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THE APPLICATION OF REMOTE SENSING TECHNIQUE AND AHP-FUZZY METHOD IN COMPREHENSIVE ANALYSIS AND ASSESSMENT FOR REGIONAL STABILITY OF CHONGQING CITY, CHINA

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ABSTRACT: Regional stability is an important factor to engineering construction. The paper, taking the TM image as a main information sources, combining with the AHP-FUZZY method, comprehensively analyses the regional geological environmental condition of Chongqing municipality. The result shows that the stable region accounts for 72.24% of total area, the less stable region and the unstable region 27.76%. This means that Chongqing city is basically in a good condition of regional stability. This reasonable result can provide references for regional planning of mid and long range planning, selecting site for important projects and immigrant in Chongqing city.

1 INTRODUCTION

Chongqing city locates in the southwest of China, between Qingzang plateau and Middle-down stream plain of Yangzi River. The landform of the area is varied with high mountains and deep valleys. Except upper Silurian system, lower Devonian system, upper Carboniferous system and the Tertiary system, other stratums from Banxi group to Quaternary system are all distributed. The faults are well development in NE and NWW direction.

After Chongqing became a municipality, its land area extended from 23,000 km^2 to 82,000 km^2. The original resource and environmental data can not meet the government any more. Thus, regional stability assessment is very important to draw up economic middle-long planning, select sites for important projects.

2 SELECTING REGIONAL STABILITY FACTORS AND EXTRACTING REMOTE SENSING INFORMATION

2.1 Selecting regional stability factors

There is no uniform recognition for regional stability concept at present, so to find a reasonable scale to evaluate the regional stability and select regional stability factors are urgently necessary. In this paper, regional stability includes the regional crust stability and land stability two respects, which are affected by some factors. In different area, different factors play different role, and main factors must be picked up. According to the substantial condition of the research area, the activity of faults, the magnitude of faults, the intensity of earthquake, tectonic stress field (the angle between principal pressure stress and strike direction of fault is take into accounts), Bouguer gravity anomaly, crust structure are selected as regional crust stability assessment factors, and rock sets and landform are selected as land stability assessment factors, then AHP and two orders fuzzy judge method are applied to evaluate the regional stability of Chongqing Municipality.

2.2 Extracting remote sensing information

The regional stability factors that can be picked up from remote sensing image are landform, nature of rock and fault, and the others factors are picked up by conventional methods.

(1) landform and type of rock sets. Different type of landform emerged with different forms and different veins on the remote sensing image. Combining with landform map, we can extract landform type exactly. The type of landform in the research area mainly controlled by nature of rock and geological structure, late tectonic movement, which is even more important. The predominant strike direction of mountains is NE and changes to NWW to northeast part. Middle mountain is the main type of landform, and low mountain, hills and platform are secondary. Rock sets information is extracted by its color, form and vein etc. combining with pertinent geological data. In this paper, rock masses and soil masses are divided into three types, loose type (Quaternary system soft debris), secondary hard – soft type (mainly consists of interbreeds of soft and hard rock level) and hard –

secondary hard type (mainly consists of Carbonate, sandstone and metamorphic rock) .

(2) Fault. Fault is often straight or with a little curve on the remote sensing image. The trait is often exhibited by the anomaly linear of color, landform, nature of rock, stratum, stream and comprehensive landscape. In order to explore detail characteristics such as the strike direction, magnitude of the fault in some special area, we use ratio (TM5/TM1, TM5 × TM7/TM1 × TM2, TM7 × TM1/TM3 × TM4) Laplace convolution, direction convolution and pseudo color synthesizes, which strengthen the linear image of different directions respectively and this is important to analyses the details of the fault.

3 FACTORS AHP ANALYSIS

As discussed above, the factors that influence the regional stability are complex, and it is difficult to decide weight of each factor. To solve this problem, AHP method is introduced here.

3.1 AHP model

AHP is a multi-objective, multi-criterion decision making approach which employs a pair-wise comparison procedure to arrive at a scale of preferences among sets of alternatives. To apply this technique, it is necessary to break down a complex unstructured problem into its component parts arraying these parts, or variables, into a hierarchy order; assigning numerical values to subjective judgements on the relative importance of each factor and synthesizing the judgement to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. The AHP model in this paper has three levels (Fig. 1), and the line between each level demonstrates the logic relationship of the factors.

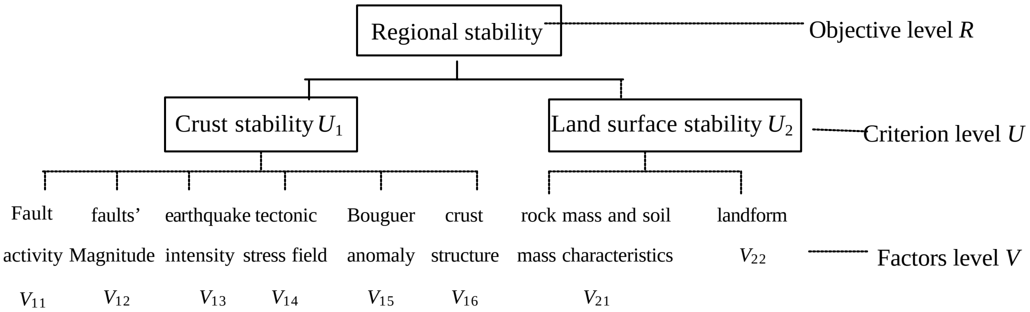

Fig.1 AHP structure model

3.2 Judge matrix generation

Judge matrix demonstrates the importance of each factor in the inferior level to a factor of the senior level. In order to make the relative importance of factors be quantitative, the scale of A.L.Saaty is introduced here. The mean of scale is shown in the table 1.

Table 1 Scale of relative importance[10]

Intensity of Relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocal	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared to i.	

Use scale and then judge the relative importance of factors of each level, we can get judge matrix *A*. Compare the relative importance of factors of the criterion level to the objective level, we can get the judge matrix of the criterion level U to the objective level R $A_{R-U} = (a_{ij})_{2x2}$ as follows:

$$A_{R-U} = (a_{ij})_{2x2} = \begin{pmatrix} 1 & 8 \\ 1/8 & 1 \end{pmatrix}$$

Similarly, the judge matrix of the factors level V_{1j} to the criterion level U can be written as:

$$A_{U_1-V_{1j}} = (a_{ij})_{6\times 6} = \begin{pmatrix} 1 & 3 & 1 & 3 & 5 & 5 \\ 1/3 & 1 & 1/3 & 1 & 3/2 & 2 \\ 1 & 3 & 1 & 2 & 3 & 3 \\ 1/3 & 1 & 1/2 & 1 & 1 & 1 \\ 1/5 & 2/3 & 1/3 & 1 & 1 & 2 \\ 1/5 & 1/2 & 1/3 & 1 & 1/2 & 1 \end{pmatrix}$$

and the judge matrix of the factors level V_{1j} to the criterion level U can be written as:

$$A_{U_2-V_{2j}} = (a_{ij})_{2x2} = \begin{pmatrix} 1 & 5 \\ 1/5 & 1 \end{pmatrix}$$

3.3 Hierarchy single sorting and consistency test

From the judge matrix , the maximum eigenvalue ? $_{max}$ of the matrix and the corresponding eigenvector W can be gotten. Make the W normalize, the weight which the factors of the inferiors level to one of factors of the senior level can be reached, and this process is called hierarchy single sorting. To ensure the confidence, the consistency test is necessary, that is to calculate consistency index $CI=(l_{max}-m)/(m-1)$,where m is the element number in the judge matrix.

To judge the consistency of different judge matrixes, the index RI of average random consistency of the judge matrixes is introduced. To 1~9 order judge matrix, RI can be gotten from table 2.

Table2 The index RI of average random consistency[10]

1	2	3	4	5	6	7	8	9
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

When the order of the judge matrix is bigger than 2, the ratio of consistency index CI to average random consistency index RI is named CR, $CR=CI/RI$. The judge matrix is considered tolerable if $CR<0.1$, and the single sorting is reasonable, in verse, the judge matrix should be modified.

3.4 Hierarchy general sorting and consistency test

The process to sort weight of all factors of the same level to the objective level is called hierarchy general sorting. The process processes from the top level to the lowest one by level. The weight of general sorting can be gotten by table3, where w' is the weight.

Table 3 General sorting weight of level *V*

Level *U* / Level *V*	U_1	U_2	……	U_m	general sorting weights of level *V*
	w'_1	w'_2	……	w'_m	
V_{11}	w'_{11}	w'_{12}	……	w'_{1m}	$\sum_{j=1}^{m} w'_j w'_{1j}$
V_{12}	w'_{21}	w'_{22}	……	w'_{2m}	$\sum_{j=1}^{m} w'_j w'_{2j}$
V_{1x}	w'_{x1}	w'_{x2}	……	w'_{xm}	$\sum_{j=1}^{m} w'_j w'_{xj}$
V_{mz}	w'_{n1}	w'_{n2}	……	w'_{nm}	$\sum_{j=1}^{m} w'_j w'_{nj}$

It is necessary to give consistency test to hierarchy general sorting, and the test processes from the top to the low too. Given CI_j represents the single sorting consistency index of each factor of V level to U_j and RI_j represents the average random consistency index, the hierarchy general sorting index CI can be expressed as: $CI = \sum_{j=1}^{m} w'_j CI_j$ and hierarchy general sorting average random consistency index RI can be calculated: $RI = \sum_{j=1}^{m} w'_j RI_j$ and then the hierarchy general sorting consistency ratio CR can be gotten by:

$$CR = \sum_{j=1}^{m} w'_j CI_j \Big/ \sum_{j=1}^{m} w'_j RI_j$$

The test to general sorting confidence is similar to that of hierarchy single sorting, that is CR must be less than 0.1. By this algorithm, the weight sorting result of this research is shown in table 4.

Table4 Hierarchy weight sorting table

level U / level V	U_1	U_2	Relative priority weights
	0.889	0.111	
V_{11}	0.341	0	0.303
V_{12}	0.115	0	0.102
V_{13}	0.271	0	0.241
V_{14}	0.104	0	0.092
V_{15}	0.095	0	0.084
V_{16}	0.073	0	0.065
V_{21}	0	0.833	0.092
V_{22}	0	0.167	0.019

The vector shows obviously that the importance of each factor to regional stability is different. The fault's activity and magnitude of the earthquake are first important, and the magnitude of fault, tectonic stress field, characteristics of rock and soil masses, gravity field and crust structure are secondary important. The landform factor is the least important among all the factors.

4 TWO ORDERS FUZZY JUDGE AND THE RESULT

4.1 General introduction

Firstly, to form the single factor fuzzy matrix A by single factor assessment. Secondly, to form the weight vector R according to the importance of each factor to objective through AHP. Thirdly, to get the assessment set of the total system by integration of A and R, that is $ROA=B$, where $B=(B_1, B_2, \ldots, B_i, \ldots)$ and B_i is the degree of membership of the assessment objective to assessment i.. This is the general procedure of fuzzy comprehensive judge.

Three models of integration of judge matrix A and weight sets B in common use, they are primary factor decision, primary factor outstanding and weighted average[10]. Because the regional stability is decided by the interaction of all factors, not one of them, it is reasonable to adopt weighted average to give assessment. The weighted average method can be described as follows:

Fuzzy matrix $A = (a_{ij})_{n\times m}$; weighted vector $R = (r_i)_{1\times n}$; assessment set B:

$B=ROA=(b_1 \quad b_2 \quad \ldots \quad b_m)$, where $b_j = \sum_{i=1}^{n} r_i a_{ij}$, j=1,2,… …,$m$.

4.2 Criterion of single factor assessment

Based on forerunners research materials and combined with facts of this area, this paper gives three scales: ? -stable area, ? -secondary stable area and ? -bad stable area to assess regional stability of Chongqing municipality.

Accordingly, the index limitation of the factor should be scaled by three scales. The assessment indexes of the factor of this research are listed in the table5.

Table5 The single factor assessment index of regional stability

factors		scale		
		stable area	secondary stable area	bad stable area
regional crust stability	fault activity	no fault or old fault	sub-fault of active fault	active fault
	fault magnitude	little fault or no fault	basement fault	crust fault
	intensity of earthquake	$<VI$	VI	$>VI$
	tectonic stress field (angle between main stress and fault strike direction)	0~ 10^0 or 71~ 90^0	11~ 24^0 or 51~ 70^0	25~ 50^0
	Bouguer gravity anomaly	$<5\times10^{-5}$m/s^2 · 10km	5~ 10 $\times10^{-5}$m/s^2 · 10km	$>10\times10^{-5}$m/s^2 ·10km
	characteristics of crust structure	block structure	mosaic structure	Block fission structure
land stability	characteristics of rock and soil masses	hard to secondary hard	secondary hard to weak	soft debris
	landform type	hills or platforms	low mountains	middle mountains

4.3 To decide the degree of membership of the single factor

The degree of membership generally described by a function. To choice the function is a very arduous work, and there is no completed and general method. In general, statistics is be used according to research objective to get it, and normality function often be used under many conditions, which is not convenient and its physical mean is blur. In this paper, we use area element to decide the degree of membership. First use the square mesh to discrete the research area, then introduce a_{ik} as follows:

$$a_{ik} = \begin{cases} 0, & \text{factor } i \text{ accounts for 0 for scale } k \text{ in one element} \\ s_k / s & \text{factor } i \text{ accounts for } S_k \text{ for scale } k \text{ in one element} \\ 1 & \text{factor } i \text{ accounts for } S \text{ for scale } k \text{ in one element} \end{cases}$$

where a_{ik} is the degree of membership of factor i to scale k in element n_{ij}. This method is easy, convenient, and feasible to calculate the degree of membership of factor .

4.4 Two orders fuzzy comprehensive judge process and the result

According to general requirement of two orders fuzzy comprehensive judge, the total assessment process is as follows:

(1) Use the square mesh(2×2cm) to discrete the map of the research area(1: 500,000), thus we can get 948 meshes .

(2) Measure the area of each factor occupied for regional stability scale in one mesh and calculate the degree of membership;

(3) The first order fuzzy comprehensive judge: use relationship matrix A_1 and A_2, and weight vectors R_1 R_2 gotten by AHP, then integrate them according to $ROA=B$, and then the assessment result of criterion levels will be attained:

U_1:

$$B_1 = R_1 O A_1 = \begin{pmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} & r_{16} \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \\ a_{41} & a_{42} & a_{43} \\ a_{51} & a_{52} & a_{53} \\ a_{61} & a_{62} & a_{63} \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & b_{13} \end{pmatrix}$$

$$U_2: B_2 = R_2 O A_2 = \begin{pmatrix} r_{21} & r_{22} \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \end{pmatrix} = \begin{pmatrix} b_{21} & b_{22} & b_{23} \end{pmatrix}$$

where b_{ij} represents the degree of membership of factor V_{ij} to criterion level U_i.

(4) The second order fuzzy comprehensive fuzzy judge: Similarly, below the objective level R, integrate fuzzy relationship matrix $A=(b_{ij})_{2\times3}$ combined by B_1? B_2 and weight vector R by $B = ROA$

$$B = ROA = (r_1 \quad r_2)\begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \end{pmatrix} = (b_1 \quad b_2 \quad b_3) = (b_j)$$

where b_j is the degree of membership of one of elements to scale j of regional stability, and j=1 represents bad stable area, j=2 secondary stable area and j=3 stable area. According to the maximum principal, the degree of stability of the element can be decided

By the process described above, the regional stability of Chongqing municipality is assessed here. There are 746 stable elements, 100 secondary stable elements and 102 bad stable elements as shown in Table 6. The most area of Chongqing municipality is stable.

Table6 The assessment result of Chongqing regional stability

	scale		
	stable area	secondary stable area	bad stable area
element number	746	100	102
area (km^2)	59126.70	11127.99	11591.50
the ratio (%)	72.24	13.60	14.16
regional distribution characteristic	widely spread, no active fault and weak earthquake	mainly spread in Pengshui, Qianjiang between Qizhaishan fault and Xianfeng fault, Rongchang, Shuangqiao near Huayingshan fault and near area along Changshou fault and Fangdoushan fault	mainly spread along fault such as Huayingshan fault, Qizhaishan fault, Chengkou fault and Xianfeng fault

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