Case Study

Suitability evaluation of land reclamation as arable land in coal mining area based on catastrophe theory

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Abstract

Niumasi Coal Mine (located in Shaodong City, Hunan Province, China) was an important producing area of high-quality coking coal in Hunan Province. After large-scale mining of underground coal seams in the area, there has been a large area of surface subsidence and serious land damage. The damaged land urgently needs to be reclaimed. In this paper, the suitability of land reclamation as arable land in Niumasi coal mining area was comprehensively evaluated, and a catastrophe progression model (CPM) for the suitability evaluation of land reclamation as arable land in coal mining area was put forward with the help of the catastrophe theory. The suitability classification was divided into four grades: suitable, moderately suitable, less suitable, and unsuitable. Eleven parameters including terrain slope grade, effective thickness of soil layer, soil parent materials, soil contamination, organic content, alkali hydrolyzable nitrogen (N), available phosphorus (P), available potassium (K), ground collapse, land destruction extent, and conditions of irrigation and drainage were selected as evaluation indicators, and the classification standards of each evaluation indicator was determined. Using MATLAB software to generate a total of 1200 samples (300 samples per level) between the arrays corresponding to each level of standards according to the normal distribution principle, of which 800 samples were used as training samples to establish the catastrophe progression criteria, and 400 samples as test samples to verify the reliability of the proposed criteria. According to CPM, the suitability status of the four land samples in Shuijingtou working area of Niumasi Coal Mine were identified. The evaluation results show that the suitability level of three lands are all 'Moderately suitable', and one sample is 'Unsuitable'. Mining coal has the greatest damage to paddy fields, followed by the dry farming lands and vegetable lands, and the least impact to the forest lands. CPM can not only evaluate the suitability of land reclamation, and comprehensively compare the suitability degrees, but also can assess the damage degree of coal mining to different types of lands. This paper aims to provide a new idea for the study of quantitative evaluation methods of land reclamation suitability. The results have reference and guiding significance for the comprehensive evaluation of the suitability of land reclamation as arable land in coal mining areas.

Article highlights

- The catastrophe theory can be used to evaluate the suitability of land reclamation as arable land in coal mining area. A catastrophe progression model for the suitability evaluation of land reclamation as arable land in coal mining area was put forward.
- Using MATLAB software to establish the catastrophe progression criteria according to the normal distribution principle.
- The results have reference and guiding significance for the comprehensive evaluation of the suitability of land reclamation as arable land in coal mining areas.

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Keywords Land reclamation · Suitability · Evaluation · Catastrophe theory · Catastrophe progression method (CPM)

1 Introduction

The exploitation of mineral resources not only promotes economic development, but also sometimes destroys land resources [1–5]. In addition, it also has adverse effects on the ecological environment, as well as the physical and chemical properties of soils [6–14]. Mining has caused land destruction and desolation, which is a serious problem universally existing in many countries in the world. Soil is a fragile and limited resource, which needs thousands of years to form, and it is not renewable in human lifespan [15]. Land reclamation is one of the effective means to deal with the damaged lands. Reclamation plays an essential role for integrated and sustainable post-mining land use [16]. The restoration of ecological functions through reclamation of the mined area can stimulate the soil formation and initiate the bio-activities on the surface of the disposal sites [17]. Land reclamation can restore the damaged land in mining area to a safe, stable and pollution-free land form [18], thus significantly improving the land type of the mining area and reducing the amounts of damaged lands [19]. Mine land reclamation, also known as land reclamation, is an activity to take remediation measures to restore the land damaged due to excavation, collapse, etc. in the process of mine construction and production in accordance with the requirements of laws and regulations on mineral resources and land management. Land reclamation is the method and process of surveying, planning, filling, regulating, developing and utilizing the land abandoned due to mining [20]. By improving the quality and condition, the damaged lands can be restored to a usable state [21]. However, it is difficult to be restored to its original state absolutely for any kind of destroyed land resource. In general, only the reclamation standard adapted to the local environmental conditions can be formulated, and the damaged land can be reclaimed and transformed into another land resource with new suitability. The suitability evaluation of land reclamation is the premise and basis for carrying out land reclamation by scientific means.

The suitability evaluation of land reclamation is to comprehensive assess the suitability of a certain utilization mode and utilization degree after land reclamation according to the natural, economic and social attributes of the land to be reclaimed [22]. The aim of the suitability evaluation of land reclamation is to determine the best utilization scheme of the land to be reclaimed under the conditions of economic feasibility and reasonable technology, and achieve the coordinated development of sustainable land utilization and ecological environment protection [23]. Suitability assessment is a key step in the reclamation planning of the damaged lands in mining areas to ensure the sustainability of land use after mining [24]. At present, the suitability evaluation of mine land reclamation in China is mainly based on the relevant contents of TD/T 1036–2013 [25]. The standard divides the evaluation results of land reclamation suitability into four grades: the most suitable, the medium suitable, the less suitable and the unsuitable. The evaluation indexes mainly include the terrain slope, soil quality, irrigation and drainage conditions and pollution degree. However, the standard also has some shortcomings, such as the difficulty in quantifying indicators such as soil quality and irrigation and drainage conditions, and the lack of assessment content of the land damage level, resulting in leading to the incorrect determination of the land reclamation suitability level of a land reclamation unit in the actual assessment, which is not conducive to the later development of land reclamation work.

Shaodong City situated in Hunan Province, China, is rich in coal resources. Mining coal not only promotes the local economic development, but also damages a lot of land resources. In this paper, the suitability of land reclamation as arable land in Niumasi coal mining area of Shaodong City was comprehensively evaluated. The suitability classification was divided into four grades: suitable, moderately suitable, less suitable, and unsuitable. According to three factors including land quality, soil nutrients and engineering suitability in the reclamation area, selecting eleven parameters as evaluation indicators including terrain slope grade, effective thickness of soil layer, soil parent materials, soil contamination, organic content, alkali hydrolyzable nitrogen (N), available phosphorus (P), available potassium (K), ground collapse, land destruction extent, and conditions of irrigation and drainage, and determining the classification standards of each evaluation indicator. Using MATLAB software to generate a total of 800 samples (200 samples per level) between the arrays corresponding to each level of standards according to the normal distribution principle, of which 600 samples were used as training samples to establish the catastrophe progression criteria as per the catastrophe theory, and 200 samples as test samples to verify the reliability of the proposed criteria. This paper aims to provide a new idea for the study of quantitative evaluation methods of land reclamation suitability.

2 Study area

The study area is Niumasi coal mine, which located in Shaodong city of Hunan Province, China. Its landform is mainly micro hilly area, and the soil is mainly clayey soil. Niumasi mining area was an important producing area of high-quality coking coal in Hunan Province. There were mainly four working areas, including Midoushan, Shuijingtou, Mayuan and Tiejishan. The total area was about 36 km^2, and the coal resources are now nearly exhausted. After the deep and large-scale mining of underground coal seams in this area, the surface subsidence was characterized by large-area, continuous and gentle in space, and the houses in the coal mine living area were cracked and deformed to varying degrees. The site surface settlement was basically stable without obvious collapse. Shaodong City land and resources administration entrusted Xiangdong mineral geological survey institute (situated in Changsha City of Hunan Province, China) to conduct a comprehensive survey of the land damage caused by coal mining in this mining area, and make a comprehensive evaluation of the suitability of reclamation for arable land based on TD/T 1036–2013 [25] (Fig. 1).

3 Methodology

3.1 Evaluating indicator

In the suitability evaluation of mine land reclamation, the evaluation indicators of the Chinese standard TD/T 1036–2013 [25] include the terrain slope, soil quality, irrigation and drainage conditions and pollution degree. Among them, the indicators such as soil quality, irrigation and drainage conditions are difficult to quantify. Moreover, the standard lacks evaluation indicators for assessing the degree of land damage. According to the research needs of this paper, in combination with the Chinese standard TD/T 1036–2013 [25] and with reference to relevant studies [26–31], three factors used as suitability evaluation index of land reclamation for arable land including land quality, soil nutrients and engineering suitability are taken into account in this mining area. Eleven parameters, including terrain slope grade, effective thickness of soil layer, soil parent materials, soil contamination, organic content, alkali hydrolyzable nitrogen (N), available phosphorus (P), available potassium (K), ground collapse, land destruction extent, and conditions of irrigation and drainage, are selected as the evaluation indicators. The classification standards for the above eleven indicators are summarized in Table 1. The hierarchy of evaluation indicators is shown in Fig. 2.

The existing researches show that the land in the coal mining area can be mainly reclaimed as arable land, forest land, grassland, garden land [26, 27, 32, 33]. The land in the coal mine area is mainly considered to be reclaimed as arable land due to less arable land per capita in Shaodong City.

Fig. 1 Distribution of main working areas in Niumashi coal mine

3.2 Survey items and results in the study area

Two parameters in land quality factor, including the terrain slope grade, effective thickness of soil layer, are quantitative indicators, which can be determined by engineering technicians on the spot. Two parameters in land quality factor including soil parent materials and soil contamination are determined by the specific situations on the spot, and the values are assigned according to Table 1 respectively. Four parameters in soil nutrients factor, including organic content, alkali hydrolyzable nitrogen (N), available phosphorus (P), available potassium (K), are quantitative indicators, which can be measured through field soil sampling. During soil sampling, the plot that can fully reflect the soil characteristics shall be selected first, and the sampling depth is generally within 20 cm. Organic matter in soils is determined by potassium dichromate volumetric method heated in oil bath. Alkali hydrolyzed nitrogen (N) in soils is determined by Kanghui dish method. Available phosphorus (P) in soils is extracted by sodium bicarbonate and determined by molybdenum antimony colorimetry. The content of available potassium (K) in soils is extracted with ammonium acetate and then determined by flame photometry. Three parameters in engineering suitability, including ground collapse, land destruction extent, and conditions of irrigation and drainage, are determined according to the specific situations on the spot by engineering technicians and the values are assigned according to Table 1 respectively.

The field survey was completed by Xiangdong Mineral Geological Survey Institute. The indicators in TD/T 1036–2013 [25] were used in the actual survey of Niumasi mining area. In the investigation of four pieces of lands with a total area of about 1.3 km^2 in Shuijingtou working area, the survey was conducted not only according to the evaluation indicators of TD/T 1036–2013 [25], but also the above 11 evaluation indicators. Since only a few regions were investigated according to the above 11 indicators in this paper, so only a few samples were obtained. In this

Table 1 Indices and criterion for suitability evaluation of land reclamation as arable land

Indices		Classification of land reclamation suitability status			
		Suitable	Moderately suitable	Less suitable	Unsuitable
Land quality	Terrain slope grade (°)	< 3	3 ~ 7	7 ~ 15	> 15
	Effective thickness of soil layer (cm)	≥ 80	50 ~ 80	30 ~ 50	≤ 30
	Soil parent materials	Loam assign the value of 8 ~ 10	Clay and sandy loam assign the value of 6 ~ 8	Sandy soil assign the value of 4 ~ 6	Gravel soil assign the value < 4
	Soil contamination	Non assign the value of 8 ~ 10	Slight assign the value of 6 ~ 8	Moderate assign the value of 4 ~ 6	Heavy assign the value < 4
Soil nutrients	organic content (g/kg)	> 40	30 ~ 40	20 ~ 30	< 20
	Alkali hydrolyzable nitrogen (g/kg)	> 150	120 ~ 150	90 ~ 120	< 90
	Available phosphorus (g/kg)	> 40	20 ~ 40	10 ~ 20	< 10
	Available potassium (g/kg)	> 200	150 ~ 200	100 ~ 150	< 100
Engineering suitability	Ground collapse	Non assign the value of 8 ~ 10	Small amount of uneven settlement on the ground assign the value of 6 ~ 8	Small amount of collapse on the ground assign the value of 4 ~ 6	Many ground collapses assign the value < 4
	Land destruction extent	Non assign the value of 8 ~ 10	Damage but not too serious assign the value of 6 ~ 8	Serious damage assign the value of 4 ~ 6	Extremely damage assign the value < 4
	Conditions of irrigation and drainage	The water source is very close, the water quality is good, and the irrigation and drainage conditions are good assign the value of 8 ~ 10	The water source is close, the water quality is general, and the conditions for establishing irrigation and drainage are general assign the value of 6 ~ 8	The water source is far away, and the establishment of irrigation and drainage conditions is not guaranteed assign the value of 4 ~ 6	No water sources assign the value < 4

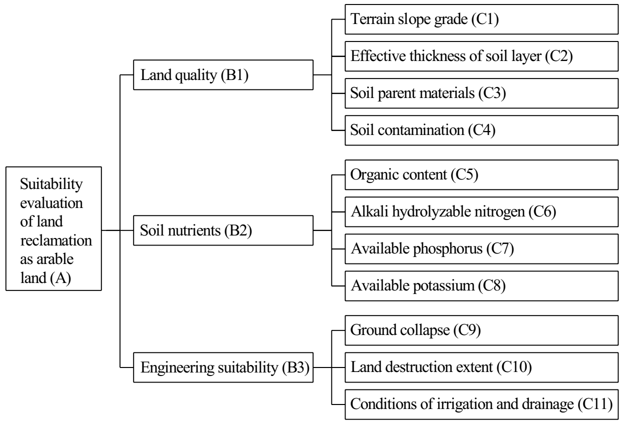

Fig. 2 The hierarchy of evaluation indicators for suitability evaluation of land reclamation as arable land

paper, four samples are selected for evaluation. The original land types of the four samples are dry farming land, forest land, vegetable land, and paddy field respectively. The results are listed in Table 2.

3.3 Catastrophe progression method (CPM)

In this paper, CPM is utilized to evaluate the four land samples in Table 2. CPM is a comprehensive evaluation method based on catastrophe theory and fuzzy mathematics theory, its basic idea [34–36] is to first determine the overall evaluation objective of the evaluation object, and then decompose it layer by layer to form an evaluation index system with a hierarchical structure. After normalizing the control variables at each level according to the mathematical model of the corresponding catastrophe system, the values of catastrophe subordinate functions are calculated layer by layer according to the principle of 'non complementarity' or 'complementarity', until the value of catastrophe subordinate function of the evaluation object, that is, the catastrophe progression criterion, Thereby determining the state category of the evaluation object.

According to the basic idea of CPM, a catastrophe progression model for comprehensive evaluation of the suitability of land reclamation as arable land in coal mining areas is established, which includes the following aspects: (1) Evaluation object; (2) Evaluation index system with a hierarchical structure; (3) Normalization; (4) Training samples; (5) Catastrophe progression criteria.

3.3.1 Evaluation object and evaluation index system with a hierarchical structure

The evaluation object is the general objective of the evaluation. The evaluation object of land reclamation is the suitability of land reclamation. In this paper, it is the

Table 2 Evaluation results of Shuijingtou working area

Indices	Sample No			
	1	2	3	4
Terrain slope grade (°)	4	3	7	10
Effective thickness of soil layer (cm)	26	35	82	45
Soil parent materials	Clay soil	Clay soil	Sandy and clay soil	Sandy loam and sand
Soil contamination	There are pesticide pollution sources and no heavy metal pollution sources	There are pesticide pollution sources and no heavy metal pollution sources	There are pesticide pollution sources and no heavy metal pollution sources	There are pesticide pollution sources and no heavy metal pollution sources
organic content (g/kg)	46.2	38.7	40.1	36.9
Alkali hydrolyzable nitrogen (g/kg)	94.1	92.0	97.8	89.3
Available phosphorus (g/kg)	33.0	28.8	25.1	23.8
Available potassium (g/kg)	104.4	126.8	135.6	142.1
Ground collapse	Serious uneven settlement	Serious uneven settlement	Serious uneven settlement	Serious uneven settlement
Land destruction extent	Serious damage	Serious damage	Serious damage	Serious damage
Conditions of irrigation and drainage	The water source is far away but the conditions are good	The water source is far away but the conditions are good	The water source is far away but the conditions are good	The water source is far away but the conditions are good

suitability of land reclamation as arable land in the coal mining area. The overall objective of this evaluation is set as 'A'. The first-class evaluation indexes are: land quality, soil nutrients and engineering suitability, set as 'B1', 'B2' and 'B3' respectively. Decompose the first-class indicators to form a secondary indicator system. The secondary index system of 'B1' are: terrain slope grade, effective thickness of soil layer, soil parent materials, and soil contamination, which are set as 'C1', 'C2', 'C3' and 'C4' respectively. The secondary index system of 'B2' are: organic content, alkali hydrolyzable nitrogen (N), available phosphorus (P), and available potassium (K), set as 'C5', 'C6', 'C7' and 'C8' respectively. The secondary index system of 'B3' is: ground collapse, land destruction extent, and conditions of irrigation and drainage, set as 'C9', 'C10' and 'C11' respectively. 'C1' to 'C11' are also called the control variables.

The above hierarchical index system (see Fig. 1.) constitutes the following catastrophe system: (i) C1 to C4 and C5 to C8 are constituted the butterfly catastrophe models B1 and B2 respectively; (ii) C9, C10, and C11 are formed as a swallowtail catastrophe model B3 (iii) B1, B2, and B3 constitute a swallowtail catastrophe model A. The control variable normalization formulas of swallow tail catastrophe system are:*** The control variable normalization formulas of butterfly catastrophe system are:****. Where x is the state variable in the catastrophe system; a, b, c, and d are the control variables; x_a, x_b, x_c, and x_d are values of x corresponding to a, b, c, and d in the above expressions.

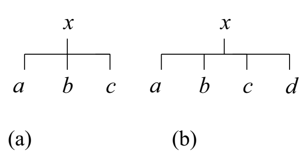

Fig. 3 CPM **a** Swallow tail catastrophe model; **b** Butterfly catastrophe model

The two CPMs mentioned above are shown in Fig. 3. The potential functions, bifurcation sets, and normalization formula of two CPMs are listed in Table 3 [37–39].

3.3.2 Normalization

Normalization processing includes two aspects: one is dimensionless processing of original data; the second is to normalize the control variables at each level according to the mathematical model of the corresponding catastrophe system, and then calculate the values of catastrophe subordinate functions. The method by Chen et al. [35], Zou et al. [36], Cao et al. [40], Cheng et al. [41], Xu et al. [42] is used for dimensionless processing of the original data.

3.3.3 Training samples and test samples

The evaluation of land reclamation suitability is essentially a pattern recognition problem, that is, the actual evaluation results of the evaluation index system used in land reclamation suitability are compared with the classification standards of the evaluation indexes, and the level corresponding to the standard value array closest to the array formed by the actual evaluation results is the level of land reclamation suitability, that is, the identification result of CPM in this paper.

According to the grading standards of evaluation indicators in Table 1, MATLAB software was utilized to generate a total of 1200 samples (300 samples per grade) between the arrays corresponding to each level of standards according to the principle of normal distribution, of which 800 samples are training samples and 400 samples are test samples.

3.3.4 Catastrophe progression criteria

By dimensionless evaluation indexes of training samples and normalizing control variables, the values of catastrophe subordinate functions and the catastrophe progression values of each hierarchical level are solved, and

Table 3 Potential functions, bifurcation sets, and normalization formula

CPM	Numbers of control variable	Potential functions	Bifurcation sets	Normalization formula
Swallow tail	3	$f(x) = \frac{1}{5}x^5 + \frac{1}{3}ax^3 + \frac{1}{2}bx^2 + cx$	$a = -6x^2, b = -8x^3, c = -3x^4$	$x_a = \sqrt{\lvert a\rvert}$, $x_b = \sqrt[3]{\lvert b\rvert}$ $x_c = \sqrt[4]{\lvert c\rvert}$
Butterfly	4	$f(x) = \frac{1}{6}x^6 + \frac{1}{4}ax^4 + \frac{1}{3}bx^3 + \frac{1}{2}cx^2 + dx$	$a = -10x^2, b = 20x^3, c = -15x^4, d = 4x^5$	$x_a = \sqrt{\lvert a\rvert}$ $x_b = \sqrt[3]{\lvert b\rvert}$ $x_c = \sqrt[4]{\lvert c\rvert}$ $x_d = \sqrt[5]{\lvert d\rvert}$

finally the catastrophe progression values of each training samples are obtained. Thus, the ranges of the catastrophe progression values of each state level are obtained, that is, the catastrophe progression criteria of suitability for land reclamation as arable land in the coal mining areas:

(i). 'Suitable' when $x \geq 0.9550$;
(ii). 'Moderately suitable' when $0.8750 \leq x < 0.9550$;
(iii). 'Less suitable' when $0.7850 \leq x < 0.8750$;
(iv). 'Unsuitable' when $x < 0.7850$.

These criteria are used to identify the test samples, and it is found that the evaluation results are completely consistent with the expected results, which indicates that the criteria can be used for the suitability evaluation of land reclamation in this paper.

4 Results and discussion

4.1 Suitability evaluation results in study area

According to the above catastrophe progression model, the suitability status of the four land samples in Table 2 are identified. First, assigning values to the qualitative indicators in Table 2, and the results are listed in Table 4. Then, computing the catastrophe progression values of four samples, and the results are listed in Table 4.

According to the catastrophe progression values, the identification results of the four land samples are as follows: the suitability level of 1#—3# lands are all 'Moderately suitable', and that of 4# land is 'Unsuitable'.

4.2 Discussion

By analyzing the catastrophe progression values of the four land samples, we can obtain: The catastrophe progression values of 1# and and 3# land samples are approximately the same, indicating that their suitability levels are approximately the same, while the catastrophe progression value of 2# are larger than those of 1# and 3# indicating that its suitability is better. 4# land sample is not suitable for reclamation as arable land, so it can be reclaimed as forest land or used for other purposes. The original land types of the four samples (1# to 4#) are dry farming land, forest land, vegetable land, and paddy field respectively. The evaluation results show that mining coal has the greatest damage to paddy fields, followed by the dry farming lands and vegetable lands, and the least impact to the forest lands. These results indicate that CPM can not only evaluate the suitability of land reclamation, and comprehensively compare the suitability degrees, but also can assess the damage degree of coal mining to different types of lands.

The evaluation of damaged land reuse in mining area is a multi-dimensional problem. There are many factors in this problem that seriously affect decision-making [43]. Suitability evaluation plays an important role in land reclamation, and the selection of evaluation methods affects the accuracy and objectivity of the suitability evaluation results, and also affects the decision-making related to land reclamation [44]. Therefore, some scholars have carried out a lot of studies in this field. In practice, the land reclamation suitability evaluation mainly adopts the qualitative evaluation method on the basis of field investigation [45]. In recent years, some other methods have been applied to the suitability evaluation of land reclamation,

Table 4 Suitability evaluation results of land reclamation as arable land in Shuijingtou working area

Indexes	Samples			
	1	2	3	4
Terrain slope grade (°)	4	3	7	10
Effective thickness of soil layer (cm)	26	35	82	45
Soil parent materials	8	8	6	6
Soil contamination	7	7	7	7
organic content (g/kg)	46.2	38.7	40.1	36.9
Alkali hydrolyzable nitrogen (g/kg)	94.1	92.0	97.8	89.3
Available phosphorus (g/kg)	33.0	28.8	25.1	23.8
Available potassium (g/kg)	104.4	126.8	135.6	142.1
Ground collapse	6	6	6	6
Land destruction extent	5	5	5	5
Conditions of irrigation and drainage	6	6	6	6
Catastrophe progression value	0.8878	0.9190	0.8853	0.7309
Suitability	Moderately suitable	Moderately suitable	Moderately suitable	Unsuitable

such as fuzzy mathematics method [23], discriminant analysis method [26, 27], immune clone algorithm method [28], neural network method [32], etc. These methods have their own merits and shortcomings. The fuzzy mathematics method has some shortcomings, such as artificial subjectivity, when assigning weights to indicators. Discriminant analysis (Bayes discriminant analysis, Fisher discriminant analysis) has no special requirements for the distribution of raw data, but requires a large number of training samples. The immune clone algorithm method and the neural network method need to select the model and parameters, which have the weakness of slow convergence. However, the CPM overcomes the shortcomings of the above methods, and the calculation process is simple. This is why CPM is adopted in this paper.

5 Conclusions

In this paper, the suitability of land reclamation as arable land in Niumasi coal mine of Shaodong city in Hunan Province, China, is evaluated by CPM. On the basis of considering three factors of land quality, soil nutrients and engineering suitability in the reclamation area, a catastrophe progression model is established by selecting evaluation indicators and determining their grading standards. This model are suitable for the suitability evaluation of land reclamation as arable land in Niumasi coal mine, and can be applied to land reclamation projects in other mining areas.

CPM can better evaluate the suitability of the land to be reclaimed, which is conducive to further understanding and mastery of the land quality, soil nutrients and the suitability of reclamation projects of the land to be reclaimed. The theoretical basis of CPM is catastrophe theory and fuzzy mathematics theory. CPM has no special requirements for the distribution of sample data, and does not need to give weight to evaluation indicators, avoiding the subjectivity brought by artificially determining the weight of each evaluation indicator, and making the classification results of different algorithms comparable.

The computed method and process of the catastrophe progression values of samples are simple, easy to understand and master. In the suitability evaluation of land reclamation in mining areas, the catastrophe progression value can be combined with qualitative analysis, which can more accurately and quantitatively describe the level attribute of the characteristic value of the evaluation index, and can better quantitatively and comprehensively evaluate the suitability of land reclamation.

The main disadvantage of the catastrophe progression model of land reclamation established in this paper is that the classification grade of suitability and the classification standard corresponding to the evaluation index are subjective. Although the calculation results of the catastrophe progression values are objective, the number of suitability classification groups and the corresponding grading standards of evaluation indicators are artificially given. In addition, up to now, there are no unified evaluation index system and classification standards for land reclamation suitability.

Through the review of existing literature, it is found that different scholars have adopted different evaluation indicators and methods in their studies. This paper refers to the results of relevant scholars and directly uses their evaluation indicators, but the evaluation model is based on catastrophe progression method. Therefore, the correlation between the evaluation indicators has not been studied. Other evaluation indicators and methods should also be reasonable. This paper only applies the catastrophe progression method to provide new idea and way for the research in land reclamation.

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Data availability Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The author states that there is no conflict of interest.

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