fuzzy problems into concepts and memberships through corresponding functional relations and has been applied in many interdisciplinary fields.

The research work on ecological evaluation of waterways has led to some theoretical results being well applied in engineering (Table 1), and these methods have laid a good foundation for the research work in this paper.

From Table 1, methods 1–4 all represent the bottom layer (i.e., indicator layer) in the comprehensive evaluation system with some definite value in their calculations, and thus, the final results are also definite values, ignoring the uncertainty of each element in the comprehensive evaluation system. Methods 5–6 are dominated by linguistic variables,
2. Introduction of the Cloud Theory

2.1. Proposal of Membership to the Cloud. The fuzzy set theory, first proposed by L. A. Zadeh, has effectively dealt with many real-life fuzzy phenomena and problems since its inception. The key and core of fuzzy set theory is to determine the degree of membership through the membership function, assuming that both fuzzy and nonfuzzy sets have their corresponding "membership function", and then, the function image of fuzzy set is generally a smooth continuous curve, and the "function" image of the nonfuzzy set is a segmented straight line. The difference between the two is illustrated in Figure 1.

At the same time, in the field of waterway ecological evaluation, there is a lack of application of concepts such as the cloud theory and membership cloud. As a model that can represent object uncertainty with quantitative values, this paper tries to apply it to waterway ecological evaluation and analyze the characteristics and applicability conditions of the integrated method of cloud model evaluation.

### Table 1: Summary of evaluation methods.

| No | Method                                      | Application examples or features                                                                 |
|----|---------------------------------------------|---------------------------------------------------------------------------------------------------|
| 1  | Traditional composite index method          | Li, T. et al. [10] established a hierarchical evaluation system and used the combined weighting  |
|    |                                             | method to evaluate it comprehensively                                                            |
| 2  | Fuzzy synthesis                             | Wu, Y. et al. [11] have conducted research studies on spatiotemporal variations of a small        |
|    |                                             | catchment by using the fuzzy comprehensive method                                               |
| 3  | Gray clustering method                       | Chang, W. et al. [12] conducted research studies of the river waterway grade division based on    |
|    |                                             | the gray system theory [12, 13]                                                                  |
| 4  | Possibility distribution                     | Included in fuzzy mathematics, it could forecast how things change and are suitable for           |
|    |                                             | representation and measurement of a small amount of data [8, 9]                                  |
| 5  | Hesitant fuzzy linguistic term set           | The ambiguity of the elements is preserved; an ordered and consecutive subset of the linguistic    |
|    |                                             | term is set for a linguistic variable [4, 5]                                                     |
| 6  | Proportional hesitant fuzzy linguistic term set | Compared with HFLTS, it would consider the linguistic terms and corresponding proportional      |
|    |                                             | information simultaneously [4, 5]                                                                |
| 7  | Cloud model synthesis method                 | Combines the vagueness and randomness in qualitative concepts and transforms them into            |
|    |                                             | quantitative expressions [6]                                                                     |

which retain the ambiguity of the elements and are less precise than numerical variables.

Compared with the abovementioned six methods, the cloud model synthesis has the following characteristics.

(1) The data sources of the indicators are applicable to the cloud model synthesis method regardless of whether they are expert scores or objective data, and the scope of application is more comprehensive.

(2) The numerical characteristics of the cloud model are easy to understand and easy to calculate, but the data for each indicator should be at least two, and the more the conditions allow, the more accurate the calculated numerical characteristics of the indicators are portrayed.

(3) The biggest difference with other methods is that the cloud droplet diagram determined by different numerical features is a metric rather than a number for each element in the comprehensive evaluation system, and the uncertainty of the elements is retained in the calculation process.

At the same time, in the field of waterway ecological evaluation, there is a lack of application of concepts such as the cloud theory and membership cloud. As a model that can represent object uncertainty with quantitative values, this paper tries to apply it to waterway ecological evaluation and analyze the characteristics and applicability conditions of the integrated method of cloud model evaluation.

As we can see from Figure 1, the proposed fuzzy set membership function transforms the fuzzy problem into a curvilinear functional relationship between concept and membership degree in one-to-one correspondence. By means of the membership function, we can calculate the value of the membership degree corresponding to any element in the thesis domain. Fuzzy problems seem to be intuitively incorporated into concrete and precise mathematical categories, but can this method fully and accurately describe all fuzzy problems in reality? In [10], a similar life example is mentioned, where the membership of picture A to the “nice picture” is 0.247 and that of picture B to the “nice picture” is 0.494. Based on this example, we can conclude that the following two conclusions can be drawn:

(1) Since B has a greater membership with the “nice picture” than A, picture B looks better than picture A.

(2) 0.494 is twice as much as 0.247, and picture B is twice as well as picture A.

Obviously, conclusion (2) is not very realistic. Human subjective consciousness is very often a qualitative concept with blurred boundaries, and excessive precision at this point is just doing useless work. We just need to know that picture B looks better than picture A, that is enough. Moreover, people’s aesthetics of pictures (judging criteria) will also fluctuate with various factors (such as age, mood, weather, temperature, humidity, etc.), so the degree of membership will also fluctuate but not drastically. There is always a value that tends to be stable.

Through the abovementioned examples, the membership function exposes the defect of excessively “precise” fuzzy problem. The uncertainty in reality has two connotations: fuzziness and randomness. Based on this, academician Deyi Li proposed the concept of the membership cloud and developed the cloud theory, which combines the vagueness and randomness in qualitative concepts and transforms them into quantitative expressions and can also transform precise quantitative data into appropriate qualitative concepts.
Digital Characteristics of Cloud Belonging. The concept of the membership cloud is proposed on the basis of the membership function, so the definition of the membership cloud is also obtained on the basis of the membership function. Improving the number specified in the definition of the membership function in the interval \([0,1]\) to a random number with stable tendency (expectation value) is the key and core of the membership cloud, which is also called the membership cloud model or cloud model, and the theory developed based on this model is called the cloud theory.

The image and numerical features of the cloud model are shown in Figure 2, where the horizontal coordinate is a particular rubric in the language evaluation set and the vertical coordinate is the membership corresponding to this rubric. Each individual point on the graph is called a cloud droplet, and the set of all cloud droplets constitutes the complete cloud model. In daily life or scientific research, a large number of fuzzy problems obey normal or approximately normal distributions, so the normal distribution is chosen as a typical cloud model distribution to study. The normal cloud model has three numerical characteristics, which are: Expected value \((Ex)\), which indicates the quantitative value that best fits a qualitative concept; entropy \((En)\), which indicates the size of the range of values that can be accepted by the qualitative concept in the domain space and is a measure of the either-or nature of the qualitative concept [13, 14], and more than 97% of all cloud droplets of the normal cloud fall in \([Ex-3En, Ex+3En]\), i.e., the “3En” law; and hyper entropy \((He)\), which indicates the degree of dispersion of entropy, the larger \(He\) is the more obvious the degree of dispersion of cloud drops. In addition, there is a cloud model covering the area within the boundary of the shape of the center \(G\), whose coordinates are \((Ex, \sqrt{2}/4)\).

According to the image and digital features, it can help to deepen the understanding of the cloud model:

1. In the cloud model, the membership degree is not the only determined value, but a random number following the law of normal distribution, which reflects the randomness of the transformation of the membership degree in the language evaluation set; the cloud drops are most dense around the expected value, and as the cloud drops extend to both sides, they turn out to be more and more dispersed, and the closer to the range boundary, the more dispersed they are, but they always do not disappear suddenly, which reflects the fuzziness of a certain rubric in the language evaluation set.

2. In the membership cloud model, it is meaningless to take out a particular cloud droplet individually for analysis. Although the cloud droplets are random in nature, all of them are generated within a certain range, and the overall shape and characteristics of the cloud model are limited by numerical features, which is a complete reflection of a certain qualitative concept when all of them form a whole.

Cloud Generator. The principle of a cloud generator is to transform the correspondence between digital features and cloud droplet map by a code or software. The cloud generator can be divided into a forward cloud generator and inverse cloud generator according to the generation order. The forward cloud generator outputs the corresponding cloud droplet map by determining the three digital features \((Ex, En,\, and\, He)\), while the inverse cloud generator does the opposite, see Figure 3. The cloud generators can be divided into one-dimensional cloud generators and two-dimensional cloud generators according to the number of dimensions, and the two-dimensional cloud generators are shown in Figure 4. The application of forward cloud
2.4. Principle of Cloudification of Objective Data and Artificial Scoring Variables. The process of generating a cloud droplet diagram from a certain type of variables through a forward cloud generator is called cloudification. Since the cloud generator is currently available as a tool, the essence of cloudification changes to solve the numerical characteristics of the variables (Ex, En, and He). The objective data variables and the numerical characteristics of human scoring variables are solved in different ways, so they need to be explained separately.

2.4.1. Numerical Feature Solving for Objective Data Variables. As a certain parameter of a certain mechanical equipment, it can determine a specific value at a certain point in time. If the parameter has upper and lower limits, such as \( I \in (C_{\text{min}}, C_{\text{max}}) \), the numerical characteristics are calculated using the following formula [16]:

\[
\begin{align*}
\text{Ex} &= \frac{C_{\text{min}} + C_{\text{max}}}{2}, \\
\text{En} &= \frac{C_{\text{max}} - C_{\text{min}}}{6}, \\
\text{He} &= k.
\end{align*}
\]

Among them, \( C_{\text{min}} \) and \( C_{\text{max}} \) are the upper and lower limits of the variable change, and \( k \) is a constant, adjusted according to the uncertainty of the variable.

2.4.2. Solving the Numerical Characteristics of Artificial Scoring Variables. As the human-made scoring variables cannot directly obtain objective data, they are usually assigned by several experts based on the comments of the language evaluation set. Assuming that a certain variable is scored by \( n \) different experts, the numerical characteristics of this qualitative variable are calculated using the following formula:

\[
\begin{align*}
\text{Ex} &= \frac{1}{n} \sum_{i=1}^{n} x_i, \\
\text{En} &= \sqrt{\frac{n}{2}} \sum_{i=1}^{n} |x_i - \text{Ex}|, \\
\text{He} &= \frac{\sum_{i=1}^{n} (x_i - \text{Ex})^2}{n - 1} - \text{En}^2.
\end{align*}
\]

3. Establishment of the Cloud Model for Ecological Evaluation of the Jingjiang Waterway

In the current research results on the ecological evaluation of waterways, the most mainstream method regarding the step of constructing a comprehensive evaluation system is based on the decomposition idea of hierarchical analysis, which breaks down the evaluation objectives layer by layer and finally forms a tree structure with three to five layers of elements [17–20].

3.1. Determination of Evaluation Objects and System. The Jingjiang section is located in the middle reaches of the Yangtze River, starting from Zhicheng and ending at Chenglingji, with a total length of about 347.2 km. According to the degree of meandering of the river, the Jingjiang section can be divided into the upper Jingjiang and the lower Jingjiang with the mouth of the Ouchi as the boundary. The Jingjiang River section is located in the Yangtze River Economic Belt and the economy along the river has developed rapidly in recent years. The demand for waterway transportation has become increasingly strong, and the problem of insufficient navigation and transportation capacity of the Jingjiang Waterway has become more and more obvious. To solve this problem, the first phase of the Jingjiang Waterway Improvement Project was launched in 2013 and completed at the end of 2015. The Jingjiang Waterway before the renovation from 2011 to the end of 2015 was selected as the evaluation object, and refers to the Jingjiang Ecological Waterway Evaluation Index System constructed by Tianhong Li and others in the literature [10]. The system is divided into target layer A and functional layer. A total of 18 indicators are selected for B and indicator level C (see Table 3 for expert scores). Relying on this evaluation system, based on the new perspective of cloud theory, it is believed that each element (including objectives, functions, and indicator layers) is random and ambiguous; the membership cloud model is used to realize the transformation between uncertainty and certainty.

3.2. Weight Determination. The process of calculating and determining the indicator weights is also known as an assignment. Different methods of calculating weights lead to different assignment results. The essence of the subjective
assignment is the experience or human judgment of experts in the field, while the essence of objective assignment is to explore the information contained in the data itself. Both subjective and objective empowerment have their inevitable defects or limitations of application, while combined empowerment can make the two complement each other, so it is more widely used. For example, the combination of assignment is based on the multiplicative synthesis principle and game theory ideas [10], and the combination of multiobjective weight coefficients [21]. In order to better combine subjectivity and objectivity as well as qualitative and quantitative characteristics, the following formula is considered to determine the weights of indicators [22].

$$
\omega_i = \begin{cases} 
\frac{1}{2} + \frac{\sqrt{-2\ln [ 2(i-1)/n ]}}{6}, & 1 < i \leq \frac{n+1}{2}, \\
\frac{1}{2} - \frac{\sqrt{-2\ln [ 2-2(i-1)/n ]}}{6}, & n+1 < i \leq n.
\end{cases}
$$

In the formula, \( i \) is the queuing level of indicators under the same functional level, \( i \) can take the same value to represent the same degree of importance, \( \omega_i \) is the weight before normalization of the indicators, when \( i = 1 \), let \( \omega_1 = 1 \), and \( n \) is the number of indicators.

From the abovementioned formula, the weights between the levels are as follows: Table 2 and 3, Figure 5 and 6.

3.3. Cloud Scale for Waterway Ecological Evaluation. According to the expert score, the evaluation language set could determine to be “inferior, poor, medium, well, and excellent,” and the corresponding scores are 1, 2, 3, 4, and 5. In order to reflect the ambiguity of these five qualitative concepts and boundary between each other, \([1, 2]\) is defined as the range of the concept of “inferior”, \([1, 3]\) is the range of the concept of “poor”, \([2, 4]\) is the scope of the concept of “medium”, \([3, 5]\) is the scope of the concept of “well”, and \([4, 5]\) is the scope of the concept of “excellent”. The interval has upper and lower limits, so the cloud drop diagram of the abovementioned five evaluation terms can be obtained by formula (1), as shown in Figure 7.

3.4. Determination of Digital Features. As can be seen from section 1, regardless of the type of indicator data, whether objective or expert scored, it can be “cloudification” to form a cloud-drop diagram using the membership cloud model based on the corresponding formula, which is essentially a number of sets of indicator data to determine the numerical characteristics. The numerical characteristics are quantitative portrayals of the overall shape and distribution of the corresponding cloud drops.

The calculation steps of numerical features adopt a layer-by-layer approach, first by calculating the numerical features of each indicator within the indicator layer C according to the expert scoring, then calculating the numerical features of each function within the function layer B by the relevant formula, and finally arriving at the numerical features of the target layer A. The schematic diagram of the calculation steps is shown in Figure 8.

3.4.1. Index Layer. Each specific indicator in the indicator layer of the evaluation system is an artificial scoring variable, and the assigned values are shown in Table 4. The Jingjiang waterway for the time period from 2011 to 2015 is considered as a whole, which includes the time series of 2011, 2014, and 2015. Unlike the objective data based on the time series or subjective data based on the scores of experts in other studies, after understanding the essence of equation (2), it can be applied to the calculation of numerical characteristics based on the subjective data of the time series, with the difference that the calculation results reflect the average situation of the evaluation target in a certain time period, rather than the combined situation of the evaluation target based on the scores of experts at a certain point in time. The difference is that the calculation results reflect the average situation of the evaluation target in a certain time period, rather than the situation of the evaluation target at a certain time point based on the combined scores of experts. Based on the abovementioned analysis and combined with the experts’ scores, the numerical characteristics of the 18 indicators can be obtained according to formula (2) as shown in Table 5.

3.4.2. Functional Layer. The digital feature of each element in the functional layer B is based on the digital feature calculated in the indicator layer C. The calculation formula is as follows:

$$
\begin{align*}
Ex & = \frac{\sum_{i=1}^{n} E_{xi} \cdot \omega_i}{\sum_{i=1}^{n} \omega_i}, \\
En & = \frac{\sum_{i=1}^{n} \omega_i^2 \cdot En_i}{\sum_{i=1}^{n} \omega_i^2}, \\
He & = \frac{\sum_{i=1}^{n} \omega_i^3 \cdot He_i}{\sum_{i=1}^{n} \omega_i^3}.
\end{align*}
$$

Among them, \( \omega_i, E_{xi}, En_i, \) and \( He_i \) are the normalized weight, expected value, entropy, and super entropy of index \( i \) under the same function. Combining the abovementioned index layer-functional layer weights and expert scoring conditions, formula (4) is used to calculate the numerical characteristics of the 7 elements in the functional layer, as shown in Table 6 below.

3.4.3. Target Layer. From the normalized weight data of the functional layer-target layer in Table 1, combined with the numerical characteristics in Table 5, the same formula (4) can be used to obtain the numerical characteristics of the target layer A as \((3.797, 0.493, 0.156)\).
4. Results and Model Analysis

Since there are 18 indicators in the indicator layer C, the three scoring values of indicators C9, C12, C13, and C17 have not changed, the two numerical characteristics of En and He are 0 and the cloud drop diagram cannot be generated, and the analysis of a single indicator is less meaningful. So, this paper only analyzes the calculation results of the functional layer and the target layer and proceeds in the order of the first target layer A and then the functional layer B.

4.1. Target Stratus Cloud Drop Map. According to the digital features of the target layer A (3.797, 0.493, and 0.156), a one-dimensional forward cloud generator is used to generate a cloud drop map and place it on the cloud scale determined in section 2.3, as shown in Figure 9. It can be seen from Figure 9 and the digital characteristics that the entropy and super-entropy of the target layer are relatively large; it indicates that the ambiguity and randomness are relatively large. If the number of expert scores for each individual index can be increased, the ambiguity and randomness can be reduced. The expected value is 3.797, the average score of the Jingjiang waterway’s ecological performance during the period from 2011 to 2015 is 3.797, which is between “medium” and “well” and is closer to “well”, compared to the literature [10], the calculation results of (3.40 in 2011, 3.80 in 2014, 4.17 in 2015, and an average of 3.79), the difference from its average is almost zero.

4.2. Functional Stratum Cloud Drop Diagram. According to the calculation results of the digital features of the functional layer, the one-dimensional forward cloud generator is used to generate cloud drop diagrams and placed on the cloud scale determined in section 2.3, as shown in a to g in Figure 10. It can be seen from Figure 10 that the expected value, entropy, and super-entropy of the seven functions are different. The highest score (expected value) is 4.667 and the lowest is 3.125, corresponding to the self-purification function and the landscape entertainment function, respectively. The entropy and super-entropy values of the water supply function in the cloud drop diagram corresponding to the 7 functions are relatively the lowest, and the cloud drop is the most concentrated compared to other functions; it indicates that the degree of ambiguity and randomness of this function is the lowest. The entropy and super-entropy of water and flood discharge, sand transportation, self-purification, the ecological, and landscape entertainment functions are medium, while the cloud drops are relatively scattered. It indicates that the degree of ambiguity and randomness of the scores of these functions is average. The entropy and super-entropy of the shipping functions are relatively large, and the cloud drops are the most scattered, the degree of ambiguity and randomness is more serious.

Combining the calculation formulas of entropy and super-entropy in formula (2), it can be concluded that during the time period from 2011 to 2015, the water supply function of the Jingjiang waterway has relatively the smallest fluctuations. On the other hand, the degree of change in

### Table 2: Weights from the functional layer to the target layer.

| Function   | Shipping B₁ | Water delivery and flood release B₂ | Sand transport B₃ | Water supply B₄ | Self-purification B₅ | Ecology B₆ | Landscape entertainment B₇ |
|------------|-------------|------------------------------------|------------------|-----------------|----------------------|-----------|-----------------------------|
| Sequence i| 4           | 1                                  | 5                | 3               | 5                    | 2         | 5                           |
| Weights Wᵢ| 0.593       | 1                                  | 0.407            | 0.676           | 0.407                | 0.764     | 0.407                       |
| Normalized weight ωᵢ | 0.139 | 0.235 | 0.096 | 0.159 | 0.096 | 0.180 | 0.096 |

### Table 3: Weights from the indicator layer to the function layer.

| Indicator and code | Sequence i | Weights Wᵢ | Normalized weight ωᵢ |
|--------------------|------------|-------------|----------------------|
| Aids to navigation facilities perfection rate C₁ | 2 | 0.696 | 0.278 |
| Navigable water depth guarantee rate C₂ | 1 | 1.000 | 0.400 |
| Water system connectivity C₃ | 3 | 0.500 | 0.200 |
| Total number of ship accidents C₄ | 4 | 0.304 | 0.122 |
| Maximum flood discharge capacity C₅ | 1 | 1.000 | 0.500 |
| Compliance rate of flood control engineering measures C₆ | 1 | 1.000 | 0.500 |
| Change rate of sediment water consumption C₇ | 1 | 1.000 | 1.000 |
| Drinking water safety guarantee rate C₈ | 3 | 0.350 | 0.175 |
| Water resources development and utilization rate C₉ | 1 | 1.000 | 0.500 |
| Water quality compliance rate in functional areas C₁₀ | 2 | 0.650 | 0.325 |
| DO C₁₁ | 1 | 1.000 | 1.000 |
| Satisfaction of ecological water demand C₁₂ | 3 | 0.500 | 0.156 |
| Wetland retention rate C₁₃ | 2 | 0.696 | 0.218 |
| Fish biological integrity index C₁₄ | 1 | 1.000 | 0.313 |
| Cherish the survival of species C₁₅ | 1 | 1.000 | 0.313 |
| Landscape diversity index C₁₆ | 1 | 1.000 | 0.500 |
| Vegetation coverage C₁₇ | 3 | 0.350 | 0.175 |
| Width of the riparian buffer zone C₁₈ | 2 | 0.650 | 0.325 |
entertainment function is average, while the change in shipping function is relatively largest.

4.3. Analysis of Integrated Evaluation Results. It is attributed to the fact that the Jingjiang River waterway improvement project has improved the navigation standard of the waterway by excavating and improving the shallows that may affect the navigation safety. At the same time, the project has improved a series of waterway safety facilities such as beacons, thus promoting the overall condition of the
Figure 8: Calculation steps of the digital features of each layer of the evaluation system.

Table 4: Statistics on the scoring of 18 index experts.

|   | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| 2011 | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 |
| 2014 | 5 | 4 | 2 | 4 | 5 | 4 | 4 | 3 | 4 |
| 2015 | 5 | 5 | 3 | 4 | 5 | 4 | 4 | 5 | 4 |
| C10 | 0.152 | 0.152 | 0.000 | 0.152 | 0.152 | 0.152 | 0.000 | 0.152 | 0.152 |
| C11 | 0.557 | 0.557 | 0.000 | 0.557 | 0.557 | 0.557 | 0.000 | 0.557 | 0.557 |
| C12 | 3.333 | 4.667 | 5.000 | 2.667 | 2.333 | 3.333 | 4.000 | 2.333 | 3.333 |
| C13 | 0.557 | 0.557 | 0.000 | 0.557 | 0.557 | 0.557 | 0.000 | 0.557 | 0.557 |
| C14 | 0.557 | 0.557 | 0.000 | 0.557 | 0.557 | 0.557 | 0.000 | 0.557 | 0.557 |
| C15 | 0.152 | 0.152 | 0.000 | 0.152 | 0.152 | 0.152 | 0.000 | 0.152 | 0.152 |
| C16 | 0.369 | 0.152 | 0.152 | 0.066 | 0.152 | 0.111 | 0.140 | 0.152 | 0.152 |

The scoring data of experts in this table are all from the literature [10].

Table 5: Numerical characteristics of 18 indicators.

|   | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Ex | 4.667 | 4.000 | 3.667 | 4.667 | 3.667 | 3.667 | 3.667 | 4.000 | 4.667 |
| En | 0.557 | 0.836 | 0.557 | 0.557 | 0.557 | 0.557 | 1.114 | 0.000 | 0.000 |
| He | 0.152 | 0.549 | 0.152 | 0.152 | 0.152 | 0.152 | 0.304 | 0.000 | 0.000 |
| C10 | 0.152 | 0.152 | 0.000 | 0.152 | 0.152 | 0.152 | 0.000 | 0.152 | 0.152 |
| C11 | 0.369 | 0.152 | 0.152 | 0.066 | 0.152 | 0.111 | 0.140 | 0.152 | 0.152 |
| C12 | 3.878 | 4.167 | 3.667 | 3.725 | 4.667 | 3.279 | 3.125 | 3.125 | 3.125 |
| C13 | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 | 0.513 | 0.513 |
| C14 | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 | 0.513 | 0.513 |
| C15 | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 | 0.513 | 0.513 |
| C16 | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 | 0.513 | 0.513 |
| C17 | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 | 0.513 | 0.513 |
| C18 | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 | 0.513 | 0.513 |

Table 6: Numerical characteristics of each element in the functional layer.

|   | B1 | B2 | B3 | B4 | B5 | B6 | B7 |
|---|---|---|---|---|---|---|---|
| Ex | 3.878 | 4.167 | 3.667 | 3.725 | 4.667 | 3.279 | 3.125 |
| En | 0.709 | 0.557 | 0.557 | 0.241 | 0.557 | 0.407 | 0.513 |
| He | 0.369 | 0.152 | 0.152 | 0.066 | 0.152 | 0.111 | 0.140 |

The shipping function to a greater extent in a short period of time.

The landscape diversity and riparian buffer zone height among the indicators included in the landscape recreation function have improved more, by 33.3% and 49.6%, respectively, between 2011 and 2015. The introduction of ecological concepts into the channel improvement process, the combination of engineering and biological measures, and the use of a combination of ecosystem self-healing and artificially assisted techniques are important reasons for the improvement in ecological properties. By using a series of ecological improvement measures, studies have shown that the permeable framework area is able to form a certain degree of the ecosystem with a higher biodiversity relative to the unimproved traditional shore protection engineering structure. In a way, the implantation of ecological concepts has a positive effect not only on biodiversity and survival rate but also on the landscape recreation function of the river. In addition, the survival of cherished species has improved significantly, which in turn has led to a certain degree of improvement in ecological conditions between 2011 and 2015.

On the other hand, the self-purification capacity of water bodies and ecological functions have a close relationship; the clever use of ecological technology in the process of waterway remediation, in the long run, has a good positive effect on the deep oxygen dissolution (DO) of the water body, while the self-purification capacity of the water body such as deep oxygen dissolution (DO) can continuously restore the water ecological environment, which also has a positive long-term effect on ecological functions.

Although biological protection and ecological restoration techniques are adopted to a certain extent, it is difficult to avoid causing pollution to the water bodies, which will have different degrees of negative impacts on various functions of the water bodies and directly or indirectly reduce the comprehensive standards of ecological and water supply functions. Under the influence of multiple factors, the overall scores of ecological function and water supply function have changed relatively little before and after, among which the two indicators of water resources development utilization rate and functional area water quality compliance rate have changed minimally between 2011 and 2015, which is mainly due to the positive effect of ecological restoration work and self-purification ability of water bodies and the negative effect of engineering pollution fused with each other. With the completion of the remediation project in 2015, the overall situation will gradually improve.

The improvement in flood control capacity is mainly attributed to the establishment of a series of water transfer and storage projects, which have improved the flood control capacity and storage capacity of the middle reaches of the Yangtze River in general.

After analyzing the actual situation, it is found that the calculation results match with the cloud model synthesis method, which reflects from the side that the cloud model synthesis method can effectively reflect the actual situation of the project, and the cloud drop diagram formed after the comparison calculation can also visually reflect the changes and differences of different functions. In addition, using the traditional calculation method, the final calculated comprehensive score is 3.797, and the difference between the calculated results is 0.007, with a relative difference of 0.185%. The different methods lead to certain differences in the results, and when the evaluation content or framework is further improved, or the annual information is further refined, the calculation accuracy of the cloud model synthesis method will be improved, and the variability of the calculation results with the traditional method will increase.
Figure 9: Cloud drop diagram of the target layer and cloud ruler.

Figure 10: Continued.
5. Conclusion

The application of the integrated cloud model method to the ecological evaluation of waterways fills the gap in the research work on the application of the membership cloud model to the ecological evaluation of waterways, and the application of this theory leads to the following conclusions:

1. In the time period from 2011 to 2015, the overall condition of the Jingjiang River waterway has been improving, with the shipping function showing the greatest change, the water supply function, the least, and the general change of the water transfer and flooding, sand transfer, self-purification, ecology, and landscape recreation functions are in line with the fact that the Jingjiang River has undergone waterway improvement and ecological restoration within a short period of time;

2. The membership cloud model has the advantages of being applicable to both objective and subjective data. The cloud model synthesis method based on the membership cloud model retains the fuzziness and randomness of each element in the evaluation calculation process and finally uses the cloud drop diagram as the metric of each element in the evaluation system to effectively quantify the fuzzy problem, and at the same time, it has the characteristics of better retaining the fuzziness and randomness of the object itself compared with the traditional method of using numerical values as the metric.

6. Prospect

The application of the cloud model synthesis method in the ecological evaluation of waterways further enriches the research results related to the ecological evaluation of waterways and expands the application gaps of cloud models and membership clouds, which can be used as a reference for other work on the ecological evaluation of waterways. In the next research work, the overall framework and indicators of waterway ecological evaluation can be further improved and refined, which can improve the accuracy of the integrated cloud model method to a certain extent. In addition, further
attempts can be made to apply theories such as two-dimensional clouds.

**Data Availability**

Hyperlinks have been added to all references through which the reader can consult the corresponding material.

**Conflicts of Interest**

All authors of this paper declare that there is no conflict of interest in the content of the paper.

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