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Objective and quantitative evaluation of environmental quality of the land for agriculture purpose

Ning Datong[1], Wang Sufen[1] and Sun Ruomei[2]

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Abstract—An objective and quantitative evaluation method on land environmental quality for agricultural purpose in a county range is studied in this paper. The method takes into account the quantity of heat, precipitation, meteorological disaster and soil fertility, which have close relationship to the potential productivity of land and can be expressed conveniently and accurately by taking Kai County as an example. Besides comprehensive grading assessment, assessment with Hilbert Space distance coefficiency and comprehensive judgement by fuzzy sets theory, the assessment factors are expanded to 18 parameters, and fuzzy dominance matrix and fuzzy clustering methods are adopted for regional comprehensive identification of agriculture-use land. Among these methods, each benefits from association with the other. In this paper, an all-round and objective new way for understanding of land environmental quality is put forward.

Keywords: land resource; environmental quality; model; evaluation; identification.

INTRODUCTION

One of the essential features of land from the others is its fertility, which is the reflection of "climate fertility" in combination with soil fertility. Because 90 to 95 percent of the dry substance in a plant is from air produced by photosynthesis, and the other 5 to 10 percent is from soil through root assimilation. Therefore, it is reasonable to lay stress on the coordinate relationship between "climate fertility" and soil fertility by analysing the concept of land system (Tokari, 1979). In land system, furthermore, climate and soil are two major elements, including solar energy, heat, precipitation, climate hazards and soil fertility, which restrict the natural productivity and are easy to be described quantitatively.

The environmental quality of land in different region has different effect on agricultural economic development. On the contrary, different agricultural activities affect the ecosystem

[1]Institute of Environmental Sciences, Beijing Normal University, Beijing 100875, China.
[2]Institute of Rural Development, Chinese Academy of Social Science, Beijing 100020, China.

in different ways. Thus, on the basis of understanding climate and soil environmental quality correctly, the multi-element and multi-phase intricate system should be fully studied on regional comprehensive identification by using proper models, analysing the advantage and disadvantage of land condition on agricultural development and the feedback effects on land environment caused by agricultural activities. Clearly, it is important to territorial planning, reasonable exploration of land resource and protection of agricultural ecological environment, and also to the coordinate development of agricultural production and environmental resources protection.

This paper aims at thoroughly inquiring into environmental quality evaluation for agriculture-use land using Kai County as an example.

NATURAL FEATURES OF KAI COUNTY

Kai County is located at a mountainous area south of Daba Mountains and east of Sichuan Basin. If it is divided into ten equal parts, then, six of them are mountains, three are hills and one is plain land in the territory structure of whole county. Its main features are as follows:

Complicated landforms and big different altitude from north to south

There are three kinds of landforms in Kai County: mountains, hills and plains. The altitude ranges from 2626m in the north to 134m in the south.

Rich biological resource and frail ecological environment

The biological resources are rich in this area because of its various landforms and vertical deference of climatic types. There are about 700 kinds of cultivated and domestic living things, 1800 species of wild animals. Because of various damages on the ecological environment, such as deforestation and grass cutting for fertilization, the forest cover decreased by 12.6% over the last 30 years. The ecological environment also deteriorated with heavy losses of soil and water; and the soil fertility decreased significantly. This made agriculture production in some regions fall into a vicious circle.

Clear "spatial climate" and different distribution of precipitation and heat

The climate ranges from subtropical monsoon climate to temperate monsoon climate with increase of altitude. Because the spatial and temporal distribution of water and heat is far from ideal, crops can not grow well even have a reduced yield.

Soils fit for crops but deficient in fertility

There are many kinds of soil: large areas of purple soil good for growing crops make up 70.1% of the dry farmland. Secondly, the paddy rice soil is an important soil for grain planting. The best soil fertility is found in river valleys and hillocks under 500m above sea level. The soil fertility reduces gradually with terrain rising and with the condition of climate, soil quality, hydrology, vegetation and so on getting poorer.

QUALITY ASSESSMENT ON AGRO-CLIMATE AND SOIL RESOURCE

The so-called agro-climate and soil resource refers to the ability of climate and soil in an area to provide natural condition, materials and energy for agricultural activities in that local area. It is an important part of land resource. It provides the basic requirement for plant growth, and also, is the major factor of the natural productivity. The regional difference of agriculture climate and soil resource determines the structure of agriculture, forest, animal husbandry, sideline production, and fishery in some way, and also determines the composition and planting ways of crops, woods and grass. In addition, different collocation of climate and soil can form different vegetation types, hydrologic conditions and ecosystems. In other words, agriculture climate and soil resource can not only provide space, materials and energy to meet plant demands, and restricts plants growth and the agriculture activities, but also affects the natural productivity by coordinating and balancing the factors in an ecosystem.

Assessment on environmental quality of agroclimate

Assessment rules

1. Emphasizing fitting in with agriculture production: agriculture, forest, animal husbandry and fishery have their own climate requirements. When the climate resource fails to meet the requirement for crops growing, the crops can not grow well as to have a decreased yield.

2. Stressing prominent factors: rice, rape and orange play a decisive role both in planting area and in output. Therefore, the climatic condition requirement of the three temperate preferring crops are selected as the main basis for assessment.

3. Considering the advantages and disadvantages comprehensively: monsoon climate always leads to great variation of some climate factors, such as temperature and precipitation in extensive area of China and sometimes results in meteorological disaster. The positive and negative factors which affect a bumper harvest or crop failure should be analysed thoroughly.

4. Striving for objective analysis: Because of the changeable climate and insufficient information from observational network in the mountainous area, the effect of local landforms and rivers should make for every effort to analyse objectively (Ning, 1988).

Index system for assessment

In the approach to vertical spectrum structure of complicated mountainous climate in the low and mid-latitude regions, it is found that temperature and amount of heat are two major factors (Lu, 1984; Yu, 1985; Barry, 1981) which change with height, and which are very important to some temperate preferring crops like rice. Thereupon, the annual average temperature (T), active accumulated temperature (for $T \geq 10°C$) and the number of day with temperature at 10–20°C are selected to represent the whole situation of temperature and heat. And annual precipitation (R), frequency of summer draught (fdh) and agroclimate productivity

(P) from Thornthwaite Memorial Model are also selected as indices for assessment.

Method and application

The general procedure of comprehensive assessment on the quality of agriculture climate resource is: using mathematical models to induce and treat the factors of climate resource as to get a value or set: assessing scale or index, which can be adopted to stand for the degree of climate resource suitable for agriculture.

1. Comprehensive grading assessment

This method is to compute assessment index first, which reflect the quality degree of assessment items through induction and statistics. Then, a comparison with assessment standards is carried out.

$$CIi = \frac{1}{N}\sum_{j=1}^{N} Xj, \tag{1}$$

where

CIi—comprehensive assessment index at the ith point;

Xj—mark given to the jth parameter;

N—number of parameters.

By analysing the values of all the points, parameters and assessment index (CIi) from the above model, the quality distribution in this county of agroclimate resource is: Fengle—the best, Wushan, Zhengba and Daci—the second best, Yanshui—below average, and Mayun—the poorest (Fig. 1).

2. Assessment with Hilbert Space distance coefficient

Quality assessment on agroclimate resource is based on the hypothesis that all the factors are independent from each other. In other words, every two of them is orthogonal:

$$\vec{C}j \cdot \vec{C}k = 0 \text{ (if } j \neq k). \tag{2}$$

If each factor (or parameter) is marked as a vector A, then, n factors could make up a n-dimension space, that is, "resource field" in Hilbert Space is formed by all factors of agriculture climate (Byron, 1981), thus the apex Ai of vector $\vec{Ai}$ can represent the comprehensive quality of agricultural resource in the ith point. If the apex A_0 of $\vec{A_0}$ under optical structure is taken as the basic point and the apex distance coefficient between Ai and A_0 is taken as the assessment scale, the sample set for all vector's apexes in the n-dimension "resource field" in Hilbert Space of agriculture climate is obtained. Obviously, the smaller the coefficient is, the closer from the ith point to the basic point, and the better the quality at the ith point, and vice versa. In order to do assessment, the units of the parameters should be removed first. Then, the effect of standardized $\bar{T}$, $\sum T \geq 10°\text{C}$, D, R, P, fdh on the quality of agriculture climate resource

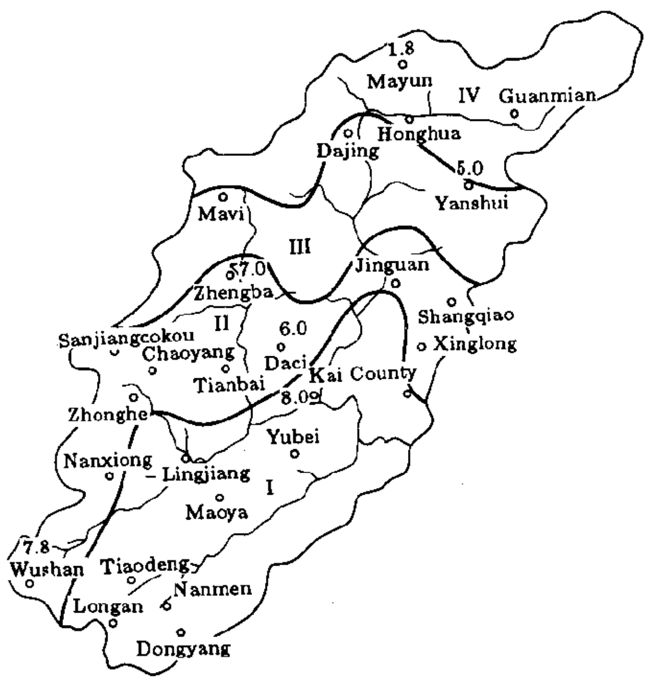

Fig. 1 The distribution of agro-climate resource quality in Kai County

can be integrally taken into account (Ning, 1988). Its assessment model is:

$$HIi = \sqrt{\sum_{j=1}^{5}(C'_{ji} - C'_{j0})^2 + (\frac{fdhi}{10} - \frac{fdh0}{10})^2}, \tag{3}$$

where, HIi is the distance coefficient in Hilbert Space at point i, or comprehensive assessment index. C'_{j0} is the standardized index of factor j at basic point.

From model (3), HIi at each of the representative point, Fengle, Wushan, Zhengba, Daci, Yanshui and Mayun, is 0.066, 0.160, 0.187, 0.269, 0.859 and 0.934, respectively. Thereby, the quality decreasing order of agriculture climate resource in Kai County is: Fengle, Wushan, Zhengba, Daci, Yanshui and Mayun.

3. Comprehensive judgement by fuzzy sets theory

The agriculture climate quality is resulted from various factors which restrict and affect each other. Their dividing lines of criteria are always indistinct. Doubtlessly, this would hamper the actual state of affairs being accurately understood that subjectively set some critical values in order to make the originally vague affairs clear. In the aspect of avoiding arbitrary analysis, the fuzzy sets method has prominent advantages (Zadeh, 1965).

Set V as the index set and W as the assessment set, the $V = \{\mu 1, \mu 2, \cdots, \mu n\}$, $W = \{W1, W2, \cdots, Wn\}$. Let judgement matrix $\underset{\sim}{R}$ ($\underset{\sim}{R} = (rij)_{n\times m}$) as the fuzzy transformation from V to W, set $\underset{\sim}{A}$ as weight for all indices in index set, $\underset{\sim}{A} = \{a1, a2, \cdots, an\}$, and compose $\underset{\sim}{A}$ to $\underset{\sim}{R}$ with <max-min>. Consequently, the fuzzy sub-set $\underset{\sim}{B}(\underset{\sim}{B} = \{b1, b2, \cdots, bn\})$ in W is obtained, $\underset{\sim}{B} = \underset{\sim}{A} \times \underset{\sim}{R}$, in which, $bj = V_{i=1}^{n}(a_j; \wedge y_{ij})$. Then setting the affiliated function for each grade of quality in terms of equally allocating the weigh, placing the values of climatic environment at the six representative points into it, and computing the values of affiliated level, in this way, the assessment sets of the points can be gotten. At last, the quality order from the best to the poorest is Fengle, Zhengba, Wushan, Daci, Yanshui and Mayun. It is found that the models are reliable as compared with the results from the above three methods.

Quality assessment on soil environment

In fact, the various factors can be classified into three kinds: ecological, physical and chemical fertility factors. Each of them includes many fertility parameters (such as water content, drainage condition, frost-free season, slope, thickness for cultivation, porosity, organic matter content, real and effective composition of N.P.K and so on). The comprehensive fertility level of soil is shown by total effectiveness of the fertility parameters.

The fertility parameters can be selected, based on the ecological principle, in terms of the main requirements of local crops and obstacle problems of soil fertility. The fertility classifying standards are determined by the fertility limits which are suitable for crop growing, and by referring to the results of local and national reconnaissance soil survey.

The effects of above three fertility factors on the course of crops growing are not put in the same bracket, in which ecological fertility is the most important one. They can be represented in fertility value in order to assess soil environmental quality as compared with assessment standards (Wang, 1987; Table 1).

It can be concluded that the soil fertility is moderate in Kai County, decreasing as the altitude goes up.

Table 1 The distribution of soil fertility in Kai County

Landforms		Hillock and valley	Platform	Low mountain	Mid mountain in the north
Fertility grade	Ecological factor	2	2	3	5
	Physical factor	2	3	4	5
	Chemical fertility factor	2	2	4	4
Fertility value	Ecological factor	44–39	44–39	38–33	<27
	Physical factor	25–21	20–16	15–11	<10
	Chemical fertility factor	16–13	16–13	8–5	8–5
Total fertility value		85–73	70–68	61–49	<45
Level of fertility		Higher	Moderate	Below average	Poor

REGIONAL COMPREHENSIVE IDENTIFICATION OF ENVIRONMENTAL QUALITY OF LAND FOR AGRICULTURE PURPOSE

Through analysing the present condition of ecological and environmental quality, taking into consideration its advantages and disadvantages for agricultural development, and the impact of agriculture economic activity on ecosystem and environment, using proper mathematic method, the land eco-environment quality has been evaluated quantitatively in different areas. A pair of multiple decision criteria models are given below, which provides a systematic technique for identifying the land environmental quality. Based on fuzzy sets theory, the models incorporate directly the fuzziness characteristics of many environmental problems. Model I, based on pairwise comparison, ranks the order in different environmental units from good to bad while model II identifies their similarity relationship. The models are complementary and their outputs, when viewed jointly, provide insight which are deeper than they are viewed individually.

In the process of regional identification of land eco-environmental quality, a set of basic assessment units $A1$, $A2, \cdots, Am$, and evaluation factors $C1, C2, \cdots, Cn$ are set first. These determine the rows and columns of a data matrix $X = \{Xik\}$, respectively. Models I and II are input by a matrix $Y = \{Yik\}$ which is obtained from the transformation of matrix X. In the application, the present thirteen administrative divisions are regarded as basic assessment units and four types, eighteen indices of identification decision are chosen in Table 2.

Table 2 Indices of regional identification on agriculture-use land

Type	assessment parameter		Unit
Soil type index	Alluvial paddy soil area/total area of all sorts of soils		%
	Purple paddy soil area/total area of all sorts of soils		%
	Alluvial soil area/total area of all sorts of soils		%
	Purple soil area/total area of all sorts of soils		%
Land use situation	Percentage of forest cover		%
	Average	cultivated area per capita	mu/a person
	Gradient Factor	nonirrigated cultivated area of slope $\leq$ 15°C/total area of nonirrigated farmland	%
		nonirrigated cultivated area of slope $\leq$ 25°C/total area of nonirrigated farmland	%
	Cultivated land area/total area of land		%
	Paddy field area/total area of cultivated land		%
	Uncovered land and bare rock area/total area of land		%
	Grassland area/total area of land		%
	Water area/total area of land		%
Climate factor index	Annual mean precipitation		mm
	Days of steady staying in $t \geq 10$°C		days/a
	Accumulated temperature of $t \geq 10$°C		
Water resource index	Average irrigated water amount of one mu cultivated land		m^3/mu
	Effective irrigated area/total area of cultivated land		%

note: 1ha =15mu

Model I—fuzzy dominance matrix model ranking identification

Its purpose is to identify dominance relationship between pairs of alternatives based on the matrix Y. For a pair of alternatives i and j, $D_k(i,j)$ and $R^I = (r^I_{ij})$ are defined as follows (Wenger, 1987):

$$D_k(i,j) = \begin{cases} 1 & \text{if } Y_{ik} - Y_{jk} > 0 \quad k = 1, 2, \cdots, n \\ 0 & \text{if } Y_{ik} - Y_{jk} < 0 \quad i, j = 1, 2, \cdots, m \\ 0.5 & \text{if } Y_{ik} - Y_{jk} = 0, \end{cases} \tag{4}$$

$$r^I_{ij} = \begin{cases} \sum_{k=1}^{n} D_k(i,j) & \text{if } i \neq j \quad i, j = 1, 2, \cdots, m \\ 0 & \text{if } i = j, \end{cases} \tag{5}$$

Finally, let Si and Cj denote the ith row sum and the jth column sum of R^I, respectively. The row sum, Si, is a measure of the degree to which unit i dominates the others. The largest one of row sum is the best one of land environmental quality in agricultural activities.

Then, put all divisions of land quality in order: the best one is Fengle, and others ranking from good to bad are Lingjiang, Chengjia, Zhaojia, Tieqiao, Yuexi, Shenshan, Zhonghe, Tianbai, Zhengba, and the last two units are Yanshui and Dajing.

Model II—fuzzy clustering model classifying identification

Model II is based on the concept of a fuzzy resemblance relation. The purpose is to identify the degree of similarity among the units which based on the information in matrix Y and classification. To do this, the authors define the matrix $R^{II} = (r''_{ij})$,

$$r''_{ij} = 1 - c\left|\sum_{k=1}^{n} \alpha(Y_{ik}, Y_{jk})\right|, \tag{6}$$

Here α is an appropriate function for measuring the difference between Y_{ik} and Y_{jk} and c is a constant which is chosen to satisfy $0 \le r''_{ij} \le 1$ for all i and j. In the fuzzy clustering analysis, moreover, R^{II} should meet the symmetry, reflexivity and transitivity property. For this reason, a new matrix R^{P} that would be satisfied the fuzzy equivalent relationship is constructed as the power matrix of R^{II}. Then let $\alpha \in [0, 1]$ and define

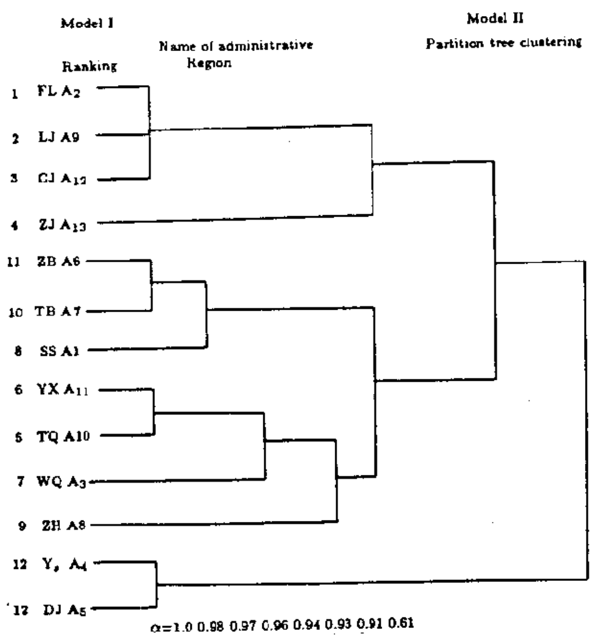

Fig. 2 Regional identification results of ranking and classifying for agriculture-use land environment in Kai County

$$R(\alpha) = [r'_{ij}(\alpha)], \tag{7}$$

where

$$r'_{ij}(\alpha) = \begin{cases} 1 & \text{if } r'_{ij} \geq \alpha \\ 0 & \text{if } r'_{ij} < \alpha. \end{cases} \tag{8}$$

In this formula, r'_{ij} refers to the ith entry in the power matrix R^P. The variable provides a similarity measure.

By systematically varying α from 1 to 0, and put the model's outputs in a partition tree form, classification of the basic units is clearly shown in Fig.2 according to deferent α value.

As is known to all, land is a kind of comprehensive body, which includes various natural resources which are interdependent and interactive. Land environment is a complex system which contains many sub-systems. The level of its quality determines the efficiency of energy transform and material circle in the system. And it plays a very important role in meeting the basic consumption demand of people.

Starting from the major factors of agriculture-use land and the whole agro-ecosystem, this article aims at approaching efficient evaluation method of environmental quality objectively and quantitatively and identifying the difference between each pair of studying regions accurately. Among three methods proposed above, each benefits from association with the other. They overcome the insufficient of qualitative experiential description in most former work. Therefore, it provides the scientific basis for exploiting and utilizing land resources reasonably, working out the land-use planning, and promoting a balanced development of population, food grain and the environment.

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