Ecological Safety Evaluation of Land Use in Ji'an City Based on the Principal Component Analysis

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Abstract   According to the ecological safety evaluation index data of land-use change in Ji'an City from 1999 to 2008，positive treatment on selected reverse indices is conducted by Reciprocal Method. Meanwhile，Index Method is used to standardize the selected indices，and Principal Component Analysis is applied by using year as a unit. F_B is obtained，which is related with the ecological safety of land-use change from 1999 to 2008. According to the scientific，integrative，hierarchical，practical and dynamic principles，ecological safety evaluation index system of land-use change in Ji'an City is established. Principal Component Analysis and evaluation model are used to calculate four parameters，including the natural resources safety index of land use，the socio-economic safety indicators of land use，the eco-environmental safety index of land use，and the ecological safety degree of land use in Ji'an City. Result indicates that the ecological safety degree of land use in Ji'an City shows a slow upward trend as a whole. At the same time，ecological safety degree of land-use change is relatively low in Ji'an City with the safety value of 0.645，which is at a weak safety zone and needs further monitoring and maintenance.
Key words   Land use，Ecological safety，Principal Component Analysis，Evaluation，China

Currently，Ji'an City is going through a phase of dramatic development of industrialization and urbanization. Consequently，developing economy and improving people's life entail the expansion of land use in city[1]. However，the cultivated land is occupied inevitably due to urban sprawl. Under this complicated and thorny circumstance of human-land relationship，we must effectively reinforce the theoretical and empirical research on regional land use，and lay out relevant policies strictly to direct practice，according to the objective law of regional land-use change. Compared with developed regions，underdeveloped regions especially should research on various ecological environment problems in terms of prevention and maintenance，such as change of regional phenomenon，change of biology diversity and environment pollution，which arise from industry transformation，and population increase and migration. At present，with remarkable economic development and increasing population，China is experiencing a large-scale and quick process of urbanization. Taking Ji'an City as an example，we conduct the analysis of land-use change，precisely extract information，gouge patterns of land use and process of evolution[2−3]，build support system of regional decision-making，and carry out ecological safety prediction and risk evaluation. Taken altogether，these researches are undeniably important in the real world.

1   Data selection and research methods

1.1   Data processing   According to the ecological safety evaluation index data of land-use change in Ji'an City from 1999 to 2008，positive treatment on selected reverse indices is conducted by Reciprocal Method. Meanwhile，Index Method is used to standardize the selected indices，and Principal Component Analysis is applied by using year as a unit. F_B is obtained，which is related with the ecological safety of land-use change from 1999 to 2008.

1.2   Research methods   Firstly，positive treatment on selected reverse indices is conducted by Reciprocal Method. Subsequently，we standardize the selected indices data，judge relativity among indices，and make sure of the quantity of principal components. Finally，the principal components value and integrative principal components value are both calculated. Integrative principal components formula is as follows：

$$F_{Total} = \sum_{i=1}^{m} (\lambda_i / P) \times F_m,$$

where λ_i is the ith characteristic root of principal component；P is the quantity of indices；F_m is the value of the mth principal component.

First，according to the ecological safety evaluation index system of land-use change in Ji'an City，natural resources index of land use F_{B1}，socio-economic indicators of land use F_{B2} and eco-environmental index of land use F_{B3}，are calculated respectively. Second，we use the three indices to calculate the ecological safety degree of land-use change C. The formula is as follows：

$$C = \sum_{i=1}^{n} F_{Bi} W_i,$$

where F_{Bi} is criteria level index ；w_i is criteria level weight；for $0 \leqslant C \leqslant 1$，the interval of ecological safety（C）value is 0 − 1. The smaller C value，the more safety，and *vice versa*.

2 Establishment of index system

Having a good knowledge of ecological safety of land condition beforehand, which is as the underpinning of reasonable land regulation and decision-making, is essential to sustainable land use. According to the scientific, integrative, hierarchical, practical and dynamic principles, ecological safety evaluation index system of land-use change in Ji'an City is established. Being that this ecological safety evaluation index system involves multidisciplinary and multi-category knowledge, and numerous items[4-5], the selection of indices must attain 3 goals. First, index system can precisely and completely reflect the sustainability and ecological safety of land use system. Second, index system can monitor the ecological environment, socio-economic condition and human pressure, which are related with the structure, function and benefit of land use[6]. Additionally, the system can be used to probe into the relationship among nature, human pressure and land-use change, and gouge the reason of this change. Finally, index system can periodically provide the statistical conclusion and explanatory report on the status quo, change and tendency of land use for government decision-making, scientific research and public need.

2.1 Evaluation of natural resources safety system of land

Evaluation of natural resources benefit is to conduct comprehensive measurement and test of, environmental, economic and social benefit which are functions stemming from the land-use change[7-8]. It aims to provide scientific evidence of decision-making in the future for coordination among land use, economic development, environmental protection and so on, by means of analyzing sundry relevant indices to appraise whether the land-use benefit is good, or whether the structure is reasonable.

2.2 Evaluation of socio-economic safety system of land use

The socio-economic safety system of land use refers to a series of human activities in the process of land-use change.

On one hand, it reflects social progress and economic development, of which detailed embodiments are urbanization process, industrial development, city construction, economic aggregate, economic benefit and so on; on the other hand, it reflects the structural change of land use caused by socio-economic development, which precipitates the mutual transformation among land types, bringing about eco-environmental effect.

2.3 Evaluation of ecological safety of land use

Environmental benefit means that land use incurs a certain impact on environment of local or other places[9-10]. As the degree of land use deepens, which interferes with the flow of matter and energy in environment and alters their order, resulting in the environmental effect. The main law is decrease of ecological coverage, degeneration of land, environmental pollution and so on. These changes, which vary with different types of land use and regional disparity, have a kind of accumulative and continuously expanding feature; namely, they are interactive and the scope of damage are distending. Based on the aforesaid principles and analysis, in view of the status quo of ecological environment of land in Ji'an City and social development level, the ecological safety evaluation index system of land-use change is established, after referring to the design of evaluation index system at home and abroad. In the process of indices selection, index system is established by drawing on the research accomplishments springing from the *Ji'an City Land Use Overall Plan* and *Ecological City Construction Plan of Ji'an City*. In addition, it has absorbed a plethora of research achievements at home and abroad, and proposals from various famous experts in China. According to the ecological safety and sustainable objective, 24 factors, as evaluation factors, are chosen to establish the index table (Table 1) of ecological safety evaluation in Ji'an City with 3 parameters: natural resources index of land use, socio-economic indicators of land use and eco-environmental index of land use.

Table 1 The evaluation index system of ecological safety of land-use Change in Ji'an City

Target layer	Criteria level B	State layer C	Index layer X
The evaluation index system of ecological safetyof land use change	Natural resources index B_1	Resources quantity C_1	Proportion of cultivated land X_1 Proportion of garden land X_2
			Proportion of woodland X_3 Forest coverage rate X_4 Land use rate X_5
		Resources output C_2	Gross agricultural product X_6 Per capita output of grain X_7 Rural per capita net income X_8
	Socioeconomic indicators of land use B_2	Economic output C_3	Per capita GDP X_9 Total investment in fixed assets X_{10} Total industrial output value X_{11} GDP growth rate X_{12}
		Ecomomic response C_4	Level of urbanization X_{13} Construction land growth rate X_{14} Percentage of primary industry in GDP X_{15} Percentage of secondary industry in GDP X_{16}
	Eco-environmental index of land use B_3	Environmental carrying capacity C_5	Per capita construction land area X_{17} Per capita road area X_{18} Population density X_{19} Natural population growth rate X_{20}

Continued（Table 1）

Target layer	Criteria level *B*	State layer *C*	Index layer *X*
		Environmental governance C_6	Percentage of environmental protection Investments in GDP X_{21} The attainment rate of the industrial waste water X_{22} The attainment rate of gas emission X_{23} Industrial solid wastes treatment rate X_{24}

3　Analysis and evaluation of ecological safety of land use in Ji'an City

3.1　The classification of the assessment of the ecological safety of the land-use change　The ecological safety degree of land-use change employs the quantization concept devoid of stationary information content, which cannot directly indicate the nature of the system condition, to reflect the safety of system and condition of sustainable development. Because there are incalculable digits which represent incalculable safety levels or safety conditions within the interval 0 – 1. The safety classification concept is put forward according to an obscure mathematics thought which stipulates those approximate safety degrees as the same type of safety level in the upper bound of subordination.

　　The classification of ecological safety is to divide the range of safety degree into several continuous intervals. Each interval represents one security level or condition, forming continuous ladder of security level. The research divides security degree interval 0 – 1 into 10 levels. Security level 0.5 indicates the threshold of safety. When security level ranges from 0 to 0.5, it is unsafe and when from 0.5 to 1, it is safe（Table 2）.

Table 2　The Classification of the assessment of the ecological safety of the land use Change

Interval	Security level	Interval	Security level
0 – 0.1	Extremely unsafe	0.5 – 0.6	Safe
0.1 – 0.2	Highly unsafe	0.6 – 0.7	Weakly safe
0.2 – 0.3	Restrictedly safe	0.7 – 0.8	Safer
0.3 – 0.4	Unsafe	0.8 – 0.9	Highly safe
0.4 – 0.5	Weakly unsafe	0.9 – 1.0	Extremely safe

3.2　Evaluation of ecological security level of land use in Ji'an City　Natural resources index of land use F_{B1}, socio-economic indicators of land use F_{B2} and eco-environmental index of land use F_{B3}, the degree of ecological safety of land use C（Table 3）are calculated respectively. Then the figure of ecological security level of land use-change from 1999 to 2008（Fig.1）is finished. As is betrayed from Fig.1, the ecological safety degree of land use in Ji'an City is strengthened year by year and increases by 0.414, implying that the ecological safety degree of land use in Ji'an City shows upward trend as a whole. And the rise before 2004 is conspicuously higher than that after 2004. However, the ecological safety degree of land-use change is relatively low in Ji'an City with the safety value of 0.645, which is at a weak safety zone, indicating that the overall level of ecological effect of land use in Ji'an City is relatively low and the ecological safety degree may be brought down, due to some unreasonable factors of land use in the process of economic development, thereupon unsafe conditions ensue. Firstly, the natural resources index of land use can evaluate ra-

tionality of land-use structure and output benefit of natural resources in an area over a given period of time. From the natural resources index of land use, we witness that the curve entirely is divided into 2 stages: in the first stage 1999 – 2004, the natural resources index of land use keeps upward, and the rise, relatively high, hits 0.42; in the second stage 2004 – 2008, the natural resources index of land use declines sharply to 0.25（Fig.1）. Both stages evince the tendency about structural change and benefit of land use in Ji'an City during the Ninth Five-Year Plan, the Tenth Five-Year Plan and the Eleventh Five-Year Plan periods. The results indicates that the structure of land use during the Ninth Five-Year Plan period is more reasonable than the other two Five-Year Plan periods, which is ascribed to the transfer of land resources into the field where can yield more economic benefit due to economic development, urbanization, industrialization and other factors. Secondly, the socio-economic index of land use can evaluate contribution arising from land use for economic development in an area over a given period of time. From Fig.1, the level of economic system development ascends identically and rises by 0.552, indicating that the structure and types of land use have greatly boosted the local economy. Finally, the socio-economic indicators of land use can evaluate degree of influence imposed by land use upon local environment in an area over a given period of time. From Fig.1, the ecological system on the whole shows a tendency of falling after rising, which can be divided into 2 stages. In the first stage 1999 – 2003, the quality of ecological environment of land use keeps fluctuating, but on the whole, rising; in the second stage 2003 – 2008, the quality of ecological environment of land use shows a slow fall. Therefore, on the whole, the trends of change between ecological system and natural resources system in Ji'an City are identical in terms of time, space and law of change, accounting for the salient influence on the change of environment by the change of natural resources of land use.

Table 3　The assessment of the ecological safety of the land use change

| Year	Natural resources index of land use	Socio-economic indicators of land use	Eco-environmental index of land use	Ecological safety of land use
1999	0.257	0.134	0.314	0.231
2000	0.417	0.172	0.429	0.324
2001	0.497	0.193	0.431	0.349
2002	0.627	0.232	0.613	0.463
2003	0.659	0.266	0.725	0.528
2004	0.670	0.370	0.731	0.574
2005	0.649	0.431	0.728	0.593
2006	0.601	0.568	0.737	0.642
2007	0.552	0.634	0.710	0.648
2008	0.523	0.686	0.666	0.645
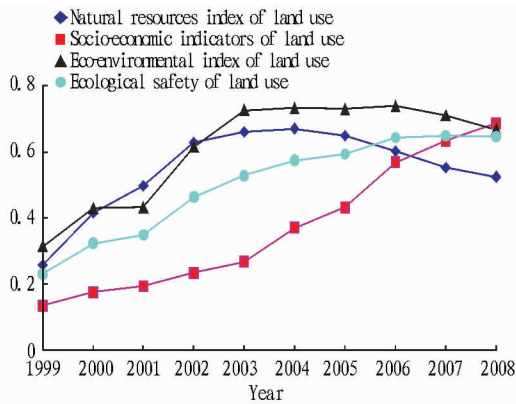
Fig. 1   Land-use charge trends of the ecological salety level in Ji'an City

3.3   Analysis of ecological safety index system of land-use change in Ji'an City   According to the evaluation, the ecological safety degree of land-use change keeps rising from 1999 to 2008. For further ascertainment of the reason and factors which are responsible for such rise, it is necessary to analyze and discuss these matters in terms of standard level and criteria level of index system. In the light of criteria level, natural resources system index of land use reaches maximum (0.67) in 2004; economic system index notably rises; ecological system index fluctuates and appears to decline during the Eleventh Five-Year Plan period. First, according to natural resources system index level of land use, such indices as proportions of cultivated land, garden land and woodland shows notable fall, reflecting that the change of occupancy volume of agricultural land have influenced the structure of land use. On one hand, a part of the traditional agricultural production, influenced by population increase pressure, farmers' income and policy, is transformed inevitably into those land types which can bring high return and benefit. On the other hand, development of urbanization and industrialization cause enormous population density and high rate of land use year by year. Second, according to economic system index level of land use, every index is rising. The rise of social investment in the fixed assets, GDP and total industrial output value, reflect the economic strength of government. The government is getting more and more powerful, and has increased input to address environmental pollution problems, enhancing the ecological system safety greatly. Meanwhile, along with the development of economy, the technology, which can support the ecological protection and construction effectively, is elevated correspondingly. Finally, according to the time scale, all 3 indices during the Tenth and Eleventh Five-Year Plan periods are higher than that during the Ninth Five-Year Plan period. Compared with the Tenth Five-Year Plan period, the natural resources index of land use and eco-environmental index of land use during the Eleventh Five-Year Plan period shows downward tendency with a small margin, but the other aggregative indicators all show identical upward trend with different rising levels.

4   Conclusion

Land use is a socio-economic activity conducted by human, who use, reclaim and transform the land according to the need of life and social development, feature of land and economic localization. We can deduce from the definition of land that land use is a kind of socio-economic activity in nature. The types of land use vary with and are subject to the objective and pattern of land use. In general, land use has duality, namely, relative stability in a period and variability in different stages. In terms of an entire region, in a period of socio-economic development, if industrial structure and developing level are relatively stable, in compliance with the technical level of land use, the objective and pattern of land use are relatively stable as well as the types of land use; in different periods of socio-economic development, if industrial structure, developing level and technical level of land use all make groundbreaking changes, it is likely to precipitate changes of the objective and pattern of land use as well as the types of land use. Consequently, there is close relationship among change of industry, technical level of land use, objective and pattern of land use and change of types of land use.

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