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Coordinated Development of Land Use and Ecological Environment in Hefei Economic Circle

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Abstract From the land use and ecological environment of Hefei Economic Circle, this paper established two sets of subsystem evaluation indicator system. It separately determined the weight coefficient of indicators in two indicator system. Using the coordination degree model, it made a scientific evaluation and analysis of coordinated development of land use and ecological environment in Hefei Economic Circle. Finally, on the basis of analysis results, it came up with pertinent recommendations for coordinated development of land use and ecological environment in Hefei Economic Circle.

Key words Land use, Ecological environment, Coordinated development, Hefei Economic Circle

1 Introduction

With the constant development of social economy and the continuous progress of urbanization, the ecological and environmental issue is getting prominent in the deepening of land use and development. The coordinated development of land use and ecological environment is an essential part for measuring the sustainable development of a region. Coordinating the relationship between land use and ecological environment is of great significance to change the traditional urban land use pattern and promote the harmonious development of human and nature. Hefei Economic Circle is the core growth pole of Anhui Province. Properly using and allocating land resources can effectively accelerate economic development of Anhui Province, and improve regional ecological environment. Excellent economic development and ecological environment can provide excellent capital and development space for land development and use of Hefei Economic Circle. It raises new environment for land use in Hefei Economic Circle to satisfy land demand of social economic development and ensuring coordinated development of land use and ecological environment.

2 Overview of the study area

Hefei Economic Circle includes Hefei City, Huainan City, Lu'an City, Tongcheng City and Dingyuan County of Chuzhou City. The total land area is up to 46800 km^2, accounting for 33.5% of Anhui Province, the total population is 21.98 million, accounting for 32% of Anhui Province. In 2015, the GDP of Hefei Economic Circle reached 910.71 billion yuan, financial revenue of 153.28 billion yuan, fixed asset assets 978 billion yuan, industrial value-added of the enterprises above designated size of 376.14 billion yuan, accounting for about 40% of Anhui Province. With Hefei as the leading city, Hefei Economic Circle has developed to be an important urban agglomeration in Pan-Yangtze River Delta of China, and is expected to realize the rise of central China together with Nanjing Metropolitan Circle, Xuzhou Metropolitan Circle, Wuhan City Circle, Central Plain City Cluster, Nanchang-Jiujiang City Cluster, and Changsha-Zhuzhou-Yingtan City Cluster. With the golden opportunity of cooperation with Pan-Yangtze River Delta and rise of central China, Hefei Economic Circle, as the important growth pole of Yangtze River Delta and central China and core growth pole of Anhui Province, will follow the *Urban System Plan for Hefei Economic Circle*, build the important hub of communications connecting the east and west, north and south, build open space structure with one core three centers and five belts and multiple poles, build important autonomous innovation base and modern industrial base, so as to drive great-leap-forward development of social economy of Anhui Province.

3 Evaluation on coordinated development of land use and ecological environment in Hefei Economic Circle

3.1 Determination of indicator system and weight

3.1.1 Building of indicator system. The evaluation indicator system is the basis for evaluating the coordination status of land use and ecological environment in Hefei Economic Circle. Therefore, building of the indicator system should fully reflect the connotation of land use and ecological environment. Following the principle of science, systematicness, hierarchy and feasibility, with the reference of related research findings[1-3], we established the evaluation indicator system separate for two systems (Table 1). Land use evaluation indicator is divided into two levels: social benefit and economic benefit of land use, a total of 9 individual indicators. The ecological environment evaluation indicator is divided into three levels: resource utilization, environmental quality and ecological environment construction, a total of 8 individual indicators.

Land use. Per capita disposable income of urban residents

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refers to the part of the income reflecting the whole cash income of the residents that can be used to arrange daily life of family.

Population density refers to the population per unit area of land. It is an indicator of population intensity.

GDP per capita is the indicator of economic development. It is one of the most important macroeconomic indicators. It is an effective tool for people to understand and grasp the macroeconomic performance of a country or region.

Ecological Environment. The amount of water resources per capita refers to the amount of water that is occupied by the average population in a region (river basin).

The forest coverage, also called forest coverage rate, refers to the percentage of forest area to land area. It reflects the forest area, forest resource abundance and the greening degree of a country or region.

Rate of green area in built-up area refers to the rate of total green space to total area of built-up area. It is an important evaluation indicator in evaluation of urban landscaping and ecological environment.

Table 1 Evaluation indicator system and weight of coordination between land use and ecological environment of Hefei Economic Circle

System hierarchy	Level I indicator	Weight	Level II indicator	Weight
Land use	Social benefits of land use	0.2500	Per capita disposable income of urban residents	0.0259
			Population density	0.0720
			Employment rate of urban population	0.0347
			Per capita farmland	0.0980
			Engel coefficient of urban resident households	0.0194
	Economic benefits of land use	0.7500	Gross value of industrial output per land	0.2249
			Gross value of agricultural output per land	0.2879
			Per capita GDP	0.0943
			Proportion of output value of tertiary industry	0.1429
Ecological Environment	Resource utilization	0.1226	Water resources per capita	0.0817
			Effective irrigation area per capita	0.0409
	Environment quality	0.5571	Discharged volume of industrial waste water	0.1857
			Discharged volume of industrial waste gas	0.1857
			Industrial solid wastes generated	0.1857
	Ecological environment construction	0.3202	Forest coverage	0.0640
			Ratio of green space in built-up area	0.1281
			Afforestation area	0.1281

3.1.2 Determination of indicator weight. Land use and eco-environmental evaluation indicator is the contribution rate of every indicator to the evaluation objectives. It reflects the value status of every indicator in the comprehensive evaluation system. Different weights will lead to different evaluation results, and whether the weight coefficient is reasonable concerns the credibility of evaluation results. Since the evaluation system of land use and ecological environment is characterized by multiple levels, multiple indicators, and high complexity, it is suitable for determining the indicator weight.

Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It is a decision making approach structuring alternatives into a weighted multiple choice criteria hierarchy. Characterized by the in-depth analysis of the nature and influencing factors of the complex decision-making problem, it builds a hierarchical model, uses the quantitative information to realize mathematically process the decision-making process, so as to solve the multi-objectives and multi-criteria complex decision-making problem. It is an effective and feasible method.

The basic steps of AHP: first, establish the hierarchical model. On the basis of in-depth analysis of the problem, it decomposes various factors into several hierarchies from top to bottom. Factors of the same level are subordinate to the upper level or have influence on factors of upper level, and dominate the lower level factors or get influenced by factors of lower level. The top level is the target level, usually it has only one factor, the bottom level is usually the program or object level, in the middle there may be one or several levels, usually the criteria level or indicator level. Second, comparison is made between any two elements at each level. The judgment matrix is built, and the degree of importance is assigned by 1 – 9, the scale value of importance is listed in Table 2. Third, single hierarchical arrangement and consistency test are carried out. Single hierarchical arrangement refers to the relative weight of judgment matrix factors for each criterion. In order to carry out the consistency test of the indicators, it is necessary to calculate the consistency index (CI). According to Table 2, it is able to determine the corresponding average random consistency index RI, and finally calculate the consistency ratio (CR) and make the judgment. When $CR < 0.1$, the consistency of the judgment matrix is acceptable; when $CR > 0.1$, the judgment matrix does not meet the consistency requirements and it is necessary to make recorrection of the matrix.

According to the indicator system established above, we established the hierarchical model for land use evaluation indicator system and the hierarchical model for eco-environmental evaluation indicator system (Fig. 1 and Fig. 2) on the basis of AHP, separately built the judgment matrix, and finally calculated the weight of indicators of two systems (Table 1).

Table 2 Importance scale and its meaning

No.	Degree of importance	*aij* assignment
1	Objectives *i* and *j* are of equal importance	1
2	Objective *i* is slightly more important than objective *j*	3
3	Objective *i* is obviously more important than objective *j*	5
4	Objective *i* is strongly more important than objective *j*	7
5	Objective *i* is extremely more important than objective *j*	9
6	Objective *i* is slightly less important than objective *j*	1/3
7	Objective *i* is obviously less important than objective *j*	1/5
8	Objective *i* is strongly less important than objective *j*	1/7
9	Objective *i* is extremely less important than objective *j*	1/9

Note: *aij* = {2,4,6,8,1/2,1/4.1/6,1/8} indicates that the importance level lies between *aij* = {1,3,5,7,9,1/3,1/5,1/7,1/9}.

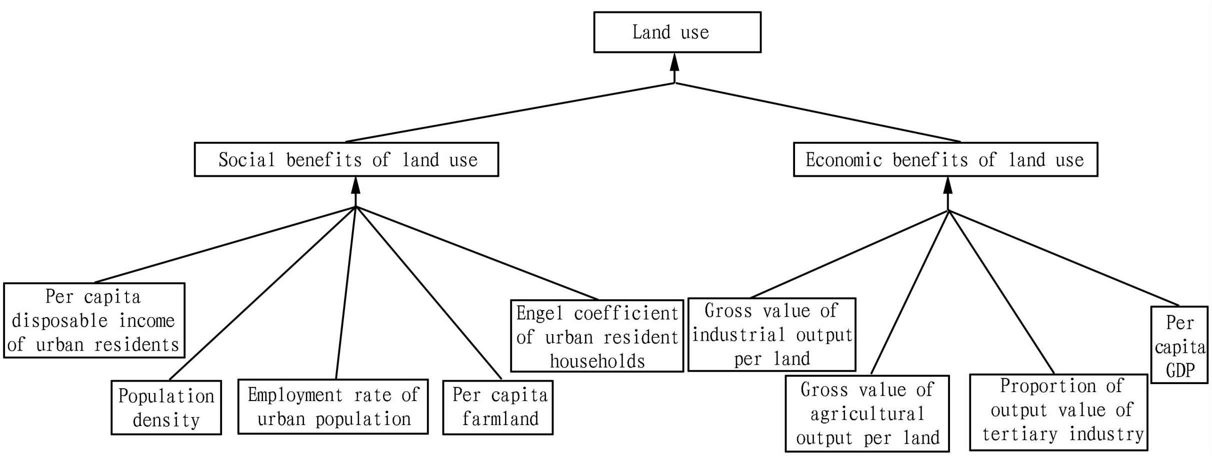

Fig. 1 Structural model for the land use evaluation indicator system based on AHP

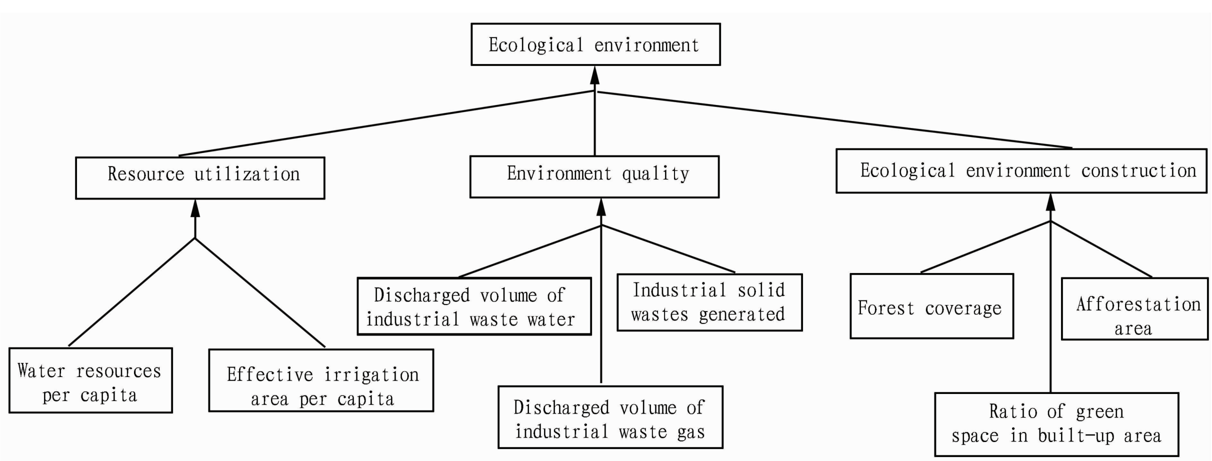

Fig. 2 Structural model for the ecological environment evaluation indicator system based on AHP

3.2 Evaluation methods We evaluated the coordination between land use and ecological environment in Hefei Economic Circle based on building composite index function of land use and composite index function of ecological environment, and measured their coordination using the coordination degree model.

Composite index function of land use:

$$F(x) = \sum_{i=1}^{m} W_i X_i$$

where $F(x)$ is the composite index function of land use, X_i is the standardized value of the i-th land use evaluation indicator, and W_i is the weight of the i-th land use evaluation indicator.

The composite index function of ecological environment:

$$G(y) = \sum_{j=1}^{n} W_j X_j$$

where $G(y)$ is composite index function of ecological environment, Y_j is the standardized value of the j-th ecological environment evaluation indicator, and W_j is the weight of the j-th ecological environment evaluation indicator.

The degree of coordinated development (D) is calculated from the coordination coefficient (C) and the composite index of coordinated development (T).

First, we calculated the coordination coefficient: in this study $K \geqslant 2$, we took 2.

$$C = \left\{ \frac{F(x) \cdot G(y)}{\left[\frac{F(x) + G(y)}{2} \right]^2} \right\}^2$$

where C denotes the coordination degree, $F(x)$ is the composite index function of land use, and $G(y)$ is composite index function of ecological environment.

Second, the evaluation function for the degree of coordinated development of land use and ecological environment:

$$D = \sqrt{CT}, T = a \cdot F(x) + b \cdot G(y)$$

where D is the degree of coordinated development, T is the composite index reflecting comprehensive benefits of land use and ecological environment, a and b are weight of land use and ecological environment in comprehensive benefits. Since land use is of the equal importance to the ecological environment, we took the value of 0.5.

With the reference to coordination criteria of Liao Chongbin, Yang Shixiang, Chen Xinglei *et al.* and division standard of related coordination types, we established the standard of coordination degree (Table 3) according to the actual situation of cities in Hefei Economic Circle. At the same time, in order to analyze coordinated development relationship between land use and the ecological environment, we established the degree division standard for coordinated development of land use and ecological environment (Table 4).

Table 3 Standard for division of coordination degree

Development status	Index evaluation standard
Benign development	$F(x) > 0.7$; $G(y) > 0.7$
Land use lagging behind	$F(x) < G(y)$; $0.4 < G(y) < 0.7$
Ecological environment lagging behind	$F(x) > G(y)$; $0.4 < F(x) < 0.7$
Decline status	$F(x) < 0.4$; $G(y) < 0.4$

Table 4 Standard for division of degree of coordinated development between land use and ecological environment

Degree of coordinated development (D)	Coordination level	Degree of coordinated development (D)	Coordination level
0 - 0.10	Extreme imbalance	0.50 - 0.60	Reluctant imbalance
0.10 - 0.20	Serious imbalance	0.60 - 0.70	Primary coordination
0.20 - 0.30	Moderate imbalance	0.70 - 0.80	Moderate coordination
0.30 - 0.40	Mild imbalance	0.80 - 0.90	Excellent coordination
0.40 - 0.50	Endangered imbalance	0.90 - 1.00	High quality coordination

3.3 Data processing and result analysis

3.3.1 Data source. The data in this study mainly came from *Statistical Yearbook of Anhui Province* (2015). The original data for each indicator are listed in Table 5. Although only Tongcheng City in Anqing City is situated in Hefei Economic Circle, considering the integrity of economic development and other factors, we took the whole Anqing City as the object of evaluation.

3.3.2 Standardized treatment and coordination degree calculation. Before calculating the composite index of land use and the composite index of ecological environment, to remove the influence of different dimensions on the evaluation results, it is necessary to make standardized treatment of every indicator.

Table 5 Value of indicators of coordination between land use and ecological environment of Hefei Economic Circle

System hierarchy	Indicator	Hefei City	Huainan City	Chuzhou City	Lu'an City	Anqing City
X	X_1	28082.74	22919.58	22591.37	21274.67	22683.11
	X_2	4256	2546	1358	3540	2086
	X_3	1.1929	0.5353	0.7240	0.7494	0.8059
	X_4	471.4733	480.1645	120.0174	743.7947	567.3629
	X_5	0.3905	0.4266	0.3781	0.4847	0.4418
	X_6	0.1800	0.1722	0.0380	0.0225	0.0430
	X_7	0.0217	0.0255	0.0155	0.0117	0.0139
	X_8	61555	34897	27474	17828	26596
	X_9	0.3942	0.2987	0.2784	0.3193	0.3176
Y	Y_1	386.31	259.64	824.15	1192.68	1812.90
	Y_2	0.5983	0.5174	1.2261	1.0292	0.6064
	Y_3	6017.56	10686.25	6459.91	2688.65	4862.83
	Y_4	2862.3	2809.7	1171.7	1126.3	1326.9
	Y_5	1024.10	2583.70	218.95	448.31	207.28
	Y_6	0.1430	0.1951	0.1501	0.3852	0.3800
	Y_7	0.3579	0.3677	0.3575	0.3425	0.3963
	Y_8	22803	2413	41455	27232	22023

The formula for standardized treatment of indicators of land use:

$$Y = \frac{X - X_{min}}{X_{\max} - X_{\min}}$$

where $X_{\max}$ and $X_{\min}$ denote the maximum and minimum values of corresponding indicators. Similarly, indicators can be obtained after the standardized treatment of the ecological environment. Specific results of standardized treatment are shown in Table 6. Through weighted calculation of standardized indicators, we obtained $F(x)$ the composite index function of land use, and $G(y)$ the composite index function of ecological environment. Through substituting into the above coordination degree evaluation formula, we obtained the coordination degree (D) of land use and ecological environment of every city. Related calculation results are listed in Table 7.

Table 6 Standardized treatment results of indicators of coordination evaluation

System hierarchy	Indicator	Hefei City	Huainan City	Chuzhou City	Lu'an City	Anqing City
X	X_1	1.0000	0.2416	0.1934	0.0000	0.2069
	X_2	1.0000	0.4099	0.0000	0.7426	0.2512
	X_3	1.0000	0.0000	0.2870	0.3256	0.4115
	X_4	0.5634	0.5774	0.0000	1.0000	0.7172
	X_5	0.1163	0.4550	0.0000	1.0000	0.5976
	X_6	1.0000	0.9505	0.0984	0.0000	0.1302
	X_7	0.7246	1.0000	0.2754	0.0000	0.1594
	X_8	1.0000	0.3903	0.2206	0.0000	0.2005
	X_9	1.0000	0.1753	0.0000	0.3532	0.3385
Y	X_1	0.1098	0.0000	0.4895	0.8090	1.0000
	X_2	0.1142	0.0000	1.0000	0.7222	0.1256
	X_3	0.4162	1.0000	0.4715	0.0000	0.2720
	X_4	1.0000	0.9697	0.0262	0.0000	0.1156
	X_5	0.3437	1.0000	0.0049	0.1014	0.0000
	X_6	0.0000	0.2151	0.0293	1.0000	0.9785
	X_7	0.2862	0.4684	0.2788	0.0000	1.0000
	X_8	0.4976	0.0000	1.0000	0.6057	0.4786

Table 7 Calculation results of standardized weighted indicators, $F(x)$, $G(y)$, and D

System hierarchy	Indicator	Hefei City	Huainan City	Chuzhou City	Lu'an City	Anqing City
X	X_1	0.0259	0.0063	0.0050	0.0000	0.0054
	X_2	0.0720	0.0295	0.0000	0.0535	0.0181
	X_3	0.0347	0.0000	0.0100	0.0113	0.0143
	X_4	0.0552	0.0566	0.0000	0.0980	0.0703
	X_5	0.0023	0.0088	0.0000	0.0194	0.0116
	X_6	0.2249	0.2138	0.0221	0.0000	0.0293
	X_7	0.2086	0.2879	0.0793	0.0000	0.0459
	X_8	0.0943	0.0368	0.0208	0.0000	0.0189
	X_9	0.1429	0.0251	0.0000	0.0505	0.0484
$F(x)$		0.8608	0.6648	0.1372	0.2327	0.2622
Y	Y_1	0.0090	0.0000	0.0400	0.0661	0.0817
	Y_2	0.0047	0.0000	0.0409	0.0295	0.0051
	Y_3	0.0773	0.1857	0.0876	0.0000	0.0505
	Y_4	0.1857	0.1801	0.0049	0.0000	0.0215
	Y_5	0.0638	0.1857	0.0009	0.0188	0.0000
	Y_6	0.0000	0.0138	0.0019	0.0640	0.0626
	Y_7	0.0367	0.0600	0.0357	0.0000	0.1281
	Y_8	0.0637	0.0000	0.1281	0.0776	0.0613
$G(y)$		0.4409	0.6253	0.3400	0.2560	0.4108
D		0.4704	0.5176	0.0954	0.1204	0.1857

3.3.3 Result analysis. After obtaining the evaluation results of the land use and ecological environment of the cities in Hefei Economic Circle, according to the degree division standard of land use and ecological environment in Table 3 and coordination degree division standard of land use and ecological environment, we obtained the degree of coordination between land use and ecological environment (Table 8).

Table 8 Degree of coordination between land use and ecological environment in Hefei Economic Circle

City	$F(x)$	$G(y)$	D	Degree of coordination	Degree of coordinated development
Hefei City	0.8608	0.4409	0.4704	Ecological environment lagging behind	Endangered imbalance
Huainan City	0.6648	0.6253	0.5176	Ecological environment lagging behind	Reluctant imbalance
Chuzhou City	0.1372	0.34	0.0954	Decline status	Extreme imbalance
Lu'an City	0.2327	0.256	0.1204	Decline status	Serious imbalance
Anqing City	0.2622	0.4108	0.1857	Land use lagging behind	Serious imbalance

4 Conclusions and recommendations

(i) Establishing the indicator systems and evaluation models for land use and ecological environment subsystems is favorable for achieving the coordination between the two systems of quantitative evaluation. The study shows that Hefei is on the verge of imbalance, Huainan remains at reluctant coordination status, Chuzhou is extremely out of balance, Lu'an and Anqing are extremely imbalanced, and every city is accompanied with different ecological environment or land use lagging problem.

(ii) In order to improve the degree of coordination between land use and ecological environment and promote the coordinated development of land use and ecological environment in Hefei Economic Circle, every city in Hefei Economic Circle should lay equal stress on the construction, protection and administration according to the coordination degree and development situation. For example, it is recommended to optimize and upgrade traditional industries, implement intensive and conserved use of land, increase input, and establish environment-friendly land use mode.

(iii) Through the implementation of various effective measures, including building urban green space system, increasing the forest coverage, increasing wetland protection zone area, building sponge city, strengthening control of land ecological environment, and ensuring sustainable use of land resources, it is expected to ensure coordinated development of land use and ecological environment in the rapid development of Hefei Economic Circle.

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5.4 Impelling whole coordinated development of rural land consolidation The essence of future urbanization land use is digging stock construction land. With impelling of urbanization process in Anhui Province, under the premise of strictly controlling total scale of urban-rural construction land, the fundamental direction is optimizing urban-rural land use structure and realizing the transformation of rural construction to urban land use[6]. To adapt to the need of land consolidation work, related policies should be perfected actively, such as land ownership and fund management. When necessary, it should improve management function of professional organization of land consolidation, sufficiently play social service role of land consolidation research and training agency, enhance continuing professional education of land consolidation, and improve business quality of management and professional technical personnel of land consolidation.

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