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Evaluation of reclamation land productivity in mining districts

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Abstract: In order to evaluate the productivity of reclamation lands in mining districts, field investigation and spatial information technique were adopted to investigate influence factors of land. Based on the collected data of each land, membership grade of each factor was obtained based on Fuzzy logic, and combined weight of each factor was got by analytica1 hierarch process and Delphi method. According to membership grades and combined weights of all factors, integrated fertility index (IFI) of every land was calculated to reflect levels of the productivity of reclamation lands in mining districts. Experimental results show that spatial information technique is an efficient method in field data collection, while lack of evaluation data. By means of quantificational analysis of this method, IFI is appropriate to describe the productive capacity level of reclamation lands.

Key words: mining districts; reclamation; productivity evaluation; membership grade

1 Introduction

Development and utilization of mineral resources play an important role in the process of the national economic and social development. However, exploitation of mineral resources also brought serious land problems. For example, a large number of land resources were digged, caved and engrossed because of the large-scale exploitation. Therefore, while continuing to speed up development of mine districts, the land should be reclaimed not only to raise the utilization rate of land resources and keep the dynamic balance of the total farmland area, but also to restore the ecological balance and promote the sustainable development of ecology, economy and society.

The soil is the basis of mine reclamation, sustainable use of land, and chief sign of quality of mine reclamation. It determines the direction and benefit of the reclamation land use. There are some standards for judging the productive capacity of reclamation lands. The production potential is one of the standards, namely productivity. The productivity of reclamation lands in mining districts is related to some factors, such as the climate, the topography, soil parent material, soil physical-chemical property and farmland infrastructure. Because the productivity of reclamation land is the productive capacity of reclamation land, its data can also be used to judge the phase results of land reclamation. This work is of paramount importance to the development of upper reclamation and financing input [1, 2].

The evaluation unit map of reclamation land in mining districts was got by 3S technology [3−5] (that is, global positioning system, remote sensing, geographic information system). According to the characteristics of influence factors, this work selected evaluation indices, described the influence effect of selected indices with fuzzy mathematics theory and calculated the weight of select indices with analytica1 hierarch process (AHP). Based on these data, the evaluation model (see Fig. 1) of the productivity of reclamation land was established. The evaluation of the productivity of reclamation land can be expediently carried out. Evaluation results preferably describe the productive capacity level of reclamation lands [6].

2 Methods and data

2.1 Methods of farmland productivity

At present, there are mainly two methods about the land productivity evaluation: one is based on the climate factor, and the other is based on the soil factor. In the mining districts, the climate is correspondingly uniform and steady. According to integrated characteristics

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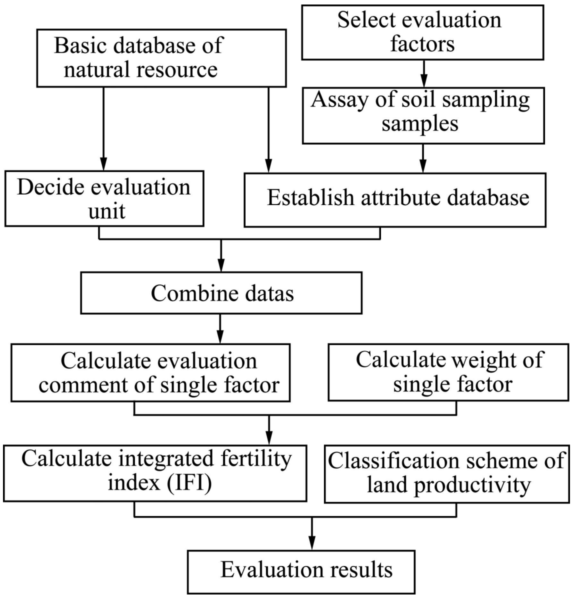

Fig. 1 Evaluation flow of land productivity

obtained from interactions between evaluation factors, such as the topography, soil parent material, soil physical-chemical property and the farmland infrastructure. The level of potential biologic fertility is developed.

The land productivity evaluation can be expressed in two ways. One is represented by the yield per unit area as

$$Y = F(C, A, S) \tag{1}$$

where Y is the yield per unit area; C is the crop state sets; A is the sets of the climate variable circumstance; S is the sets of the soil variable circumstance.

The advantage of above-mentioned method is that Y can be calculated by parameters of naturally evaluated factors of the sampling spot. But in practice these factors are incontrollable and changeful. Furthermore, in addition to land natural factors, the great change of Y is also due to technical level or economic capacity of planters.

Another method is expressed by the evaluation index of land factors as

$$V_{\text{IFI}} = b_1X_1 + b_2X_2 + \cdots + b_nX_n \tag{2}$$

where V_{IFI} is the evaluation index of the land; X_i is the land natural attributes (evaluation factors); b_i is the contribution rate of the corresponding evaluation factor to land productivity got by AHP or Delphi method.

In above method, V_{IFI} is used to show the level of land productivity, the makeup of V_{IFI} may also be used to develop influence factors and corresponding impact of the land productivity. If adopting the right methods, V_{IFI} can be converted into Y which can more visually reflect the real level of land productivity.

2.2 Evaluation factors list

Since 2002, Ministry of Agriculture, China, has established the evaluation index system of the productivity according to Chinese climate and the landform characteristics. Experts can select the evaluation indices from this system according to the circs of the reclamation land in mining districts.

2.3 Analytica1 hierarch process

Single factor weight of the evaluation index is its proportion in the comprehensive evaluation system. Methods to determine the weight are divided into two kinds: one is the mathematical statistics method, such as

Table 1 Evaluation factors of land productivity

Factor type	Factor name
Climate	Accumulated temperature, annual precipitation, annual sunshine duration, solar energy radiation, frost-free period, aridity
Site condition	Longitude, latitude, elevation, geomorphic type, topographic position, gradient, terrain slope, soil parent material, soil erosion type, soil erosion degree, woodland coverage ratio, surface crushing status, earth surface rock outcrop status, earth surface gravel, field slope
Profile shape	Profile form, texture configuration, valid soil thickness, topsoilply, humic horizon, field capacity, dry season groundwater level, groundwater depth, water type
Physical-chemical property	Soil texture, bulk density, pH, cation exchange capacity (CEC)
Nutrient status	Organic matter, total nitrogen, available phosphorus, rapidly available potassium, slowly available potassium, available zinc, water-soluble boron, available molybdenum, available copper, available silicon, available manganese, available iron, exchangeable calcium, exchangeable magnesium
Obstacle factor	Obstacle layer type, obstacle layer position, obstacle layer depth, topsoil salinity, one-meter soil layer salinity, salinization type, groundwater mineralization degree
Soil management	Irrigation capacity, irrigation module, drought resistance, drainage capacity, drainage module, crop rotation system, facility type

principal component analysis, multiple regression analysis and gray relational grade analysis. The other is the expert consultation method, such as compositor method AHP [7]. Analytical hierarch process is an architecture-free and multi-criteria decision method, which is much suitable for the case that the objective architecture is very complicated or short of evaluation data. The AHP method was adopted in this work, 16 factors was allocated by relations and assigned relative importance through comparison between every two factors. By coupling with experts estimation, the influence of each factor on the evaluation was ranked and the decisions were made. Through AHP, the combined weight of single factor would be calculated.

2.4 Evaluation comment of membership grade

Fuzzy mathematics forms a branch of mathematics related to fuzzy logic. There are three important concepts in fuzzy mathematics, such as fuzzy subset, membership function and membership grade. A fuzzy subset A of a set X is a function A: $X \to L$, where L is the interval as the range of [0,1]. This function is also called a membership function. A membership function is a generalization of a characteristic function or an indicator function of a subset defined for L={0,1}. It can present the relation between the selected factor and membership grade.

According to the theory of fuzzy mathematics, the relation, which is between the selected factor and the farmland productivity, was divided into the following membership function:

1) Upper limit model. It is for factors, such as organic matter, available phosphorus and available potassium. Its function model is shown as

$$y_i = \begin{cases} 0, u_i \le u_{t2} \\ \dfrac{1}{1+a_i(u_i-c_i)^2}, u_{t2} < u_i < c_i \ (i=1,2,3,\cdots,m) \\ 1, c_i \le u_i \end{cases} \quad (3)$$

where y_i is the membership grade or the comment of the factor i; u_i is the measure value of the sampling spot; c_i is the standard index; α_i is the coefficient; u_{t2} is the lower value of the index.

2) Lower limit model. It is for factors, such as terrain slope. Its function model is showed as

$$y_i = \begin{cases} 0, u_{t1} \le u_i \\ \dfrac{1}{1+a_i(u_i-c_i)^2}, c_i < u_i < c_t \ (i=1,2,3,\cdots,m) \\ 1, u_i \le c_i \end{cases} \quad (4)$$

where u_{t1} is the upper value of the index.

3) Apex model. It is for soil acidity. Its function model is showed as

$$y_i = \begin{cases} 0, u_i > u_{t1} \text{ or } u_i < u_{t2} \\ \dfrac{1}{1+a_i(u_i-c_i)^2}, u_{t1} < u_i < u_{t2} \ (i=1,2,3,\cdots,m) \\ 1, u_i = c_i \end{cases} \quad (5)$$

where u_{t1} is the upper value of the index and u_{t2} is the lower value of the index.

4) Concept model. It is for factors, such as soil parent material, soil profile structure, and relief type. Its membership grade is got from the experts estimation.

2.5 Evaluation unit map

In the process of the evaluation of farmland productivity, the evaluation unit map of farmland productivity is the basis of evaluation. Based on the overlay analysis of administrative map, the present land use map and soil image (see Fig. 2), the evaluation unit map of reclamation districts could be gained by spatial overlay tools of ArcGIS9, as shown in Fig. 3 [8].

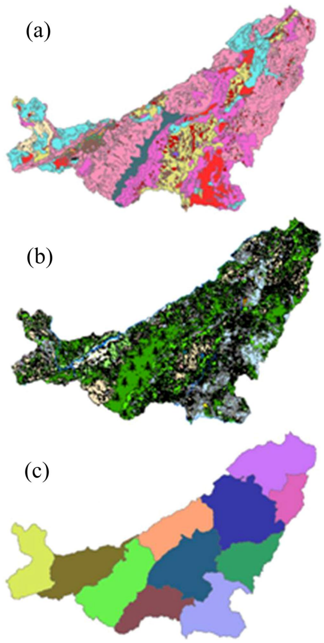

Fig. 2 Overlay of soil image (a), present land use map (b) and administrative map (c)

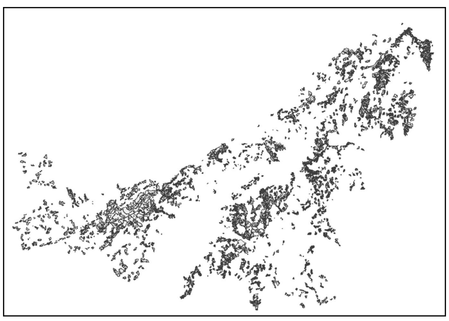

Fig. 3 Evaluation unit map

2.6 Data of evaluation factors

Every block of evaluation unit map should own attribute data of evaluation factors. According to the characteristics of different data, attribute data of evaluation factors can be got by the following steps:

Step 1 Sample spot data

① Collect the spatial position of sampling spot with GPS receiver.

② Make spot distribution map (see Fig. 4).

③ Based on the soil analysis data, adopt spatial interpolation to make grid map (see Fig. 5).

④ Assign soil attribute data of grid map to the evaluation unit map.

Step 2 Assign attribute data of vector map to the evaluation unit map

Step 3 Isoline map

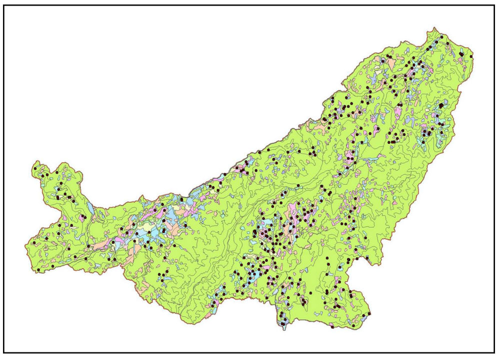

Fig. 4 Sampling spot map

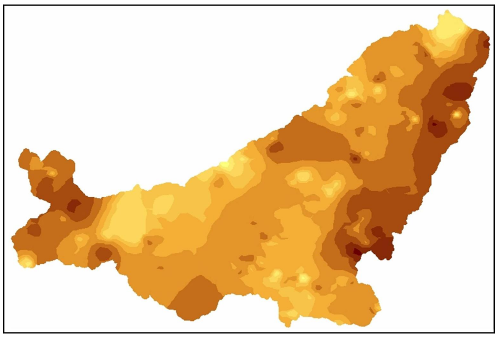

Fig. 5 Organic matter map interpolated from sampling spots

① Make grid map from isoline map.

② Carry through districted statistics in grid map.

③ Assign attribute data of regionalization to the evaluation unit map.

3 Experiment

3.1 Calculation of weight of single factor

① According to the characteristic of the mining area locality, experts must select evaluation factors to establish AHP model [9−13].

② Experts assigned scores or estimation values of the evaluation factors (Table 2).

③ Adopt maximum characteristic root method to calculate the combined weight of evaluation factors.

Table 2 Index weights of land productivity evaluation and results of AHP

Rule hierarchy	Score	Index hierarchy	Score	Combined weight
Soil management	1	Irrigation capacity	1	0.31
		Drainage capacity	3	0.10
		Crop rotation system	5	0.06
Site condition	2	Soil parent material	1	0.12
		Gradient	2	0.05
		Elevation	3	0.03
		Terrain slope	5	0.02
Profile shape	3	Plough layer depth	1	0.08
		Plough layer ply	3	0.02
		Soil profile structure	4	0.02
		Soil acidity	3	0.02
Physical-chemical property	4	Organic matter	1	0.04
		Soil texture	2	0.02
		pH	3	0.01
		Total nitrogen	3	0.01
		Available phosphorus	4	0.01
		Rapidly Available potassium	4	0.01

3.2 Example of calculating membership grade

1) Using the SPSS statistic software to carry on the membership function fitting of pH factor. Its procedure is given as follows:

① Experts estimate (see Table 3).

② Calculate parameters *a*, *c* (see Tables 4 and 5).

③ Match membership function Eq. (6).

$$y = 1/[1+0.265(u-c)^2],\ c=6.8,\ u_{t1}=4,\ u_{t2}=9 \quad (6)$$

2) Through experts estimation and the membership function fitting, description table about the soil fertility evaluation membership function and membership grade of concept model was got (see Table 6).

3) The membership grade of single factor was calculated through membership function and attribute data of the single factor in the evaluation unit extracted from the evaluation unit map.

Table 3 Experts estimation

pH	9.1	8.8	8.5	8.2	7.9	7.6
Expert estimation	0.28	0.44	0.58	0.70	0.80	0.88
pH	7.3	7.0	6.8	6.5	6.2	5.9
Expert estimation	0.94	0.98	1.00	0.98	0.94	0.88
pH	5.6	5.3	5.0	4.7	4.4	
Expert estimation	0.80	0.70	0.58	0.44	0.28	

Table 4 Iterative step

Iteration	Residual SS	*C*	*A*
1	0.065 7	6.800	0.300 0
1.1	0.053 1	6.751	0.260 9
2	0.053 1	6.751	0.260 9
2.1	0.052 9	6.749	0.265 7
3	0.052 9	6.749	0.265 7
5.1	0.052 9	6.750	0.265 5

Table 5 Parameter estimation of membership function

Parameter	Estimate	Standard error	Lower	Upper
c	6.750	0.55	6.632	6.868
a	0.265	0.20	0.222	0.309

3.3 Integrated fertility index

Additive model was used to calculate IFI of reclamation lands in mining districts:

$$I_{\text{IFI}} = \sum F_i \times C_i \quad (i=1,\ 2,\ 3,\ \cdots,\ n) \quad (7)$$

Table 6 Parameter estimation sets of membership function

Index	Function type	*a*	*c*	u_{t1}	u_{t2}	Condition
Available phosphorus	Upper limit model	0.004 29	30	2	0	Soil texture ='mid soil' or ' sandy soil' or 'loose sandy' or 'close sandy'
Available phosphorus	Upper limit model	0.004 29	30	5	0	Soil texture ='heavy soil' or 'light clay' or 'mid clay' or 'heavy clay'
pH	Apex model	0.265	6.8	4	9	
Terrain slope	Concept model	0.4	0	0	0	Terrain slope ='North' or 'NorthEast' or 'NorthWest'
Terrain slope	Concept model	0.6	0	0	0	Terrain slope ='West'
Terrain slope	Concept model	0.7	0	0	0	Terrain slope ='SouthWest'
Terrain slope	Concept model	0.8	0	0	0	Terrain slope='SouthEast' or 'East'
Terrain slope	Concept model	1	0	0	0	Terrain slope ='South'

Table 7 Classification scheme of land productivity

Classification	I_{IFI}	Classification	I_{IFI}
1-class	≥0.91	6-class	0.41−0.50
2-class	0.81−0.90	7-class	0.31−0.40
3-class	0.71−0.80	8-class	0.21−0.30
4-class	0.61−0.70	9-class	0.11−0.20
5-class	0.51−0.60	10-class	≤0.10

where I_{IFI} is integrated fertility index; F_i is the membership grade of the factor i; C_i is the combined weight of the factor i [14, 15].

3.4 Classification scheme of land productivity

With method of equal interval, classification scheme of the land productivity in mining districts was listed in Table 7.

4 Conclusions

1) This evaluation model is developed to estimate the productivity of reclamation lands in mining districts which is agricultural dependent on expert knowledge.

2) Productivity evaluation of reclamation land covers mutually related many natural elements and some factitious elements (such as irrigation and drainage capability), some of these elements can be rationed, such as plough layer depth and available phosphorus. Some of these elements are conceptual, such as geomorphic type and soil texture. In the process of evaluating land productivity the description of conceptual elements was by means of experts experiences or converted to ration with quantitative method generally. It also has reliance on the experts experiences when defining every element's contribution.

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