A SET PAIR ANALYSIS MODEL FOR SUITABILITY EVALUATION OF HUMAN SETTLEMENT ENVIRONMENT

by

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The human settlement environment is a dynamic subsystem where people live and produce in the social system. This paper aims at evaluating comprehensively the suitability state of a given human settlement environment in a certain time and space and its evolutionary trend, the set pair analysis theory and its connection numbers are introduced into the suitability evaluation, and the set of human settlements is established. The set pair analysis model based on partial connection number is used to assess the suitability status and the development trend of human settlements in Guizhou Province from 2014 to 2017. The result shows that the set pair analysis model has the features of convenience, impersonality and good feasibility.

Key words: *human settlement environment, suitability evaluation, set pair analysis, partial connection number*

Introduction

The human settlement environment is an artificial environment built on the basis of natural environment. It is a dynamic system in which people produce and live in a large social system that is constantly evolving [1]. The development of economy and society makes residents pay more and more attention to their quality of life. As the basic unit of human settlement, a city's livability has always been the focus of residents [2, 3]. At present, the living quality of residents is getting better and better, the transportation is more convenient, the information is more convenient, but it also causes a series of problems such as environmental pollution, traffic congestion, housing shortage, *etc.* Therefore, the suitability of human living environment has become a hot spot of current research.

Zhao [4] first proposed the set pair theory to study the uncertainty problem of a system and to judge the trend of the change of the uncertain problem. The set pair refers to a pair of two collections that are related under the background of the specific problems by analyzing quantitatively characteristics of two sets from three perspectives of *with*, *different*, *against*. The set pair analysis theory is often applied to the engineering safety, trend prediction, and risk assessment [5]. Characteristics of the set pair analysis includes mathematical modeling, uncertain system analysis, target recognition, systems description, quantitative description, and specific analysis of research object. In resource and environment systems, there are many

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evaluation and decision models [6]. To improve the accuracy and reduce the uncertainty of the evaluation model, some set pair analysis models have been developed [7, 8].

In this paper, the set pair analysis theory and its connection numbers are introduced into the suitability evaluation of human settlements, and the set of human settlements is established. The set pair analysis model based on partial contact number is established. This model is used to assess the suitability status and development trend of human settlements in Guizhou Province from 2014 to 2017.

Partial connection number

Connection number is an important concept in the set pair analysis. Its expression is:

$$\mu = \frac{S}{N} + \frac{F}{N} i + \frac{P}{N} j \tag{1}$$

where N is the total number of features contained in all object sets, S – the same feature number in all object sets, P – the opposite feature number in all object sets, and F – the feature number that is neither the same nor opposite between two object sets. The relation is $N = S + P + F$. Set $a = S/N$, $b = F/N$, $c = P/N$, thus eq. (1) can be simplified into the form of the following connection number:

$$\mu = a + bi + cj \tag{2}$$

According to eq. (1), it can be known that $a + b + c = 1$, and $a, b, c \in [0, 1]$, $i \in [0, 1]$, $j = -1$, a is the same degree component, and the coefficient is 1, which belongs to the positive level. The b is the difference degree component, and the coefficient range is [–1, 1], which is at the uncertainty level where part is positive and part is negative. The c is the component of the degree of opposition, and the coefficient is –1, completely at the negative level.

Connection number is a kind of structural function of the research object under the condition of the uncertain relation state. Partial association number is an adjoint function of connection number. It can represent the development trend of the research object from three perspectives: the same, difference, the opposite [9]. The development trend of the research object can be predicted. In the connection number μ, a, b, c, and j are macroscopic parameters, i is the parameter at the micro level. The element of the connection number at the micro level can be increased by expanding the b_i section, the form is:

$$\mu = a + b_1 i_1 + b_2 i_2 + ... + b_{n-2} i_{n-2} + cj \tag{3}$$

According to the set pair analysis, when $n = 5$, eq. (3) is the five-element connection number:

$$\mu = a + bi + cj + dk + el \tag{4}$$

By calculating the partial association number, the development trend of the research object can be obtained and the prediction can be made. The following only provides the knowledge of partial ternary connection number associated with the calculation of the example in this paper.

Definition 1. With a ternary connection number $\mu = a + bi + cj$, $a \in [0,1]$, $b \in [0,1]$, $c \in [0,1]$, $a + b + c = 1$, $i \in [-1,1]$, $j = -1$. The first order partial positive connection number is:

$$\partial^+\mu=\partial^+a+i\partial^+b=\frac{a}{a+b}+\frac{b}{b+c}i,\quad\left(\partial^+a=\frac{a}{a+b},\quad\partial^+b=\frac{b}{b+c}\right)\tag{5}$$

Definition 2. With a ternary connection number $\mu=a+bi+cj,\ a\in[0,1],b\in[0,1],\ c\in[0,1],\ a+b+c=1,\ i\in[-1,1],\ j=-1$. The first order partial negative connection number is:

$$\partial^-\mu=i\partial^-b+j\partial^-c=\frac{b}{a+b}i+\frac{c}{b+c}j,\quad\left(\partial^-b=\frac{b}{a+b},\quad\partial^-c=\frac{c}{b+c}\right)\tag{6}$$

Definition 3. With a ternary connection number $\mu=a+bi+cj,\ a\in[0,1],b\in[0,1],\ c\in[0,1],\ a+b+c=1,\ i\in[-1,1],\ j=-1$. The first order total partial connection number is equal to the algebraic sum of the first order partial positive connection number and the first order partial negative connection number, then the first order total partial connection number is:

$$\partial^\pm\mu=\partial^+\mu+\partial^-\mu=\frac{\mathrm{a}}{a+b}+\frac{b}{b+c}i+\frac{b}{a+b}i+\frac{c}{b+c}j\tag{7}$$

Definition 4. With a ternary connection number $\mu=a+bi+cj,\ a\in[0,1],b\in[0,1],\ c\in[0,1],\ a+b+c=1,\ i\in[-1,1],\ j=-1$. The first order partial positive connection number is:

$$\partial^+\mu=\partial^+a+i\partial^+b=\frac{a}{a+b}+\frac{b}{b+c}i$$

then the second order partial positive connection number is defined as:

$$\partial^{2+}\mu=\partial^+(\partial^+\mu)=\frac{\partial^+a}{\partial^+a+\partial^+b},\quad\left(\partial^+a=\frac{a}{a+b},\quad\partial^+b=\frac{b}{b+c}\right)\tag{8}$$

similar to the second order partial positive connection number, the second order partial negative connection number is as follows.

Definition 5. With a ternary connection number $\mu=a+bi+cj,\ a\in[0,1],b\in[0,1],\ c\in[0,1],\ a+b+c=1,\ i\in[-1,1],\ j=-1$. The first order partial negative connection number is:

$$\partial^-\mu=i\partial^-b+j\partial^-c=\frac{b}{a+b}i+\frac{c}{b+c}j$$

then the second order partial negative connection number is defined as:

$$\partial^{2-}\mu=\partial^-(\partial^-\mu)=\frac{\partial^-c}{\partial^-b+\partial^-c}j,\quad\left(\partial^-b=\frac{b}{a+b},\quad\partial^-c=\frac{c}{b+c}\right)\tag{9}$$

Definition 6. With a ternary connection number $\mu=a+bi+cj,\ a\in[0,1],b\in[0,1],\ c\in[0,1],\ a+b+c=1,\ i\in[-1,1],\ j=-1$. The total partial connection number of the second order is equal to the algebraic sum of the partial positive connection number of the second order and the partial negative connection number of the second order. Then the total partial connection number of the second order is:

$$\partial^{2\pm}\mu=\partial^{2+}\mu+\partial^{2-}\mu=\frac{\frac{a}{a+b}}{\frac{a}{a+b}+\frac{b}{b+c}}+\frac{\frac{b}{a+b}}{\frac{b}{a+b}+\frac{c}{b+c}}j=\frac{\frac{a}{a+b}}{\frac{a}{a+b}+\frac{b}{b+c}}-\frac{\frac{b}{a+b}}{\frac{b}{a+b}+\frac{c}{b+c}}\tag{10}$$

Similarly, we can obtain the quaternion total partial connection number and the five-element total partial connection number.

Suitability evaluation of human settlements in Guizhou Province from 2014 to 2017

Guizhou is located in the ecological barrier area of the upper reaches of the two rivers, rich in natural resources and playing an important role in the strategic pattern of national ecological environment security. At present, the quality of water, gas, soil, natural ecology and other environmental elements is generally good. However, with the sustained and rapid economic and social development of Guizhou province, the compression-type, compound, structural environmental problems have been existing for a long time and become more and more obvious. The Karst region of Guizhou is ecologically fragile and sensitive, and has a high risk of environmental pollution. This makes environmental protection face the complicated situation of high difficulty, high pressure, time shortage, heavy task, both opportunity and challenge exiting. It also makes the evaluation of the suitability of human settlement environment in Guizhou province especially important.

This study takes Guizhou Province as an example to evaluate the suitability of human settlements in this evolution process by understanding the trends and current status of the quality of human settlements in Guizhou Province from 2014 to 2017, and then summarize the evaluation results. According to the Statistical Yearbook and the State of the environment bulletin of Guizhou Province from 2014 to 2017, the per capita housing area, environmental investment as a percentage of GDP, water source of Guizhou Province actual water quality compliance rate, the actual data of urban green coverage from 2014 to 2017, tab. 1, and the evaluation criteria for the suitability of human settlements, tab. 2, this paper makes the evaluation of the suitability of human settlements in Guizhou Province from 2014 to 2017, and judged the short-term development trend of Guizhou Province in 2014 to 2017.

Step 1

Establish a set pair [10] according the measured data in tab. 1 and the evaluation index system and its grading standards for human settlements in tab. 2. The suitability status of the living environment given in tab. 2 is divided into V level, IV level, III level, II level, and I level, a total of 5 levels. The 5-element connection number $\mu(t) = a(t) + b(t)i + c(t)j + d(t)k + e(t)l$ is selected as 4 subset pairs (t_{2014}, t_{2015}, t_{2016}, t_{2017}) characteristic function. The $a(t)$ represents the sum of the weighted degrees of equality of the t-year indicator value q_n (n = 1, 2, 3, 4) belonging to the V-level. Similarly, $b(t)$ indicates that the t-year index value q_n (n = 1, 2, 3, 4) belongs to the sum of the weighted degrees of the IV level. The $c(t)$ represents the weight of the t-year index value q_n (n = 1, 2, 3, 4) belonging to the level III, and so on. i, j, k, l are the level marks, when the value needs to be counted, take $i \in [0.333, 1]$, $j \in [-0.333, 0.333]$, $k \in [-1, -0.333]$, $l = -1$. The $\mu(t)$ means that the t-year total index value belongs to the contact level of each standard level with.

Step 2

Calculate the sum of the weighted degrees of equality of the annual total indicator value q_n(n = 1, 2, 3, 4) belonging to a certain level. The weighted identity of all the indicator values at each level is counted, that is, the contact component corresponding to this level is obtained. Then the corresponding 5-element connection number is determined [11]. After calculation, 5-element connection number for the suitability of human settlements in 2014-2017 was obtained.

Table 1. The measured values of the four major indicators of the suitability of human settlements in Guizhou Province from 2014 to 2017

Year	Urban per capita housing area [m^2][q_1]	Water source water quality compliance rate [%][q_2]	Urban green coverage [%][q_3]	Environmental investment as a percentage of GDP [%][q_4]
2014 [t_1]	36	96	34	1.9
2015 [t_2]	36	98	36	1.5
2016 [t_3]	37	99	37	1.5
2017 [t_4]	38	98	37	1.7

Table 2. Evaluation index system for human settlement environment suitability and its rating criteria (s)

Evaluation index	Standard division point of membership degree of *suitability for human settlements*				
	V	IV	III	II	I
Urban per capita housing area [m^2]	> 45	38-45	32-38	25-32	< 25
Water source water quality compliance rate [%]	> 99	90-99	80-90	70-80	< 70
Urban green coverage [%]	> 70	50-70	30-50	20-30	< 20
Environmental investment as a percentage of GDP [%]	> 3.5	3-3.5	2.5-3	2-2.5	< 2

Table 3. Calculation of the 5-way connection number of people's living environment suitability evaluation in 2014

Evaluation index	V	IV	III	II	I
Urban per capita housing area [m^2]	0	0.667	0.333	0	0
Water source water quality compliance rate [%]	0.667	0.333	0	0	0
Urban green coverage [%]	0	0.2	0.8	0	0
Environmental investment as a percentage of GDP [%]	0	0	0	0	1
The algebraic sum of the weighted indices	0.167	0.3	0.283	0	0.25
$\mu(2014) = 0.167 + 0.3i + 0.283j + 0k + 0.25l$					

Step 3

According to the theory of set pair analysis, it can be known that the normalized 5-way connection number $\mu = a + bi + cj + dk + el$ has a value interval of [–1, 1]. The interval of [–1, 1] is divided into five sub-intervals: [0.6, 1], [0.2, 0.6], [–0.2, 0.2], [–0.6, –0.2], [–0.6, –1], which respectively correspond to the 5 levels of the suitability of the human settlement environment, *excellence*, *good*, *medium*, *low*, and *poor*.

Table 4. Calculation of the 5-way connection number of people's living environment suitability evaluation in 2015

Evaluation index	V	IV	III	II	I
Urban per capita housing area [m^2]	0	0.667	0.333	0	0
Water source water quality compliance rate [%]	0.889	0.111	0	0	0
Urban green coverage [%]	0	0.3	0.7	0	0
Environmental investment as a percentage of GDP [%]	0	0	0	0	1
The algebraic sum of the weighted indices	0.222	0.270	0.258	0	0.25
$\mu(2015) = 0.222 + 0.270i + 0.258j + 0k + 0.25l$					

Table 5. Calculation of the 5-way connection number of people's living environment suitability evaluation in 2016

Evaluation index	V	IV	III	II	I
Urban per capita housing area [m^2]	0	0.833	0.167	0	0
Water source water quality compliance rate [%]	1	0	0	0	0
Urban green coverage [%]	0	0.35	0.65	0	0
Environmental investment as a percentage of GDP [%]	0	0	0	0	1
The algebraic sum of the weighted indices	0.25	0.296	0.204	0	0.25
$\mu(2016) = 0.25 + 0.296i + 0.204j + 0k + 0.25l$					

Table 6. Calculation of the 5-way connection number of people's living environment suitability evaluation in 2017

Evaluation index	V	IV	III	II	I
Urban per capita housing area [m^2]	0	1	0	0	0
Water source water quality compliance rate [%]	0.889	0.111	0	0	0
Urban green coverage [%]	0	0.35	0.65	0	0
Environmental investment as a percentage of GDP [%]	0	0	0	0	1
The algebraic sum of the weighted indices	0.222	0.365	0.163	0	0.25
$\mu(2017) = 0.222 + 0.365i + 0.163j + 0k + 0.25l$					

For $\mu(2014)$, $\mu(2015)$, $\mu(2016)$, $\mu(2017)$, calculate the values of $i = 0.333$, $j = -0.333$ and $i = 1$, $j = 0.333$, respectively, and get:

$$\mu(2014) = [-0.077, 0.311]$$

$$\mu(2015) = [-0.024, 0.327]$$

$$\mu(2016) = [0.031, 0.364]$$

$$\mu(2017) = [0.039, 0.391]$$

According to the agreement of evaluation and grading, it can be seen that the suitability of human settlements in Guizhou Province between 2014 and 2017 is between *good* and *medium*.

Step 4

Calculate the 4th-order all-bias connection number of the five-way connection number in the assessment of the suitability of human settlements environment in Guizhou Province from 2014 to 2017. Get:

$$\partial^{4\pm}\mu(2014) = 0.683 - 1 = -0.317$$

$$\partial^{4\pm}\mu(2015) = 0.697 - 1 = -0.303$$

$$\partial^{4\pm}\mu(2016) = 0.666 - 1 = -0.334$$

$$\partial^{4\pm}\mu(2017) = 0.615 - 1 = -0.385$$

Since $\partial^{4\pm}\mu(t) < 0$, it is believed that the development trend of the suitability of human settlements in Guizhou Province from 2014 to 2017 is developing in a worse direction every year, but the intensity of this trend is not very large, between –0.39 and –0.3.

Step 5

Recommends. Considering that the development trend of the suitability of human settlements is not so good, it is only between –0.39 and –0.3. Therefore, the relevant government departments still need to continuously increase the investment in the suitability of human settlements. Continuing to work for a resource-conserving and environment-friendly society.

Conclusions

In this paper, set pair analysis theory and its connection numbers are introduced into the suitability evaluation of human settlements. The set pair analysis model based on partial contact number is established. This model is used to assess the suitability status and development trend of human settlements in Guizhou Province. Result shows that the suitability of human settlements in Guizhou Province in 2014-2017 is between good and medium, and tends to medium. This medium state has a not good trend of further development, but its trend strength is not very large, between –0.39 and –0.3. It suggests that the relevant government decision-making departments need to continuously strengthen the investment and attention to the suitability of human settlements, and reverse the not so good development trend of suitability status, and efforts are made to build a resource-conserving and environment-friendly society.

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