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Original Research Paper

The Reclamation Soil Suitability Study of the Highway Dumping Site Based on Fuzzy Comprehensive Evaluation Method

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ABSTRACT

Because the highway temporarily covers large areas, this article proposes fuzzy comprehensive evaluation method to evaluate the suitability of the reclamation soil in the highway dumping site. According to the impact factors of the land reclamation and the field survey, combining with the principle of fuzzy mathematics, we chose eleven influence factors, including weather conditions, soil physical properties, and soil chemical properties as evaluation factors. In this paper, we regarded nine dumping sites in Chengdu-Chongqing Expressway double-track (Chongqing section) project as samples to make the fuzzy comprehensive evaluation. The results indicate that the reclamation soil suitability in Chengdu-Chongqing Expressway double-track (Chongqing section) dumping sites is relatively good. It provides a useful reference value for the reclamation soil suitability evaluation of the national highway dumping sites.

INTRODUCTION

In recent years, with the high-speed development of the national economy and the accelerated industrialization and urbanization, highway - a modern construction project at the cost of damaging the ecological environment is in the period of high-speed industrial development (Wang 2006, Zhang 2003). Amid the construction of highway, the dumping site as a temporary area (agricultural lands occupied for parts of the dreg site), is the key place of occurring soil and water loss in the highway construction (Xie 2010, Wang 2006). Most of the places are loose heaped body. Its surface exposed and it has strong hydraulic permeability and severe uneven settlement, which easily results in landslide and debris flow under the combined effects of hydraulic power and gravity and has a direct threat to the safety of the production and living along the highway (Zeng 2004).

In order to better ensure the construction finished and reclaimed dumping sites to restore their original ecological functions, it requires analysis and the evaluation for the reclamation of soil physical properties, chemical properties and climate conditions and so on. Nowadays, the existing reclaimed land suitability comprehensive evaluation methods are: The comprehensive index method, the expert evaluation method, the extreme conditions of method, the extension method, etc. Su Haimin & Chen Jianfei (Su & Chen 2005) used the model of matter-element for land suitability assessment. Liu Jing and Li Jianxue (Liu & Li 2007) adopted the index pulsing method for land reclamation suitability evaluation on the land consolidation project of Qian County, Xianyang City, Shanxi Province, Xuelu town, Pan Qingyuan, Liu Xiaoli, etc. (Pan et al. 2007) based on extension method, evaluated the land reclamation suitability on the soil which was damaged from the reclamation lands to the cultivated lands in Jiawang, Xuzhou. However, using the currently existing indicators to quantify whether the soil is suitable for reclamation is still very difficult, so this paper introduces the fuzzy comprehensive evaluation method. The study adopts fuzzy mathematics theory to alter qualitative evaluation into quantitative evaluation. This method can make the results clear and systematic, and can better solve the problems which are vague and difficult to quantify. It is suitable for solving a variety of non-deterministic problems. Therefore, this article introduces the fuzzy comprehensive evaluation method to evaluate reclamation soil suitability of the dumping site of the Chengdu-Chongqing Expressway double-track (Chongqing section). The research results can provide guidance and be used for reference for reclamation work of the lands of dumping site of highway.

OVERVIEW OF THE STUDY AREA

The study site is the Chengdu-Chongqing Expressway double-track (Chongqing section), of which the specific choices of site are the Bishan County, Tongliang, Dazu County in Chongqing Municipality.

Chengdu-Chongqing Expressway double-track (Chongqing section) is located in the central tectonic parallel

Ridge (low mountains) Valley (hills) district, Western Hills district of Chongqing, a subtropical humid monsoon climate zone; mean annual rainfall ranges from 1004mm to 1231mm. The place has subtropical vegetation type, that is, humid evergreen broad-leaved forest. Plant species are mainly masson pine, fir, cedar and so on. Soil types are mainly paddy soil, purple soil and yellow soil. The highway starts in Chongqing Ring Road, connects planned city trunk road eastward, and traverses Jinyun pulse to the west. Crossing Bayue Mountains, through the place 4km from Bishan County in the north and 5km from the Dazu county in the south, stoping at Guanyinqiao, the junction of Sichuan and Chongqing and connecting with the Chengdu-Chongqing Expressway double-track (Sichuan section), the whole line is located in the key national supervision region and the key national rehabilitation region for the soil and water loss of Chongqing. The length of the line is about 79.880km, covering an area of 642.97 hm^2, which permanently covers an area of 570.90 hm^2 and temporary land of 72.07hm^2. The full range of excavation is 17.49 million m^3 and the fill is 16.21 million m^3. The abandon party is 4.10 million m^3 (permanently abandoned party 3.23 million m^3, planning 26.50 hm^2/12 dumping sites, temporary disposable party 86.8500 km^3). The debit is 2.83 million m^3(planning 19.60 hm^2/nine earth fields).

The geographical coordinates of Bishan County are 106° 02'-106°20'E, 29°17'-29°53'N, and the average temperature is 17.9°C. Over the years the extreme maximum temperature is 40.6°C and the minimum temperature is -3°C. The average annual frost-free period is 337d. The geographical coordinates of Tongliang county are 105°46'-106°16'E, 29°31'-30°06'N. The average temperature is 17.8°C. The annual average relative air humidity is 82% and the average annual frost-free period is 225d. The geographical coordinates of Dazu county are 105°28'-106°02'E, 29°23'-29°52'N. The average annual temperature of 17.20°C over the years and the average annual frost-free period is 323d.

MATERIALS AND METHODS

Sample collection: Along the route selected of the dumping sites, we selected a point respectively in the upper, centre and lower, excavated the soil profile (0-30 cm selected) and use soil sample collector to collect the soil at 0-10cm (layer A) 10-20cm (layer B) and 20-30cm (layer C). If the dumping is large enough, we can select multiple points along the length, and select the corresponding points to collect soil in the centre and lower parts. Then, the taken soil samples on the same height and same profile heights were uniformly mixed. One kg mixed soil samples were taken back to the laboratory for indoor testing. Altogether, 27 soil samples were collected.

Analytical methods: Soil moisture content was measured by the drying method. Soil compaction was measured by a SC-900 soil compaction. The content of the soil organic matter (SOM) was measured by the potassium dichromate method, and total nitrogen (TN) content by sulphuric acid digest diffusion method. The content of total phosphorus (TP) was measured by NaOH melt-molybdenum antimony anti-colorimetric determination, content of total potassium (TK) using NaOH melting-flame photometric determination, and content of available nitrogen (AN) by alkaline solution diffusion method. Determination of available phosphorus (AP) was made by $NaHCO_3$-molybdenum antimony anti-colorimetric method, and the content of available K (AK) by NH_4Ac-flame photometry (Yang 2008).

Data processing: The experimental data were analyzed by MATLAB mathematical analysis software and Excel statistical software.

FUZZY COMPREHENSIVE EVALUATION

Fuzzy Comprehensive Evaluation Method

Fuzzy comprehensive evaluation method is based on the principle of fuzzy mathematics, using the fuzzy statistical methods through considering a combination of relative factors for evaluation and the subjective assignment method to determine the weight of various factors to make the evaluation of the pros and cons of the research objects. It is not only a quantitative evaluation, but also a qualitative assessment. What is more important is that it can combine quantitative and qualitative factors to evaluate comprehensively (Yu 2004), which can better reflect the impact under the combined effects of various factors. Specific evaluations have the following steps:

1. To determine the set of factors of the evaluation object
2. To determine the factors the weight set
3. To determine the reviews set
4. To make the evaluation of the single factor
5. Comprehensive evaluation

The Choice of Fuzzy Factor

In this paper the choice of fuzzy factor is based on the combination of the land potential factors and reality. Overall it includes: (1) weather conditions: the average annual rainfall, average annual temperature; (2) soil physical properties: soil moisture content, soil compactness; (3) soil chemical properties: soil organic matter content, soil nutrient content (TP, AP, TK, AK, TN, AN). The data of the above factors are easy to be collected or measured, and are strongly representative. Therefore, it is more conductive to the promotion of fuzzy comprehensive evaluation method.

Fuzzy Comprehensive Evaluation Process

1. Establish the factor set: R = {r1, r2, ...ri, rm}. Among them, R is the influencing factors set, ri is the ith influencing factors and m is the number of the factors (Zhang 2003). Now regard the factors from r1 to r11 respectively as soil moisture, soil compaction, soil organic matter content, AP content, TP content, TK content, AK content, AN content, TN content, average annual rainfall and the average annual temperature.

2. Establish weight set: A = (a1, a2, ...ai, am). Among them, A is the factor weight set and ai is the corresponding weight coefficient of factor ri, requiring ai ≤ 0, Σai = 1 (Zhang 2003). Now, take the weight coefficient of various factors respectively as follows: soil moisture is 0.25, soil compaction is 0.175, the soil organic matter content is 0.175, AP content is 0.025, TP content is 0.025, TK content is 0.025, AK content is 0.025, AN content is 0.025, TN content is 0.025, average annual precipitation is 0.175 and average annual temperature is 0.075. Namely, the weight set A = (0.25, 0.175, 0.175, 0.025, 0.025, 0.025, 0.025, 0.025, 0.025, 0.175, 0.075).

3. Establishing an evaluation set: V = {v1, v2, ...vj, vn}. Among them, V is the evaluation set and vj represents the jth evaluation result and n is the total number of evaluation results (Zhang 2003). Now, taking the set n = 5, which can be divided into five evaluation ranks v1 to v5 separately on behalf of suitability, less suitability, general, less unsuitability, unsuitability (Table 1).

4. Single factor fuzzy evaluation: Ri = {ri1, ri2, ..., rij}. Among them, Ri is the evaluation set of the single factor and rij represents the degree of membership which ri is relative to vj. Make a matrix:

$$R=\begin{bmatrix} R1 \\ R2 \\ M \\ Ri \end{bmatrix}=\begin{bmatrix} r_{11} & r_{12} & \mathbf{L} & r_{1j} \\ r_{21} & r_{22} & \mathbf{L} & r_{2j} \\ M & M & M & M \\ r_{i1} & r_{i2} & \mathbf{L} & ri_j \end{bmatrix}, \qquad ...(1)$$

R is the single factor evaluation matrix (Zhang 2003) as given in Table 2.

5. Fuzzy comprehensive evaluation: fuzzy comprehensive evaluation can be expressed as B = A • R, That is,

$$(b_1 \quad b_2 \quad \mathbf{L} \quad b_n) = (a_1 \quad a_2 \quad \mathbf{L} \quad a_m) \bullet \begin{bmatrix} r_{11} & r_{12} & \mathbf{L} & r_{1j} \\ r_{21} & r_{22} & \mathbf{L} & r_{2j} \\ M & M & M & M \\ r_{i1} & r_{i2} & \mathbf{L} & ri_j \end{bmatrix} ...(2)$$

Among them, b_j is the evaluation index, and is the degree of membership which is evaluation factors membership to evaluation sets considering all the factors (Zhang 2003). The sign "•" representing a synthesis method of A and R, the composite model has the following four:

Model one: M, (the main factors determine type,

$$b_j = \bigvee_{i=1}^{m} (a_i \wedge r_{ij});$$

Model two: M, the highlight the type of the main factors,

$$b_j = \bigvee_{i=1}^{m} (a_i r_{ij});$$

Model three: M, the weighted average type,

$$b_j = \min\left\{1, \sum_{i=1}^{m} a_i r_{ij}\right\}$$

Model four: M, the weighted average type,

$$b_j = \sum_{i=1}^{m} a_i \cdot r_{ij};$$

Finally, according to the maximum membership degree principle the evaluation results can be estimated (Zhang Jianxia et al. 2003).

Model one "the main factors determine type" mainly operate ¸ and °. The operation is simple, but for some of the issues it may miss a lot of information. Its evaluation results depend only on the factors that play a major role in the total evaluation. The remaining factors did not affect the evaluation results (Chen 2005), thus, the results are somewhat rough. When the Factors are too many and the weight distribution is more balanced, according to

$$\sum_{i=1}^{m} ai = 1 \qquad ...3$$

each factor shares weight ai must be very low. Only with the operator ¸, ° getting the low bj (bj ≤ Vai) is also destined in the comprehensive evaluation, and then the smaller weight taken by the ¸ operator is actually unable to get satisfactory results.

Model two is the main factors highlight type, and it is more specific compared with the model one, which not only highlights the main factors, but also takes other factors into account (Chen 2005). Although a_i is related to the importance of the factors x_i, it doesn't have the meaning of weight coefficient. Therefore, the vector A needn't be normalized, either.

Model three and four are the "weighted average-type". The vector A has the right meaning of weight coefficient which represents the importance of each factor xi, and therefore it should meet the requirements of-

$$\sum_{i=1}^{m} ai = 1$$

But the model IV should be evenly in accordance with the weights of all factors.

Since each of the four models has its own distinct characteristics, this article use the four models at the same time to make a comprehensive evaluation to ensure the comprehensiveness of the evaluation results.

RESULTS AND DISCUSSION

According to the above process step by step evaluation, available results can be concluded in the Table 3.

Based on the maximum membership degree principle of fuzzy comprehensive evaluation method, it can be ensured that the results determined by the four model evaluation are the second grade. The reclamation soil suitability for the highway dumping site is relatively suitable.

Fuzzy comprehensive evaluation method used in this article is based on the principle of fuzzy mathematics (Han 1998) to establish a quantitative evaluation model in a fuzzy environment, considering a variety of factors to make an overall assessment. In the study on suitability of reclamation soil for highway dumping sites, due to the fact that the suitability of the reclaimed soil is affected by many factors, each of the factors are not only evaluated separately, but also analyzed through combining the influence of each factors by the comprehensive evaluation. In the process of evaluation of qualitative factors, it can alter qualitative factors into quantitative evaluation, which adds to the scientificity and reliability of the evaluation model. Therefore, this study proposes the use of fuzzy comprehensive evaluation method for reclamation soil suitability evaluation of highway dumping site.

In this study, the evaluation model is built in accordance with the steps of the fuzzy comprehensive evaluation method. And the fuzzy comprehensive evaluation model is used to analyze on the Chengdu-Chongqing Expressway double-track (Chongqing section). Select 9 the dumping sites of the section, according to the reclamation soil suitability factors, choose 11 evaluation factors combining the facts as the evaluation factor to input the fuzzy comprehensive evaluation model for the reclamation soil suitability analysis. The conclusions are as follows:

A. In the reclaimed soil suitability evaluation, due to the fact that the factors which impact the reclamation soil suitability are too many and each of the factors has different nature. If it is just analyzed from a single factor to estimate the reclamation soil suitability, it is difficult to get a comprehensive evaluation results. However, using fuzzy comprehensive evaluation method to evaluate the suitability of the highway dumping sites for reclamation of soil is more rigorous theoretically and can take advantage of the limited data to clearly estimate the soil reclamation, and to get comprehensive results to accurately reflect the suitability of the reclamation soil.

B. Using of the existing highway dumping site research data and the relevant parameters as samples to establish the fuzzy comprehensive evaluation model, and the reclamation soil of Chengdu-Chongqing Expressway double-track (Chongqing section) dumping site as samples to evaluate its suitability, the data come from engineering practice, which have certain representativeness. The research can provide a reference for the new highway reclamation soil suitability research and guidance.

C. Using fuzzy comprehensive evaluation method can more objectively represent the reclamation soil suitability classification boundaries of the highway dumping sites by the membership and the right weight, note that the actual blur-

Table 1: Highway soil and water conservation measures benefit in the evaluation factor classification table.

Evaluation factors		Evaluation factor level				
		Grade Ⅰ	Grade Ⅱ	Grade Ⅲ	Grade Ⅳ	Grade Ⅴ
Soil moisture content (%)	Classification range	≤75	75～115	115～125	125～139	≥139
Soil compaction	Classification range	≤4%	4%～5.6%	5.6%～6.5%	6.5%～7%	≥7%
Soil organic matter content	Classification range	≤7	7～8.2	8.2～9.3	9.3～10	≥10
Soil available phosphorus content	Classification range	≤0.4	0.4～0.48	0.48～0.57	0.57～0.7	≥0.7
Total soil phosphorus content	Classification range	≤8	8～8.5	8.5～9.2	9.2～10	≥10
Total K content	Classification range	≤15	15～15.8	15.8～16.5	16.5～18	≥18
Available potassium	Classification range	≤40	40～45	45～55	55～64	≥64
Soil nitrogen content	Classification range	≤55	55～69	69～75	75～91	≥91
Total soil nitrogen content	Classification range	≤0.6	0.6～0.68	0.68～0.74	0.74～0.8	≥0.8
Average annual precipitation (mm)	Classification range	≤1005	1005～1066	1066～1142	1142～1200	≥1200
Average annual temperature (℃)	Classification range	≤16.2°	16.2°～16.9°	16.9°～17.0°	17.0°～17.7°	≥17.7°

Table 2: Single factor evaluation of the calculation table.

Evaluation factors	Rank membership				
	Grade Ⅰ	Grade Ⅱ	Grade Ⅲ	Grade Ⅳ	Grade Ⅴ
Soil moisture content (%)	0.231	0.115	0.115	0.269	0.077
Soil compaction	0.077	0.423	0.154	0.115	0.231
Soil organic matter content	0.385	0.077	0.192	0.154	0.192
Soil available phosphorus content	0.269	0.269	0.192	0.154	0.115
Total soil phosphorus content	0.077	0.269	0.346	0.115	0.192
Total K content	0.154	0.231	0.346	0.192	0.077
Available potassium	0.192	0.231	0.269	0.192	0.115
Soil nitrogen content	0.077	0.346	0.269	0.231	0.077
Total soil nitrogen content	0.154	0.192	0.115	0.192	0.346
Average annual precipitation (mm)	0.462	0	0.462	0	0.077
Average annual temperature (℃)	0	0	0.462	0	0.538

Table 3: Highway soil and water conservation measures.

Evaluation Model	Rank					Maximum degree of membership	Evaluation results
	Grade Ⅰ	Grade Ⅱ	Grade Ⅲ	Grade Ⅳ	Grade Ⅴ		
Model 1	0.231	0.25	0.231	0.154	0.175	0.25	Grade Ⅱ
Model 2	0.081	0.101	0.081	0.029	0.04	0.101	Grade Ⅱ
Model 3	0.243	0.273	0.239	0.103	0.143	0.273	Grade Ⅱ
Model 4	0.243	0.273	0.239	0.103	0.143	0.273	Grade Ⅱ

ring of the distinction, so that evaluation results close to the facts. On the basis of the operation of the existing highway project, using the Matlab programming language as a platform has a strong scientificity and feasibility for the final reclamation soil suitability evaluation model established by the input sample data analysis and the processing and nonlinear optimization.

D. Fuzzy comprehensive evaluation method applied to the highway dumping sites for the reclamation of soil suitability evaluation can scientifically estimate the soil reclamation suitability degree of reclamation soil of dumping sites. For the dumping site in the same area, the reclamation soil can be estimated whether it is suitable according to the level of scores. Thus, the effect of soil reclamation can be predicted, providing the reference for the land reclamation work in the road construction in the same area.

E. The actual evaluation results further validate the feasibility, accuracy and objectivity of the fuzzy comprehensive evaluation method. It can be a viable and an effective way for the reclamation soil suitability analysis, but the calculation of fuzzy comprehensive evaluation method for adaptability evaluation of reclamation soil in highway dumping site is relatively more complex and not as simple and quick as a single factor evaluation method.

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