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# Suitability evaluation for land reclamation in mining area: A case study of Gaoqiao bauxite mine

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**Abstract:** Suitability evaluation plays an important role in land reclamation because the choice of evaluation methods affects the accuracy and objectivity of the suitability evaluation results. Furthermore, it influences the decision-making related to land reclamation. An improved method, which is called limit comprehensive conditions method, was developed after different suitability evaluation methods were studied. Based on this method, the reclaimed land of the Gaoqiao bauxite mining area was evaluated. The Gaoqiao mining area was divided into seven evaluation units that were evaluated respectively by selecting evaluation factors and establishing grade standards. The results show that the proposed method is more applicable and easier to handle. Moreover, its evaluation results are more scientific compared with the traditional evaluation methods. The improved method can be beneficial to the rapid monitoring and the effective management of reclaimed land in the opencast mine area.

**Key words:** mining area; land reclamation; suitability evaluation; Gaoqiao bauxite mine

## 1 Introduction

With the successful development of the mineral resources industry, lands destroyed by mining have expanded, along with the deterioration of the ecological environment in these mining areas. Such inefficient utilization of land resources has resulted in the loss of agricultural land.

Land reclamation, as a method used to return disturbed land to a state which is useful once again, can achieve the dynamic balance of farmland gross [1−2]. Therefore, land reclamation has become an important part of modern mining practice. Since the suitability evaluation for land reclamation is the premise and foundation of a reclamation plan [3−4], it has a guiding significance to the establishment of a land reclamation scheme, including the reclamation measures to be used, the amount of fund to be allocated, and so on.

Suitability evaluation for land reclamation in mining area determines reasonable ways, through which the land to be reclaimed is utilized based on the investigation on the overall quality of mining land and the statistics of destroyed land [5]. Although there are similarities between the mining land and other types of land, such as evaluation steps, evaluation principle and evaluation approaches, they have distinct differences in terms of evaluation objects, unit partition, timeliness. The characteristics of the suitability evaluation for land reclamation in mining area are listed below.

1) Evaluation objects. The objects of suitability evaluation for land reclamation in mining area are the lands that have been destroyed partly or entirely by exploitation activities.

2) Predictability and dynamic tracking performance. The suitability evaluation for land reclamation in mining areas aims to evaluate the mining lands that may be destroyed in the future. Thus, it focuses on the future. Furthermore, the suitability evaluation for land reclamation needs to be adjusted in the course of reclamation according to the particular conditions of the reclaimed land that has been destroyed. Therefore, this evaluation is also a dynamic tracking process.

3) Considering the multi-suitability of land. A piece of reclaimed land may have different kinds of suitability, therefore, this must be considered. In addition, the final direction of reclaimed land should be determined based on the local conditions.

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## 2 Existing suitability evaluation methods

The choice of evaluation methods affects the accuracy and objectivity of suitability evaluation results for land reclamation in mining areas and also influences the decision-making related to land reclamation [6]. The commonly used approaches include limit conditions, sum of indexes, extenics, fuzzy comprehensive evaluation, and artificial neural networks methods.

### 2.1 Limit conditions method

The limiting factors of the suitability evaluation of land reclamation have an huge impact on the selection of land reclamation methods. The limit conditions method sets the minimum land quality evaluation standard as the basis of reclamation grades that can clearly obtain all the constraints in every reclamation direction through suitability evaluation.

The limit conditions method is established based on the "Cannikin law" of system engineering, which states that the ultimate quality of an evaluation unit depends on the quality of the poorest condition. The model can be expressed as:

$$Y_i = \min(Y_{ij}) \tag{1}$$

where $Y_i$ is the ultimate value for evaluation unit $i$, and $Y_{ij}$ is the value of evaluation factor $j$ for evaluation unit $i$. Land reclamation improves these limit conditions in order to make them more suitable for crop growth.

The limit conditions method is one of the most commonly used approaches in suitability evaluation. It is especially ideal for conditions where land destruction is severe (i.e., the original land type has been greatly changed), such as open pit mines and subsidence lands that have been badly damaged. The disadvantage of this method, however, is that the obtained suitability grades are undervalued. This method does not consider the situation in the absence of certain land of which attributes can be replaced by other ones. In addition, it only takes the suitability grade of a major limiting factor as the overall evaluation grade for an evaluation unit. Therefore, the evaluation result is somewhat conservative and lacks a comprehensive consideration on various impact factors.

### 2.2 Sum of indexes method

The sum of indexes method evaluates the suitability of the destroyed land by calculating the integrated numerical values of various evaluation factors; it is also used to determine the suitability degree of each evaluation factor for farmland, woodland, grassland, and so on [7].

If each evaluation unit has $n$ single evaluation factors, the sum of weighted factors can be expressed as:

$$R_j = \sum_{i=1}^{n} a_i b_i \tag{2}$$

where $R_j$ is the total score of evaluation unit $j$, $a_i$ is the numerical value of evaluation factor $i$, and $b_i$ is the weight of evaluation factor $i$.

In the beginning of the evaluation, $n$ suitability evaluation factors are selected according to farmland, woodland and grassland, respectively. They are weighed ($b_i$) depending on different grades for different land types, and the evaluation scores ($a_i$) are obtained in proportion to the grade for every evaluation factor. The weight ($b_i$) is multiplied by the value ($a_i$), after which the score $a_ib_i$ of weighted factors and the ultimate score $R_j$ of evaluation unit $j$ are calculated.

For the sum of indexes method, the importance of each impact factor is fully considered, and the impact degree of each factor can be quantized. Thus, all indexes for each evaluation unit are taken into account. The weights of evaluation factors and the range of land grade indexes must be determined in advance. Nonetheless, the evaluation result has certain subjectivity due to the different ways in determining weights. Moreover, this method is suitable for general land, but not for mining areas that have been badly damaged.

### 2.3 Extenics method

The extenics method is used to solve a problem from both qualitative and quantitative aspects using formalized tools. It reflects the comprehensive quality level of evaluation objects by establishing an evaluation model with multi-index parameters [7]. The process of suitability evaluation for land reclamation using extenics method is presented below.

1) Determine the classical domain. The ordered triple $R$=($N$, $c$, $x$) was taken as matter-element. Here, $N$ denotes the assembling item with its eigenvalue $c$ and quantity value $x$. If the item $N$ has $n$ eigenvalues, we call it $n$-dimensional matter-element which is expressed by the following matrix:

$$\boldsymbol{R}_{oj} = (N_{oj}, c, V_{oj}) = \begin{bmatrix} N_{oj} & c_1 & V_{oj1} \\ & c_2 & V_{oj2} \\ & \vdots & \vdots \\ & c_n & V_{ojn} \end{bmatrix} = \begin{bmatrix} N_{oj} & c_1 & \langle a_{oj1}, b_{oj1} \rangle \\ & c_2 & \langle a_{oj2}, b_{oj2} \rangle \\ & \vdots & \vdots \\ & c_n & \langle a_{ojn}, b_{ojn} \rangle \end{bmatrix} \tag{3}$$

where $N_{oj}$ denotes $j$ suitability grades; $c_i$ ($i$=1, 2, ⋯, $n$) is the eigenvalue of suitability grade; $V_{oji}$ is the range of quantity value of $N_{oj}$ with respect to eigenvalue $c_i$. It is the data range of each suitability grade with respect to its corresponding eigenvalue.

2) Determine the limited domain. In the equation below, $P$ denotes the overall partition of suitability grades, and $V_{pi}$ is the range of quantity value of $P$ with respect to $c_i$, which is the limited domain of $P$.

$$\boldsymbol{R}_p=(P,c,V_p)=\begin{bmatrix} P & c_1 & V_{p1} \\ & c_2 & V_{p2} \\ & \vdots & \vdots \\ & c_n & V_{pn} \end{bmatrix}=$$

$$\begin{bmatrix} P & c_1 & \langle a_{p1},b_{p1}\rangle \\ & c_2 & \langle a_{p2},b_{p2}\rangle \\ & \vdots & \vdots \\ & c_n & \langle a_{pn},b_{pn}\rangle \end{bmatrix} \tag{4}$$

3) Determine the matter-element to be evaluated. The evaluation object can be expressed as a matter-element mode given by Eq. (5):

$$\boldsymbol{R}=\begin{bmatrix} P & c_1 & V_1 \\ & c_2 & V_2 \\ & \vdots & \vdots \\ c_n & c_n & V_n \end{bmatrix} \tag{5}$$

where $P$ is the evaluation object; $v_{\mathrm{i}}$ is the quantity value of $P$ with respect to $c_i$, which is the specific index value of evaluation object.

4) Calculate the correlation of the evaluation object $P$ with respect to each quality grade.

$$K_{j(vi)}=\begin{cases} 1+\dfrac{-p(v_i,V_{oji})}{|V_{oji}|}, v_i\in V_{oji} \\ 1+\dfrac{p(v_i,V_{oji})}{p(v_i,V_{p1}-p(v_i,V_{oji}))}, \ v_i\notin V_{oji} \end{cases} \tag{6}$$

In the equation above, the numerical value of correlation function denotes the degree of membership that each evaluation unit corresponds with in a certain standard range. Therefore, the suitability grade of reclaimed land can be determined based on the different values of $K_{j(vi)}$.

5) Determine weight. The weight can be calculated using the following formula:

$$a_{ij}=\frac{x_{ij}}{\sum\limits_{i=1}^{n}x_{ij}}, j=1, 2, 3, \cdots, m; i=1, 2, 3, \cdots, n \tag{7}$$

where $a_{ij}$ denotes the weight coefficient of the index $i$ of grade $j$, and $x_{\mathrm{ij}}$ is the threshold value of index $i$ of grade $j$.

6) Calculate the correlation of the evaluation object $P$ with respect to grade $j$ as follows:

$$K_j(P)=\sum_{i=1}^{n}a_iK_j(v_i) \tag{8}$$

7) Evaluate suitability grade. If $K_{j0}$ = max ($K_j$ ($P$)), the object $P$ belongs to grade $j_0$.

The extenics method applied to the suitability evaluation for land reclamation quantizes each factor to overcome limitations arising from subjectivity. Therefore, it greatly enhances the accuracy of evaluation results. However, the available correlation functions are limited, because extenics is an emerging subject. Thus, this method is seldom used in suitability evaluation for land reclamation in mining area.

### 2.4 Fuzzy comprehensive evaluation method

The fuzzy comprehensive evaluation method is used to evaluate the suitability of land to be reclaimed. Fuzzy mathematics theory is used to process evaluation factors with exact value, interval value and language value. Two domains of discourse need to be taken into account.

1) The domain of discourse of suitability grades $V$. The suitability of land to be reclaimed is divided into four grades: high-$A$, middle-$B$, low-$C$ and unsuitable-$D$, as denoted by set $V=\{A, B, C, D\}$.

2) The domain of discourse of suitability evaluation factors $U$, which is denoted by set $U=\{E, F, G, H, I, J\}$, where $E$−$J$ denote the selected evaluation factors. For the suitability evaluation of land reclamation in a mining area, the commonly selected evaluation factors include degree of damage, soil texture, slope, soil reliability, irrigation conditions, traffic conditions, and so on.

In practice, the evaluation suitability of land reclamation in mining area examines the relationship between fuzzy subsets $A_1$ and $B_1$ that are defined in two domains of discourse $U$ and $V$, respectively.

The fuzzy comprehensive evaluation method fully considers the fuzziness involved in each evaluation factor and their impacts on the quality of land. It is not easy to recognize the quality of land; thus, it is logical to use the fuzzy method. However, the index system of evaluation factors must be determined in advance, and some subjective impacts on evaluation results [1] may occur. Due to its complex calculation, this method is seldom used in the suitability evaluation for land reclamation in mining area.

### 2.5 Artificial neural networks method

Artificial neural networks (ANNs) are non-linear mapping structures based on the function of the human brain. They are powerful modeling tools, especially when the underlying data relationship is unknown. ANNs can identify and analyze correlated patterns between input data sets and the corresponding target values. After training, ANNs can be used to predict the outcome of new independent input data [8].

The suitability evaluation of reclaimed land based on ANNs aims to establish the mapping relationship between impact factors and the suitability degree of land reclamation. The relationship between quantized impact factors and the suitability degree is then mapped with continuous variation. According to the approximability of the ANN function, this relationship can be approximated easily if the appropriate network structure is chosen.

This method does not need to determine the degree of indexes and weight of factors. It overcomes the dependence on empirical knowledge; therefore, the evaluation results are more objective compared with traditional approaches. A major limitation of the ANN method lies in its dependence on training data; in addition, users lack knowledge on optimizing network structure. At present, only a few successful case studies on the suitability evaluation for land reclamation in mining area using this method have been reported.

## 3 Study area and methods

### 3.1 Profile of study area

The Gaoqiao bauxite mine was selected as study area. It is located in Mianchi county in northwest Henan Province, China (E111°33′ to 112°01′ and N34°36′ to 35°05′). The elevation in the area ranges from 260 m to 927 m. There are high hypsographies and developed gullies in the Gaoqiao mining area. The conditions of the surface runoff of the earth are good and are not conducive to conglomerate surface water. The degree of slope ranges from 15° to 50°, with an average of around 30°. The Gaoqiao mining area is covered by low-nutrient loess that belongs to drab soil, mostly red clay. Furthermore, the area has sparse vegetation and is exposed to water and wind erosion.

The study area includes farmland, woodland, other agricultural land, rural resident land, and unused land. Farmland and woodland account for the main parts; woodlands are distributed mainly in the massifs and gullies, whereas the farmlands are distributed mostly around villages.

The designed average annual production of the Gaoqiao bauxite mine is 0.65 Mt/a, and its service period is 10 years (2008—2018). The exploitation of the Gaoqiao bauxite mine is a combination of opencast working and underground mining. The formation of destroyed land is a result of digging, covering and subsidence. The Gaoqiao bauxite mine adopts the chamber-pillar exploitation method, in which the jambs are not recycled. Furthermore, rubbles are used to backfill into the goaf. The rate of backfilling is not less than 80%; therefore, the impact from the subsidence on ground is slight. The objects of suitability evaluation for land reclamation are focused mainly on digging and covering the land which have been destroyed by opencast working.

### 3.2 Overview of improved method

Currently, there are no uniform regulations for the methods of undertaking suitability evaluation for land reclamation in mining areas. Each method has its own set of advantages and disadvantages. Therefore, we developed an improved method, i.e., limit comprehensive conditions method, based on current research achievements.

This method was executed by adopting the limit conditions method for each reclamation direction, and obtaining a result which was a numerical value between 1 and 4. We assembled the result through limit conditions of different reclamation directions in the order of farmland, woodland and grassland. The result is a quaternary number with 3 digits that reflect synthetically the degrees of suitability of each evaluation unit along different reclamation directions. The range of evaluation results ranged from 111 to 444, in which the less the numerical value, the higher the degree of land quality. The evaluation results reveal not only the limit degree of land, but also the suitability of different directions. It is convenient to arrange different land use types and represent biodiversity principle better. Its mathematic relationship is as follows:

$$R_j = \max(V_{aji}) \times 10^2 + \max(V_{bji}) \times 10 + \max(V_{cji}); \quad i=1,\ 2,\ \cdots,\ n \tag{9}$$

where $R_j$ denotes ultimate evaluation results of evaluation unit $j$; $V_{aji}$ denotes the degree of evaluation factor $i$ of evaluation unit $j$ for farmland; $V_{bji}$ denotes the degree of evaluation factor $i$ of evaluation unit $j$ for woodland; $V_{cji}$ denotes the degree of evaluation factor $i$ of evaluation unit $j$ for grassland; $n$ is the number of evaluation factors.

### 3.3 Technical process of suitability evaluation

The technical process of the improved method is shown in Fig. 1. The whole process of suitability evaluation can be divided into two parts, i.e., qualitative evaluation and quantitative evaluation. The general premise of this method is based on the full understanding of destructive situations in the study area. On the other hand, the initial directions of reclamation are determined through qualitative analyses on society, economy, policy, other natural characteristics of land before and after destruction, public desire and so on, and then combining them with the analysis of some similar reclamation cases. Therefore, we divided the evaluation units using GIS technology according to the types and extent of the

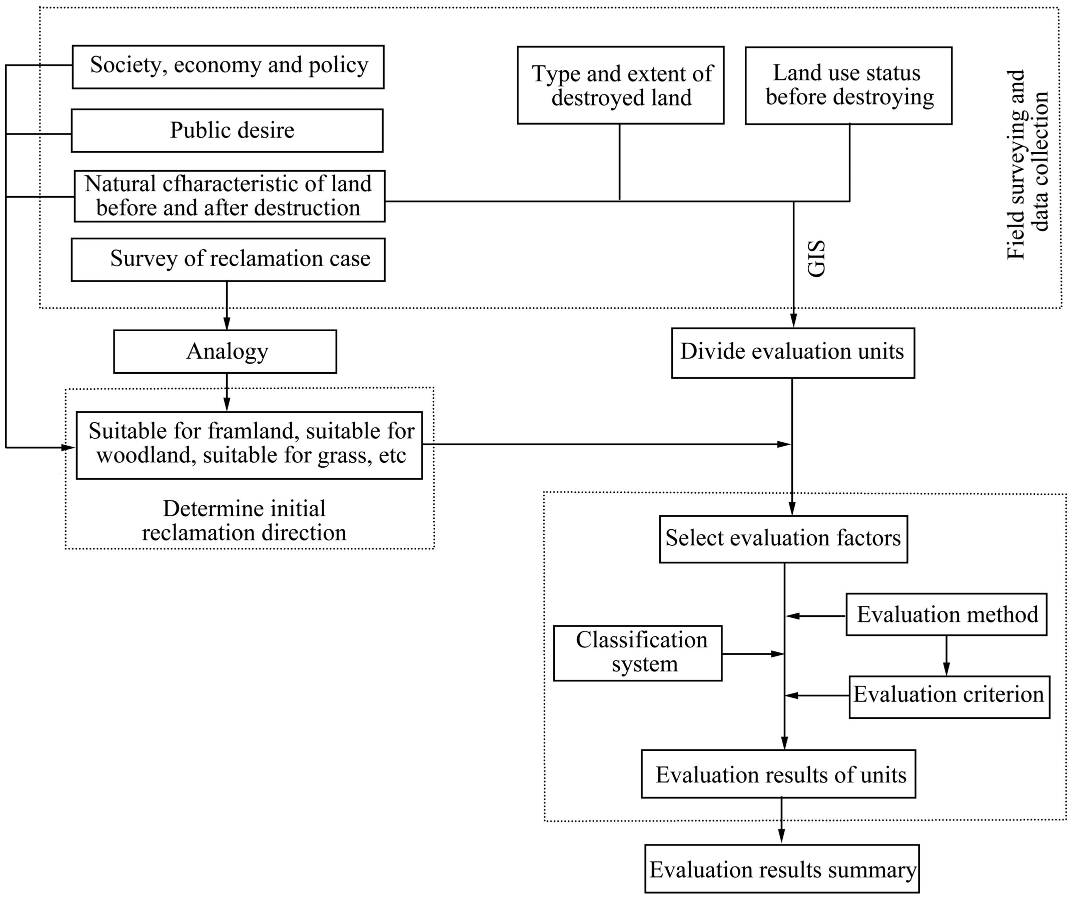


**Fig. 1** Process of suitability evaluation for land reclamation in mining area

destroyed land. Afterwards, we combined them with the original situation of the destroyed land. The evaluation factors were selected according to the initial reclamation direction in order to analyze quantitatively the suitability of the evaluation units [9−10].

### 3.4 Determining objects of suitability evaluation and divide evaluation units

3.4.1 Determining objects of suitability evaluation

According to the forecast of destruction in the Gaoqiao mining area, the destroyed land includes five parts: open pit, subsidence area, dump, temporary storage soil dump, and land for roads.

In the Gaoqiao mining area, only the third mine section is an open-pit mining. According to the landform in the study area, the pit can be divided into side slope (including slope platform) and pit bottom. The total area is $26.45\times10^4$ m$^2$.

A dump is a place for the stacking mullock; it belongs to a covering land, including dump slope, slope platforms, and end platform. The slope platform and the end platform are similar so they can be referred to as a dump platform. The total area of three dumps is $18.40\times10^4$ m$^2$. According to the reclamation plan, the platform of dump I must be covered with 0.5 m topsoil and those of dumps II and III must be covered with 0.3 m topsoil.

In the Gaoqiao mining area, the first, second and fourth mine sections, along with a small part of the southern area of the third mine section, the underground mining method is used, which adopts the chamber-pillar exploitation method and uses mullock to backfill into the goaf. Hence, the impact from the subsidence on ground is slight and does not influence the original types of land used in the mining area. In the course of land reclamation, some measures are to be taken to monitor the deformation of ground surface. In the reclamation plan, the subsidence area does not need reclamation and maintains the original land use types. Therefore, the subsidence area does not need to be evaluated.

The temporary storage soil dump is a place, where the stripped topsoil belonging to temporary occupation is stored. During occupation, a substance for covering dust is sprayed on the soil surface in order to maintain the fertility of soil and microbial activities. Therefore, it does not need to be evaluated in a period of service. However, some reclamation measures should be taken after a period of service; it just needs to be evaluated when the topsoil is removed after a period of service. In the Gaoqiao mining area, there is a temporary storage soil dump with a total area of $2.84\times10^4$ m$^2$. Meanwhile, land for roads belonging to covering land has a total area of $2.81\times10^4$ m$^2$. The surface of roads must be removed, loosened, and restored after mine closure.

Based on the above points, the evaluation objects include open pit, subsidence area, dump, temporary storage soil dump, and land for roads.

3.4.2 Dividing evaluation units

Since the suitability evaluation for land reclamation in mining areas aims to evaluate the land to be destroyed in the future, the time of evaluation is inconsistent with the present land use conditions. In addition, the original soil conditions and land use types can still change due to mine exploitation. Hence, the evaluation units can not be divided according to the present soil types.

Based on the above analysis, the process of dividing evaluation units must be based on the integrated impact of various factors, such as types of destruction, limiting factors, and reclamation measures. An integrated method is used to divide evaluation units. This method uses ArcGIS software as the platform, according to the spatial overlay analysis on geographical map, land map, and map of destruction degree, thus leading to the formation of a map with comprehensive evaluation units. We analyzed these small, closed patches on the map of comprehensive evaluation units, and sorted out some small patches that have the same attributes as a final evaluation unit.

In the study, the evaluation units were divided into seven parts: open-pit slope, open-pit bottom, platform of dump I, platforms of dumps II and III, dump slope, temporary storage soil dump and land for roads. The topsoil thickness of the platform of dump I is different from those of the platforms of dumps II and III; hence, they were divided correspondingly.

**3.5 Selection of evaluation factors and determination of grade standards**

3.5.1 Selection of evaluation factors

The evaluation factors play an important role in the accuracy of suitability evaluation for land reclamation in mining area. A set of independent but complementary factors should be selected in the course of suitability evaluation [11−13].

In the current study, the following evaluation factors were chosen: surface slope, composition of surface materials, thickness of covering soil, irrigation conditions, drainage conditions and pollution.

3.5.2 Determination of grade standards of evaluation factors

After determining the evaluation factors, the evaluation grade standards of the main limiting factors should be established for evaluating the reclaimed land.

The main reclamation directions should be farmland and woodland based on the actual conditions in the Gaoqiao mining area. The reclamation direction of grassland should also be considered for ecological environment protection. Therefore, the reclaiming land must be evaluated from three directions: suitable for farmland, suitable for woodland, and suitable for grassland in the Gaoqiao mining area.

Based on the above analysis, we obtained the grade standards of the main limiting factors of suitability evaluation (Table 1). We also obtained the status of the corresponding index system of each evaluation unit (Table 2) on the basis of integrated consideration on the main evaluation factors in the Gaoqiao mining area.

## 4 Results and discussion

We can obtain the evaluation results of each evaluation unit by comparing and analyzing the land quality of each unit with the grade standard of the main limiting factors, as shown in Table 3.

According to the evaluation results of each unit in Table 3, we can obtain the appropriate reclamation direction and result of the area statistic of each evaluation unit, as shown in Table 4. The map of the suitability evaluation results of land reclamation in the Gaoqiao bauxite mine is shown in Fig. 2.

The above suitability evaluation results are explained as follows:

1) The open-pit slope is unsuitable for planting trees and shrubs, therefore, two kinds of reclamation measures, namely planting vines at the base of slope and spraying plant grass, are chosen. However, we should consider both technical feasibility and socio-economic impacts when choosing reclamation measures. The cost of spraying plant grass is higher than that of planting vines, and the Gaoqiao mining area is poor and undeveloped. Therefore, planting vines is a better choice.

2) The configuration of vegetation pattern in the early reclamation is just temporary. In order to increase biological diversity and increase the similarity between the vegetation configuration and nature, there should be some reasonable adjustments according to the specific conditions of the Gaoqiao mining area at different periods after reclamation [14−15].

The total area of the evaluated land is $50.50\times10^4$ m$^2$. The area suitable for farmland and woodland is $3.60\times10^4$ m$^2$ and $6.90\times10^4$ m$^2$, respectively, and the rate of land reclamation is 100%. The land suitable for farming in the study area is 7% of the entire area. In addition, 93% of the reclaimed land has been found to be suitable for forestation which is better for protecting ecological environment through the restoration of vegetation, soil maturation, and good management measures. Overall,

**Table 1** Grade standards of main limiting factors

| Limiting factor | Grade index | Evaluation of suitable for farmland | Evaluation of suitable for woodland | Evaluation of suitable for grassland |
|---|---|---|---|---|
| Surface slope/(°) | <6 | 1 | 1 | 1 |
| | 6−15 | 2 | 1 | 1 |
| | 15−25 | 3 | 2 | 2 |
| | >25 | 4 | 3 | 4 |
| Composition of surface materials | loam, sandy loam | 1 | 1 | 1 |
| | mixture of rock and soil | 4 | 2 | 2 |
| | sand clay, gravel | 4 | 3 | 3 |
| | rock | 4 | 4 | 4 |
| Thickness of covering soil/cm | >50 | 1 | 1 | 1 |
| | 20−50 | 2 | 2 | 1 |
| | <20 | 4 | 3 | 1 |
| Irrigation conditions | Reliable irrigation conditions in particular period | 1 | 1 | 1 |
| | Poor irrigation conditions | 2 | 2 | 1 |
| | No irrigation water | 3 | 3 | 2 |
| Drainage conditions | No submersion or seldom submersion, very good drainage conditions | 1 | 1 | 1 |
| | Seasonal and short-term submersion, good drainage conditions | 2 | 2 | 2 |
| | Seasonal and long-term submersion, bad drainage conditions | 3 | 3 | 3 |
| | Long-term submersion, very bad drainage conditions | 4 | 4 | 4 |
| Pollution | No | 1 | 1 | 1 |
| | Low-grade | 2 | 2 | 2 |
| | Moderate | 3 | 3 | 3 |
| | Severe | 4 | 4 | 4 |

Note: “1” denotes the first grade land; “2” denotes the second grade land; “3” denotes the third grade land; “4” denotes unsuitable land. For the irrigation conditions, the “reliable irrigation conditions in a particular period” means the particular protection period of three years after reclamation or dry season when the waterwheels will be used to ensure irrigation.

**Table 2** Land quality of evaluation units

| Evaluation unit | Limiting factor | | | | | |
|---|---|---|---|---|---|---|
| | Surface slope/(°) | Composition of surface materials | Thickness of covering soil/cm | Irrigation condition | Drainage condition | Pollution |
| Open pit slope | >25 | Rock | 20−50 | No irrigation water | No submersion or occasional submersion, very good drainage conditions | No |
| Open pit bottom | <6 | Sand clay, gravel | 20−50 | No irrigation water | Seasonal and short-term submersion, good drainage conditions | No |
| Platform of dump I | <6 | Mixture of rock and soil | >50 | No irrigation water | Seasonal and short-term submersion, good drainage conditions | No |
| Platforms of dumps II and III | <6 | Mixture of rock and soil | 20−50 | No irrigation water | Seasonal and short-term submersion, good drainage conditions | No |
| Dump slope | >25 | Mixture of rock and soil | 20−50 | No irrigation water | Seasonal and short-term submersion, good drainage conditions | No |
| Temporary storage soil dump | 6−15 | Mixture of rock and soil | 20−50 | No irrigation water | Seasonal and short-term submersion, good drainage conditions | No |
| Land for roads | <6 | Loam, sandy loam | <20 | No irrigation water | No submersion or occasional submersion, very good drainage conditions | No |

**Table 3** Evaluation results of every unit

| Evaluation unit | Evaluation direction | Suitability grade | Main limiting factors | Evaluation result | Determination of the final reclamation direction |
|---|---|---|---|---|---|
| Open pit slope | Farmland | 4 | Surface slope | 434 | The unit has higher grade of woodland; therefore, the final reclamation direction should be woodland |
| | Woodland | 3 | Surface slope | | |
| | Grassland | 4 | Surface slope | | |
| Open pit bottom | Farmland | 3 | Irrigation conditions | 332 | The unit has multi-suitability considering a better conservation of soil and water; therefore, the final reclamation direction should be woodland |
| | Woodland | 3 | Irrigation conditions | | |
| | Grassland | 2 | Irrigation conditions | | |
| Platform of dump I | Farmland | 3 | Irrigation conditions | 332 | The unit has multi-suitability. Because the thickness of covering soil reaches to 0.5 m, the final reclamation direction should be farmland |
| | Woodland | 3 | Irrigation conditions | | |
| | Grassland | 2 | Irrigation conditions | | |
| Platforms of dump II and III | Farmland | 3 | Irrigation conditions | 332 | The unit has multi-suitability. Because the thickness of covering soil reaches to 0.5 m, the final reclamation direction should be farmland |
| | Woodland | 3 | Irrigation conditions | | |
| | Grassland | 2 | Irrigation conditions | | |
| Dump slope | Farmland | 4 | Surface slope | 434 | The unit has higher grade of woodland; therefore, the final reclamation direction should be woodland |
| | Woodland | 3 | Surface slope | | |
| | Grassland | 4 | Surface slope | | |
| Temporary storage soil dump | Farmland | 3 | Irrigation conditions | 332 | The unit has multi-suitability considering a better conservation of soil and water; therefore, the final reclamation direction should be woodland |
| | Woodland | 3 | Irrigation conditions | | |
| | Grassland | 2 | Irrigation conditions | | |
| Land for roads | Farmland | 4 | Thickness of covering soil | 432 | The unit has multi-suitability considering a better conservation of soil and water; therefore, the final reclamation direction should be woodland |
| | Woodland | 3 | Irrigation conditions | | |
| | Grassland | 2 | Irrigation conditions | | |

**Table 4** Evaluation results and area statistic

| Evaluation unit | Evaluation result | Area/$10^4$ $m^2$ |
|---|---|---|
| Open pit slope | Third grade land suitable for woodland | 9.75 |
| Open pit bottom | Third grade land suitable for woodland | 16.70 |
| Platform of dump I | Third grade land suitable for farmland | 3.60 |
| Platform of dump II and III | Third grade land suitable for woodland | 8.92 |
| Dump slope | Third grade land suitable for woodland | 5.88 |
| Temporary storage soil dump | Third grade land suitable for woodland | 2.84 |
| Land for roads | Third grade land suitable for woodland | 2.81 |
| Subtotal | Area suitable for farmland | 3.60 |
| | Area suitable for woodland | 46.90 |

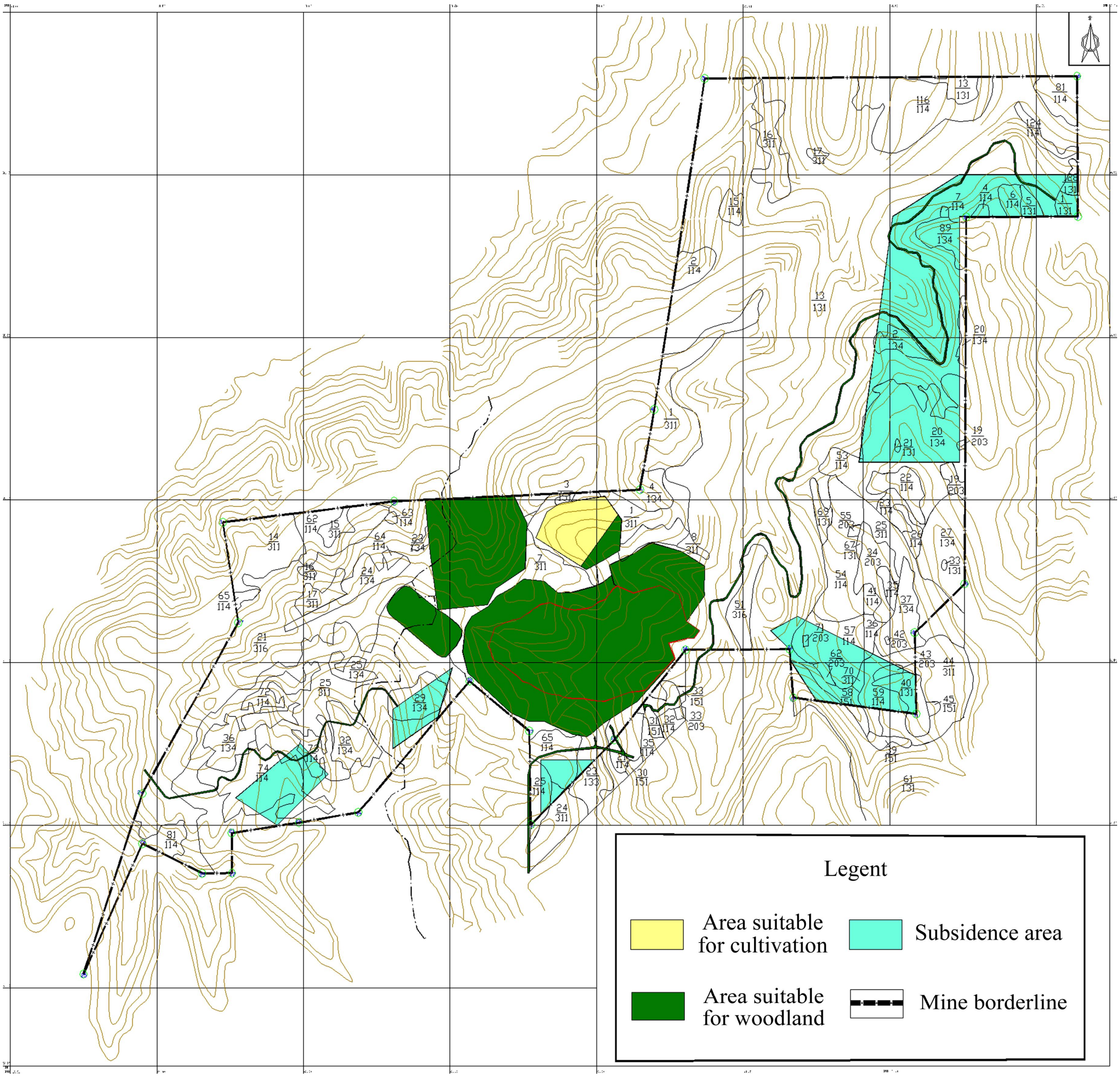


**Fig. 2** Map of suitability evaluation results of land reclamation in Gaoqiao bauxite mine area

this study includes an analysis of the distribution of different levels of reclaimed land in various areas. The evaluation factors of the reclaimed land developed in the study can be used in the rapid monitoring and scientific management of reclaimed land used for mining in the study area and in other areas.

## 5 Conclusions

1) Land reclamation in mining areas is an important measure for solving contradiction between natural resources and man's economic activities, with the aim of achieving a balance of farmland gross. However, the achievement of efficient reclamation and utilization of reclaimed land must be based on suitability evaluation for land reclamation. The choice of evaluation methods affects the accuracy and objectivity of the suitability evaluation results; moreover, it influences the decision-making related to land reclamation. Thus far, there is no uniform regulation on the methods of suitability evaluation for land reclamation in mining area. It can be known from the existing suitability evaluation methods that each method has its own set of advantages and disadvantages. In the paper, an improved method called limit comprehensive conditions method was developed based on current research achievements. This method is used in land reclamation in the Gaoqiao bauxite mine located in Mianchi county of Henan province, China.

2) On the basis of the comprehensive analysis of the types of land destruction, limiting factors and reclamation measures, the Gaoqiao mining area is divided into seven evaluation units that are respectively evaluated by selecting evaluation factors and establishing grade standards. The total area of $50.50\times10^4$ m$^2$ is

evaluated using the developed suitability evaluation method. An area of $3.60\times10^4$ m$^2$ is found to be suitable for farmland, whereas the area suitable for woodland is $6.90\times10^4$ m$^2$. The result of suitability evaluation is appropriate for protecting the ecological environment surrounding the Gaoqiao mining area. The evaluation results agree with the actual investigation conditions, which demonstrates that the methods used in this study provides an effective and objective evaluation of the reclaimed land in a mining area.

3) Compared with traditional evaluation methods, the improved method has better applicability, it is easier to handle, and can produce more scientific evaluation results. Therefore, it can be applied widely to land reclamation projects in other mining areas.

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