Research on the application of cloud modeling in the comprehensive evaluation of exploration effectiveness

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Abstract: In the comprehensive evaluation of exploration effectiveness, there are many indicators involved in it, the evaluation boundaries of the indicators are different, and the indicators are interrelated, quantifying the small amount of data is difficult, so it is necessary to adopt scientific and reasonable comprehensive evaluation methods to establish a comprehensive evaluation model of exploration effectiveness. In this paper, three representative evaluation methods are selected: fuzzy comprehensive evaluation, hierarchical analysis and TOPSIS method.Then we analyze advantages and disadvantages of the three methods, and on this basis, the cloud model is used to produce new evaluation index evaluation criteria, combined with the entropy weighting method to generate evaluation index weights, and establish a comprehensive evaluation method for exploration effectiveness. The new method has better adaptability to the less evaluation index data through case analysis.

1. Introduction

The comprehensive effect evaluation of exploration effectiveness can simultaneously assess the exploration effect of the previous stage and guide the direction of the next stage of work. At present, the comprehensive evaluation of exploration effectiveness in the XXX Basin is mainly based on the indicators of exploration success rate, exploration reserves and exploration cost, and there are fewer applicable comprehensive evaluation methods, which makes the evaluation standards of certain indicators different and the results deviate greatly. To address these problems, a research on the comprehensive effect evaluation method of exploration in the XXX Basin was carried out, the core indicators were screened out, the cloud model was used to establish the evaluation standard of the core indicators, and the weights of the core indicators were determined by combining the entropy weighting method and the hierarchical analysis method. The application results show that the method can quantitatively and scientifically evaluate the evaluation of exploration effectiveness in the XXX Basin, and can provide guidance for the follow-up exploration in the field.

2. Establishment of a comprehensive evaluation system for exploration effectiveness

The study established a systematic and diversified comprehensive evaluation index system for exploration effectiveness, including index elements in four dimensions: exploration, seismic, reserves and economy. The qualitative and quantitative analysis of the indicators and the establishment of an indicator screening model based on correlation theory and evidence theory were used to reduce the correlation between the indicators. Finally, according to expert opinions, indicators with strong correlation were selected and fused to form a multidimensional comprehensive evaluation index system of exploration effect including 19 secondary indicators, as shown in Figure 1.

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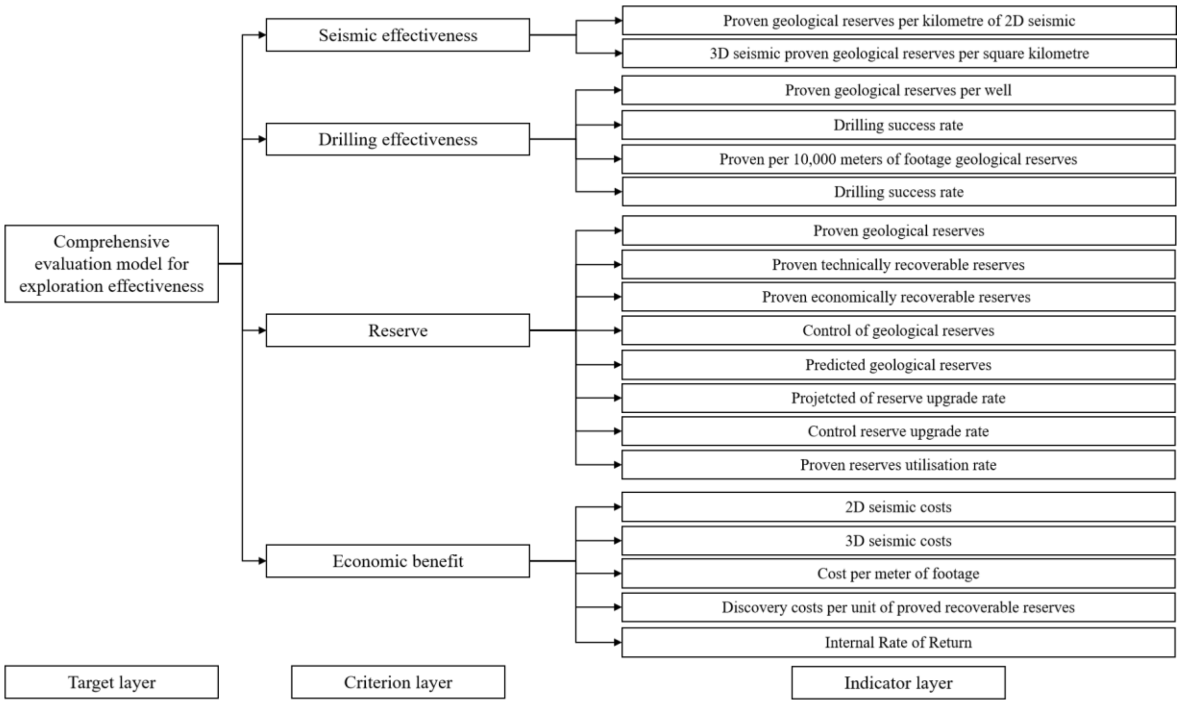

Figure 1 Comprehensive evaluation index system for exploration effectiveness

3. Introduction to comprehensive evaluation methods for conventional exploration effectiveness

3.1 Fuzzy comprehensive evaluation

As early as 1965, L.A. Zadeh, an American cybernetics expert [1], Fuzzy mathematics[2-8] is an important method for dealing with uncertainty and has been widely used in various fields. The fuzzy comprehensive evaluation method can carry out scientific and close to the actual quantitative evaluation of the fuzzy evaluation object, but the calculation is complicated, the determination of weights is subjective, and it is prone to hyper-fuzzy phenomenon when the indicator set is large. The evaluation result is a vector containing rich information, which can be further processed to get reference information. The hierarchical fuzzy evaluation method can be improved.

3.2 Hierarchical analysis[9-11]

Hierarchical analysis of the research object as a system, in accordance with the decomposition, comparative judgment, synthesis of the way of thinking for decision-making, and become an important tool for systematic analysis developed after the mechanistic analysis and statistical analysis.

Hierarchical analysis is an important tool in systems analysis, combining qualitative and quantitative methods in a concise and practical way. However, it cannot provide new solutions, has less quantitative data and more qualitative components, is complicated to calculate and difficult to determine the weights when there are too many indicators, and is more complicated to solve the eigenvalues and eigenvectors.

3.3 TOPSIS method[12]

TOPSIS is called the distance between superior and inferior solutions method, which takes the ideal solution as the reference standard, and derives the superiority or inferiority of the solution or the ranking of multiple solutions by comprehensively considering the distance of the indicators of the evaluation object from the ideal value. The disadvantage of the TOPSIS method is that it can only reflect the relative proximity within each evaluation object, and does not reflect the relative proximity to the ideal optimal program.

4. A New Approach to Integrated Evaluation of Cloud Modeling

The cloud model can reflect the fuzziness and randomness of the evaluated object, and can realize the mutual transformation between quantitative numerical values and qualitative concepts for real problems [13]. Compared to the methods in traditional mathematics that require precise numbers, cloud model system evaluation is more in line with the characteristics of most ambiguity problems in the real world. It is more objective and intuitive and therefore widely used [14].

4.1 Cloud Modeling Principles

Cloud model is a mathematical model of uncertainty for qualitative-quantitative conversion, the core of it is the mapping between qualitative and quantitative by constructing a cloud generator. The cloud model represents quantitative concepts through numerical features such as expectation (Ex), entropy (En) and super-entropy (He). Especially for the case where the amount of comprehensive evaluation data is small, the data can be generated by the cloud model for analysis.

Expectation (Ex) is both the point that best represents the concept and the best sample point for quantification.

Entropy (En) is a measure of conceptual uncertainty and a reflection of the fuzziness of the system.

Super-entropy (He) is the entropy of entropy, which not only reflects the thickness of cloud droplets, but also reflects the randomness of the system.4.2 Establishment of a new methodology for integrated evaluation of cloud models.

(1) Cloud generator

With a small number of samples, the conversion is achieved by the forward cloud generator, which obtains the determinism and cloud droplets from cloud digital features. Its principle is shown in Figure 2

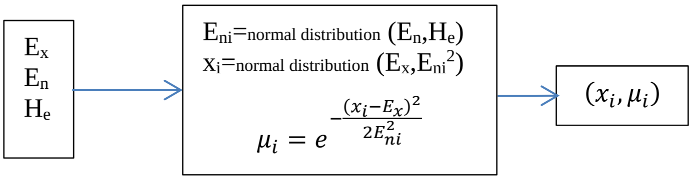

Figure 2 Positive cloud producer

The inverse cloud generator is the opposite of the forward cloud generator, and the distribution characteristics of the samples are obtained from the sample data obtained.

According to the principle of the cloud model generator, using the theory of normal distribution, the probability of each sample data is calculated by the following formula:

$$P(E_x, \sigma, x) = \frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{x} e^{-\frac{(t-E_x)^2}{2\sigma^2}} dt \qquad (1)$$

In this formula: σ^2--variance of the random variable;

(2) Indicator level thresholds

Table 1 Criteria for the grading of evaluation indicators (evaluated in terms of interval grading)

Level	**Threshold value**	**Estimation**
I	$\left[0, E_x - \frac{1}{2}E_n\right]$	Inferior
II	$\left[E_x - \frac{1}{2}E_n, E_x\right]$	Range
III	$\left[E_x, E_x + \frac{1}{2}E_n\right]$	Medium
IV	$\left[E_x + \frac{1}{2}E_n, E_x + E_n\right]$	Good
V	$[E_x + E_n, +\infty]$	Better

Indicator grading is usually based on experience and lacks a theoretical foundation. A common method is to use the cloud transformation idea to grade the indicators, determine the distribution characteristics of the indicators through the mathematical normal cloud model[15]and the inverse cloud generator, and set the threshold value of the evaluation indicators according to the probability interval of the evaluation samples. The method shown in Table 2 can solve the problem that the larger the evaluation sample value, the higher the probability as shown in Table 1.

Table 2 Improved criteria for grading evaluation indicators (evaluated on a probability scale)

Level	Positive indicator thresholds	Negative indicator thresholds	Estimation
I	$\left[0, P\left(E_x, \sigma, E_x - \frac{1}{2}E_n\right)\right]$	$\left[1, 1 - P\left(E_x, \sigma, E_x - \frac{1}{2}E_n\right)\right]$	Inferior
II	$\left[P\left(E_x, \sigma, E_x - \frac{1}{2}E_n\right), P(E_x, \sigma, E_x)\right]$	$\left[1 - P\left(E_x, \sigma, E_x - \frac{1}{2}E_n\right), 1 - P(E_x, \sigma, E_x)\right]$	Range
III	$\left[P(E_x, \sigma, E_x), P\left(E_x, \sigma, E_x + \frac{1}{2}E_n\right)\right]$	$\left[1 - P(E_x, \sigma, E_x), 1 - P\left(E_x, \sigma, E_x + \frac{1}{2}E_n\right)\right]$	Medium
IV	$\left[P\left(E_x, \sigma, E_x + \frac{1}{2}E_n\right), P(E_x, \sigma, E_x + E_n)\right]$	$\left[1 - P\left(E_x, \sigma, E_x + \frac{1}{2}E_n\right), 1 - P(E_x, \sigma, E_x + E_n)\right]$	Good
V	$[P(E_x, \sigma, E_x + E_n), P(E_x, \sigma, +\infty)]$	$[1 - P(E_x, \sigma, E_x + E_n), 0]$	Better

The probability of the indicator being in different evaluation levels can be obtained by taking the sample indicator value x_i into the forward cloud generator. This in turn yields the evaluation value P, and then combine that with the weight W, can yield the sample composite evaluation value R.

$$R = \sum_{i=1}^{n} W_i P_i \tag{2}$$

The weight indicators are obtained by the entropy weighting method, and the comprehensive evaluation of exploration effectiveness can be obtained by ranking the comprehensive evaluation values.

5. Example analysis

This paper carries out a comprehensive evaluation based on the exploration effectiveness data of different gas reservoir fields in XXX Basin from 1990 to 2022. The evaluation index and sample data are shown in Table 3, the cloud model is used to generate 500 sample data, take two-dimensional proved geological reserves per kilometer as an example, and the generated sample data are shown in Figure 3, sort according to the probability of the sample data can obtain a one-way evaluation, as shown in Table 4, the use of the mature entropy weight method to determine the weight vector of each index is: W=(0.108151364, 0.109712364, 0.082358364, 0.082430364, 0.066037364, 0.055065364, 0.098966364, 0.094864364, 0.095813364, 0.105181364, 0.101419364)

According to the formula (2) to obtain the evaluation of the comprehensive value table, shown in Table 5, from the total score ranking, the exploration effectiveness from good to bad are: Xhujiahe, Feixianguan, Changxing Formation, Qixia Formation, Maokou Formation.

Table 3 Table of exploration sample data for each layer in XXX basin

Reservoir unit name	unit	Jurassic system	Xujiahe	Leikou slope	Carboniferous system	Longwangmiao Formation	Sinian system
2D seismic per kilometer Proven Geological Reserves	billion cubic meters /km	0.0863	0.1111	0.01541	0.0728	0.221	0.29366
3D seismic per square kilometer Proved Geological Reserves	billion cubic meters / km^2	0.3762	1.51774	0.7181	6.59	0.341	0.609
Proven per 10,000 meters of footage geological reserves	billion cubic meters/ten thousand meters	46.16	53.61	14.3	19.74	229.7	93.81
Drilling success rate	%	64.8	58.5	35	41.4	75	65.4
Proven technically recoverable reserves	billion cubic meters	1001.57	3217.381	166.061	2054.613	3164.43	5052
Proven geological reserves	billion cubic meters	3147.43	8330.72	425.75	3065.34	1492.04	14525.49
Control of reserve upgrade rate	%	93	65.4	84.3	78.1	100	99.3
Proven reserves utilization rate	%	91.0398	59.91459	100	98.989	97.5997	59.88

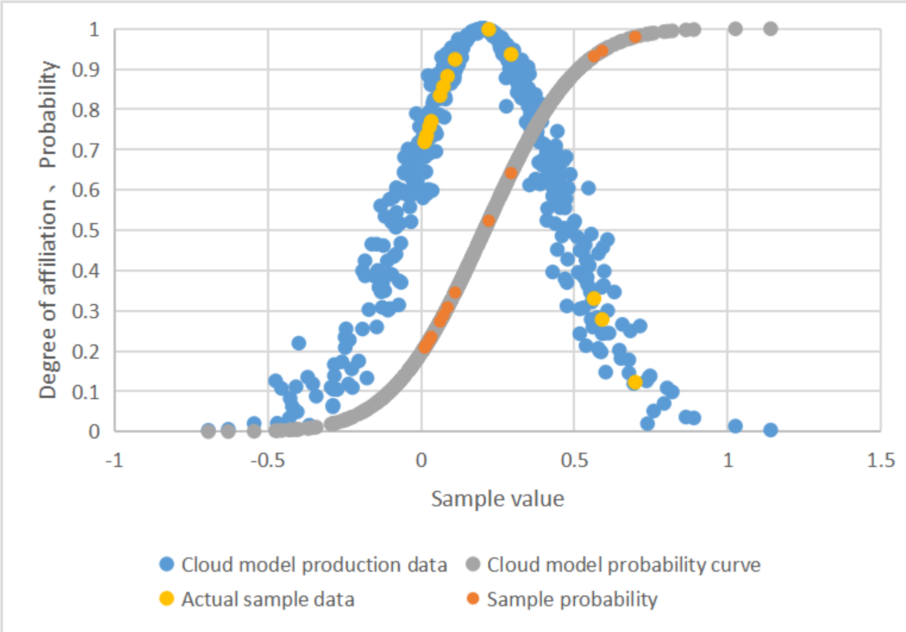

Figure 3 Schematic diagram of cloud model generation curve

Table 4 Evaluation of 2D Proven Geological Reserves per Kilometer

Name	valid value	degree of affiliation	probability	owning interval
Maokou group	0.011728	0.719076	0.208355	0
Leikou slope	0.015416	0.72802	0.21279	0
Changxing group	0.018418	0.735255	0.216441	0
Qixia group	0.027298	0.756385	0.227451	0
Jialing River	0.033228	0.770245	0.234975	0
Feixian Pass	0.062046	0.834023	0.273426	0
Carboniferous system	0.072825	0.856035	0.288568	0
Jurassic system	0.086287	0.881843	0.308016	1
Xujiahe	0.111084	0.923794	0.345256	1
Longwangmiao group	0.220782	0.998266	0.52349	2
Sinian system	0.293661	0.936383	0.64154	2

Table 5 Comprehensive evaluation results table

	Sinian system	Longwangmiao group	Xujiahe	Carboniferous system	Feixian Pass	Changxing group	Jurassic system	Jialing River	Qixia group	Leikou slope	Maokou group
Proven geological reserves per kilometer of 2D seismic	0.638821	0.52302	0.348202	0.292397	0.277459	0.221081	0.311562	0.239449	0.231996	0.217459	0.213056
3D seismic per square kilometer Proved Geological Reserves	0.389406	0.323439	0.625547	0.999881	0.310471	0.27182	0.331846	0.471183	0.274325	0.417335	0.254075
Proven geological reserves per well	0.687903	0.976748	0.291832	0.232727	0.557007	0.327728	0.240285	0.214755	0.310783	0.204765	0.176444
Proven geological reserves per 10,000 meters of footage	0.739193	0.998736	0.474908	0.25594	0.801335	0.42176	0.423336	0.278624	0.321501	0.22628	0.168832
Drilling success rate	0.410079	0.521591	0.333721	0.17591	0.856067	0.993627	0.403253	0.671524	0.875691	0.131629	0.24398
New trap drilling Success rate	0.132269	0.990415	0.280071	0.265705	0.367797	0.386036	0.731727	0.811164	0.270452	0.081616	0.825112
Proven technically recoverable reserves	0.857346	0.629542	0.637333	0.458912	0.393228	0.24987	0.303348	0.230014	0.214679	0.200066	0.209373
Proven geological reserves	0.951918	0.292525	0.730209	0.390016	0.337816	0.22737	0.395367	0.242992	0.302665	0.233672	0.244354
Control of reserve upgrade rate	0.850059	0.861816	0.07034	0.297031	0.774976	0.255004	0.715741	0.511864	0.051683	0.47054	0.861816
Proven reserves utilization rate	0.277606	0.784581	0.278058	0.799124	0.150398	0.717795	0.708213	0.809328	0.043723	0.809328	0.809328
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totals	0.636014731	0.629713167	0.479936696	0.442873925	0.48949224	0.43163397	0.377807937	0.368499419	0.344980227	0.302209456	0.299016857

6. Conclusion

(1) Combined with the exploration results of XXX Basin, 19 key indicators are selected to form the XXX Basin Exploration Effectiveness Evaluation Indicator System, which is capable of comprehensively evaluating the exploration effectiveness of XXX Basin in terms of exploration, seismicity, reserves and economy.

(2) The cloud modeling method is used to more reasonably reflect the importance of each index in the XXX Basin under the circumstance of fewer sample data.

(3) Utilizing cloud model probability for comprehensive evaluation avoids the problem of index grading, and the results show that this method can comprehensively evaluate the exploration effectiveness and provide guidance for the direction of subsequent exploration in the field.

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