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MODELING OF REGIONAL DIFFERENTIATION OF LAND-USE DEGREE IN CHINA[①]

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ABSTRACT: This paper presents an index system and a method for calculating the comprehensive index of land-use degree. The latest data from two projects titled "Remote Sensing Macro Investigation and Dynamic Study of National Resources and Environment" and "Resources and Environment Database of China" have been fully applied. In addition, this paper analyzes the regularity of the regional differentiation of land-use degree in China and the socio-economic and physical factors which affect the change of land-use degree in China. The "polar" model and the "longitude-distance" model of land-use degree of China are also developed.
KEY WORDS: land-use degree, comprehensive index, regional differentiation model

The study on land-use and land-cover changes becomes more and more important in global environment change research. A global research plan named LUCC was founded by IGBP and HDP in 1995 and one core project plan and project committee (CPPC/RPPE LUCC) was also founded. An international conference on land-use and land-cover changes was held in the Netherlands. In this conference, five frame questions(IGBP, 1996) and three research focuses (IGBP, 1996) have been proposed.

Study on land-use and land-cover changes possesses an important position in the field of national resources and environment research. The study on land-use degree has also been developed as the research on land-use has been carried out. We can learn it from the Atlas of Land-use Map of China at scale of 1:1 000 000 published in the 1980s, "Land-use in China"(Wu, *et al.*, 1994), which is published in 1992 and related to the atlas. We can also learn it from the national land-use investigation at county level carried out in the Seventh Five-Year Plan. In the Eighth Five-Year Plan, in order to understand national quantity, distribution and current situation of land resources as well as environmental affected factors, "National Resources & Environment Macro Survey and Dynamic Change Study Using Remote Sensing Techniques" had

① Key project of the Chinese Academy of Sciences: National Resources & Environment Macro Survey and Dynamic Change Study Using Remote Sensing Techniques.

been set as a key project by the Chinese Academy of Sciences. It will help to solve the key technical matter in macro and quick investigation of land resources and environment factors and lay foundation for further multi-temporal resource & environment investigation and dynamic analysis.

Based on the background stated above, this paper analyzes the natural environmental factors affecting land-use degree and their influences on land-use degree. The regional environmental differentiation model of land-use degree in China has been developed by means of analyzing the relationship between regional differentiation of land-use degree and its affected factors such as longitude, latitude, terrain and altitude. Comprehensive methodology for simulating and predicting the changes of land-use degree in China has also been proposed.

I. QUANTIFIED COMPREHENSIVE INDEX SYSTEM OF LAND-USE DEGREE

There are two ways for land-use degree study. The first one emphasizes on the model-developing of land-use patterns. For example, the summarization of land-use intensity proposed by Dr. Van Talent of Germany, common land-use model, graphic model, gravitational model, polarization and anti-polarization model of land-use(Li, 1986). These models were constructed mainly by means of analyzing the affected factors of land-use from nature and human society. The second way uses quantified index system to describe land-use degree. One example is the indirect index system usually used in China. Nine indirect indexes of land-use degree have been used in "County Level Land-use Comprehensive Planning"(Qian, 1992). It is relatively well using indexes to describe certain characteristics of land-use degree, but it is not suitable for describing overall degree, what is more, it is not suitable for comparative study in different area and regional analysis. In "Land-use in Xizang (Tibet)", Prof. Liu Jiyuan *et al*. developed a new set of quantified land-use degree analysis methodology in which land-use degree has been divided into four degrees according to the stable condition of land affected by nature and human society. Each degree is given an index to describe land-use degree quantitatively (Li, 1992).

The quantified land-use degree is developed on the basis of the limitation of land-use intensity. The upper-limit is the intensity of land resource that can not be further cultivated and the lower limit is the initial stage of land cultivation. We think that land-use degree can be described by an uncontinuous function. So we can define four ideal stages of land-use as four land-use degrees and give a value for each degree. Then, we can get four degree indexes of land-use degree as shown in Table 1.

The four land-use degrees are only four ideal stages. In the actual situation, four stages are mixed in the same area and each type possessed different percent. Each type has its contribution to the land-use degree according to its weight. The comprehensive quantified indexes of land-use degree is derived from the mathematical synthesizing of these four degrees. It is a continuous index between degree 1 and degree 4, which reflects the land-use degree of a certain area. So, the quantified comprehensive index of land-use degree is a Weaver index(Zhang, *et al*.,

Table 1 The classification values of land-use degrees

Items	Un-used land degree	Land degree of forest, grassland and water body	Cultivated land degree	Urban land degree
Land-use pattern	Un-used land or land hard for using	Forest, grassland and water body	Cultivated land, garden plot and artificial-grassland	Cities and towns, residential area, industrial and mining area
Degree index	1	2	3	4

1984). Considering the convenience of processing in Geographic Information System, we multiplied the index by 100 when we give the value which expressed as

$$L_a = 100\sum_{i=1}^{n} A_i \times C_i \tag{1}$$
$$L_a \in [100,400]$$

where L_a is comprehensive index of land-use degree,

A_i is classification value of No. i land-use degree,

C_i is area percent of No. i land-use degree.

Then, we can learn that the quantified index system of land-use degree is an index between 100 and 400. Because the comprehensive index of land-use degree is a continuous function valued between 100 and 400, in a certain raster area, the index value reflect the land-use degree and we can know the land-use degree in any area by calculating its comprehensive index.

II. THE MODEL OF REGIONAL DIFFERENTIATION OF LAND-USE DEGREE IN CHINA

1. The Polar Model of Land-use Degree in China

The concept of land-use degree is derived from polar region – the equator – polar region of the earth and the driving affecting factor is climatic factor(Li, 1986). The land-use pole of the world is shown in Fig. 1.

The main continent of China is located between the south tropical zone and the cold temperate zone which is between the fourth and fifth zone of land-use polar of the world. The land-use degrees do not change much from south to north. But the special terrain and geomorphic characteristics in China determine the distribution of population which is dense in the east and sparse in the west. On the other hand, the climatic factor which affects the land-use degree also changes with the terrain ascending from east to west, which cause the special longitudinal polar model of land-use degree in China. In the other word, because of the influence of "the ridge of the world" and terrain rising, the land-use degree of China from east to west has the same regularity as that of the world. This differentiation regularity is derived from the influence of altitude polarity and earth polarity which is shown in Fig. 2.

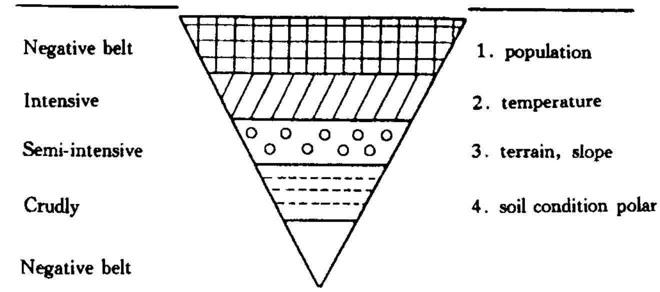

Fig. 1 The common conception of land use pole in the world

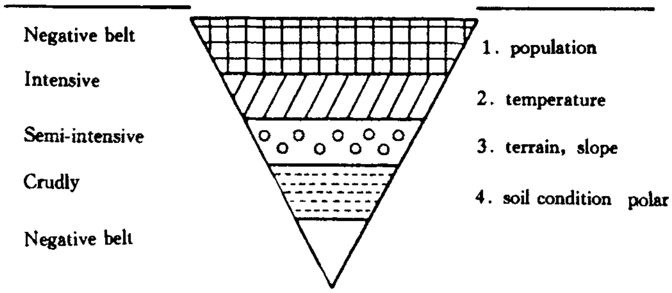

Fig. 2 The terrain polar model of land use degree in China

2. The Distance-altitude Model of Regional Differentiation of Land-use Degree in China

The terrain polar model of land-use degree in China not only reflects the influence of the main terrain characteristic of China, on the changes of land-use degree, but in fact, the other affecting factors of land-use degree are also determined by the terrain polar. So, the terrain polar model of regional differentiation of land-use degree can be described by the distance-altitude model.

Let's suppose that there is a relationship between the comprehensive index of land-use degree La_i in a certain area and the distance to the seashore and altitude of this area, then there is

$$La_i = a_0 d_i + b_0 h_i + c_0 \tag{2}$$

In this study, we sampled randomly by counties along the Changjiang River, the outputs are shown in Table 2.

We can get the sample site distribution figure(Fig. 3) from the sample data listed in Table 2. From the Fig. 3, obviously, we can know that the land-use degree L_a is negatively to the distance d_i. It means that the far the distance to the sea shore is, the lower the land-use degree is, and vice versa.

Considering the particularity of sampling along the river, and the river affected by terrain, especially by slope changes, so, in formula 2, we need only to consider the influence of distance to the sea shore on land-use degree driver, then formula 2 can be simplified as:

$$La_i = a_0 d_i + c_i \tag{3}$$

Using correlation then there is

$$\gamma = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})^{[9]}}{\sqrt{\Sigma(x_i - \bar{x})^2 \Sigma(y_i - \bar{y})^2}} \tag{4}$$

that is

$$\gamma l_A - d_i = \frac{\Sigma(d_i - \bar{d})(la - \bar{la})^{[9]}}{\sqrt{\Sigma(d_i - \bar{d})^2 \Sigma(la_i - \bar{la})^2}} \tag{5}$$

Table 2 The distance between the sample sites and the river mouth and the land use degree at the county level along the Changjiang River

Record No.	Name of county	Index of land-use degree L_{ai}	Distance to river mouth d_i(km)
1	Haimen	327	70
2	Jingjiang	319	168
3	Yangzhong	302	218
4	Jiangpu	313	328
5	Hexian	275	370
6	Wuwei	300	440
7	Huanggang	279	821
8	Songliu	277	1270
9	Wushan	218	1518
10	Zhongxian	300	1718
11	Jiangbei	292	1878
12	Nanxi	291	2248
13	Leibo	229	2248
14	Ningnan	227	2388
15	Derong	193	2788
16	Batang	186	3982
17	Dege	189	4128

when $n-2=17-2=15$, we can learn from the check table that the critical value $\gamma_{0.01}(15) = 0.606$. Obviously, $|\gamma la - d_i| > |\gamma_{0.01}|$, it means that land-use degree index correlate with distance of test site to the river mouth. Using the Method of Least Square, we can get the equation:

$$\bar{la} = 310.23 - 0.033\bar{d}$$
$$\bar{d} \in (0,6000) \tag{6}$$

The Standard Error (S_e) = 24.4, Coefficient Variance($C.V$) =0.005.

Since this regression equation is derived only from the sampling sites along the Changjiang River, in order to extend it into other, we must revise the equation by means of adding altitude index. We can learn from equation 6 that, when the distance increases 1 km, the value of land – use degree decreases 0.033. Considering one county is a plot area instead of one point, there

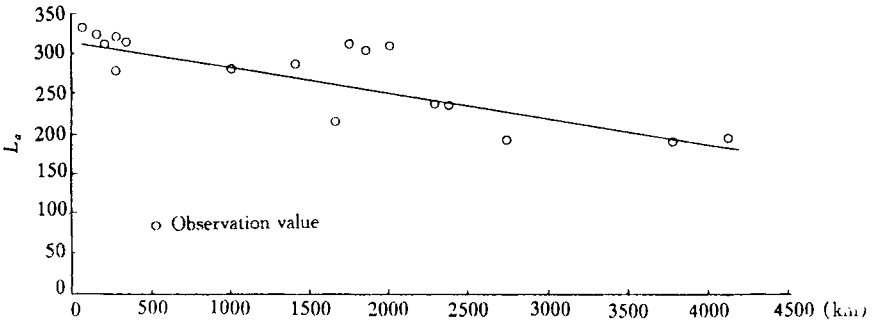

Fig. 3 The sampling sites distribution and the land-use degree along the Changjiang River

is difference between our actual situation and calculating distance between two points. So, in order to describe the longitudinal differentiation regularity more precisely, we express the distance from the county to sea shore by longitude. On the main terrain characteristic of China, we use logarithm for altitude data. Then, the function 2 can be expressed as:

$$La_i = a_0 d_i + b_0 \ln h_i + c_0 \tag{7}$$

In this study, we randomly selected 20 samples and calculated its altitude and longitude, along 30° - 32°N, which is shown in Table 3.

Table 3 The longitude, altitude and indices of land-use degree of the sampling sites

Record No.	Longitude(Le)	Altitude(H)	ln(H)	Degree of land-use (La)
1	121	50	3.91	328
2	120	50	3.91	312
3	119	50	3.91	320
4	118	100	4.61	278
5	117	200	5.30	284
6	116	500	6.21	270
7	115	200	5.30	278
8	114	200	5.30	277
9	113	50	3.91	312
10	112	200	5.30	307
11	111	1500	7.31	212
12	110	1500	7.31	218
13	109	1000	6.91	228
14	108	750	6.62	279
15	107	500	6.21	304
16	106	500	6.21	282
17	105	750	6.62	251
18	104	1000	6.91	205
19	103	2500	7.82	184
20	102	3000	8.01	177

We can get the second of degree regression equation:

$$\bar{la} = 776.227229 - 2.483177\bar{le} - 40.26754\ln(\bar{h}) \quad (8)$$

The parameters are shown as follows: Standard Error (Se): 22.21854, Dependent Mean(Dep. Mean): 262.6, Coefficient Variance($C.V$): 8.46098, Correlation Coefficient Square(R^2): 0.8039, The Correlation Coefficient Square after adjusted($A_{dj}R^2$): 0.7808, in which,

$$C.V = \frac{Se}{Dep \cdot mean} \times 100\% \quad (9)$$

$$AdjR^2 = 1 - \frac{(1 - R^2)(n - 1)}{dfe} \quad (10)$$

The dfe is the degree of freedom. The R is tested by F Test and R' is tested by T Test:

$$F = \frac{(n - 1 - m)R^2}{m(1 - R^2)} = 34.848 \gg F_{0.01} \quad (11)$$

$T_{(le)} = -1.551{:}0.1393$, $T_c = 3.617{:}0.0021$, $T = -5.722{:}0.0001$

We can find that variances of equation is obviously correlation. The equation 8 means that the land-use degree index decreased 2.48, when the longitude increases 1 westward and the land-use degree index decrease 40.267540 when the logarithmic value of altitude increases 1.

III. CONCLUSION AND DISCUSSION

1. Conclusion

(1) On the basis of summarization indirect index system of land-use degree, the comprehensive quantified index system of land-use degree has adopted the non-direct index system. By means of giving value for different land-use degrees according to their affecting factors and the area weight of a certain land-use degree is also developed. This equation is suitable for statistics calculating using Geographic Information System

(2)The affecting factors of land-use degree in China from natural environment are hydrology, temperature, geology, terrain, soil and illumination, but all of these are affected by the polar feature of the particular terrain of China, which caused the overall spatial change of land-use.

This paper presents not only the equation reflecting the relationship between land-use degree along the Changjing River and its distance to the seashore, but also the mathematical models which indicated the regularity longitudinal changes of land-use degree.

2. Discussion

(1)Considering the simplicity, universality and practicability, different types of land-use patterns have been taken into account in the comprehensive index system of land-use degree. But the different land-use degree in the same land-use pattern have been considered. This is our further work for the comprehensive quantified index system of land-use degree if we can acquired enough data.

(2)The natural environment factors model of land-use degree in China must be a multi-index comprehensive model developed on the basis of the effecting factors of land-use /cover changes such as climatological factor, geological factor, geomorphological factor and hydrological factor. So we can study not only how the environmental factors influence land-use/cover change, but also how land-use/cover change influence the environmental factors. The construction of this model needs collaboration of scientists from many fields, especially the collaboration work in fundamental data acquiring.

(3) Microcosmic model of land-use degree will be developed with the collection and improvement of fundamental data, such as regional model of land-use degree in urban and rural area, and land-use degree model for mountain area, which will make progress in microcosmic study of land-use/cover change.

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