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Article

Coupling and Coordination of Implicit Land Use and Ecological Security in Huaihe River Basin, China

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Abstract: The Huai River Basin is located in Jiangsu, Anhui, Shandong, Hubei, and Henan provinces of China. We explored the spatiotemporal characteristics and their changes in the ecological security and the form index of implicit land use using an equivalent factor method and a coupling coordination model. The coupling coordination between land use and ecological security was explored by evaluating the transformation of implicit land use. It was important to optimize the spatial pattern of the Huai River Basin and develop the area as eco-friendly. The research results indicated that the form index of land use in the five provinces increased from 2000 to 2015 and the degree of implicit land use was high with spatiotemporal differentiation. The transformation of land use showed a cycle, and the transformation speed was fast but slowed. The level of coupling and coordinated development in the provinces varied greatly. The implicit land use and ecological security in each province were imbalanced which was improved.

Keywords: Recessive land use morphology; Land use transition; Coupling and coordination

1. Introduction

Human survival and development are based on land resources, and the interaction between humans and nature occurs mainly on land. Therefore, land use is important in the development of the economy and ecology [1]. There are two forms of land use. One is the explicit form, which is mainly used to characterize the changes in land quantity and land use methods. The other is the implicit form, which is used to reflect changes in land quality, input, and output [2]. The research on implicit land use has yielded fruitful results. Cheng et al. explored the spatiotemporal pattern of implicit forms of land use in China using an index method and horizontal comparison method based on non-spatial description [3]. Long et al [4]. studied the implicit regional land use from the perspective of development, utilization, and output, taking the Huanghuaihai region as an example. However, further research is needed on the coupling and coordination of implicit forms of land use and ecological security. The Huai River Basin is a plain with flat terrain, fertile land, convenient transportation, and abundant mineral resources. It provides energy, mineral resources, and manufacturing in China. With the rapid development of urbanization in the Huai River Basin, the demand for construction has surged, and the contradiction in land use between people and land has become increasingly severe. To guide the allocation of land resources in the Huai River Basin, we analyzed the coupling coordination problem in implicit land use and ecological security using the form index, an equivalent factor method, and a coupling coordination model.

2. Research Overview and Data Sources

The Huai River Basin flows through five provinces with a vast basin area: Jiangsu, Shandong, Anhui, Henan, and Hubei. The cultivated land area in the watershed accounts for 12% of the national cultivated land area, making it an important food production base in China. The forest and grassland areas reach 33299.4069 km^2, accounting for 12.1% of the total watershed area. The unused land area in the watershed is relatively small. Thus, it is important to establish a strategy for development in central China. The proportion of the tertiary industry in the Huai River Basin is increasing, and the industrial structure has been upgraded. The secondary industries in the provinces emit pollutants by producing coal, paper, and electricity and account for 30 to 40% of the total industries, but the proportion is decreasing. Agriculture accounts for a relatively high proportion, and the industrial structure still needs to be optimized.

We constructed the form index of implicit land use by collecting the data on assets, investment, total GDP, total social service expenditure, and total pollution emissions in the Statistical Yearbooks of Jiangsu, Shandong, Anhui, Hubei, and Henan provinces from 2000 to 2015. Ecological service value was estimated based on the remote sensing monitoring data of China in a 1:100000 provided by the Environmental Science Data Center of the Chinese Academy of Sciences. The data on forest and grassland areas in the Huaihe River basin were obtained from the Department of Land and Resources of Jiangsu, Shandong, Anhui, Hubei and Henan provnices.

3. Research Methods

3.1 Index of Hidden Forms of Land Use

In general, research on the implicit form of land use is conducted by defining the form index of land use between (0,1). The higher the value, the higher the level of implicit form of land use [5]. The formula for calculating its index is as follows.

$$L = \sum_{i=1}^{n} x_i' w_i \tag{1}$$

In equation (1), L is the implicit form index of land use, x_i' is the standardized value for the i-th indicator, w_i is the weight of the i-th indicator. Weights are grouped into subjective and objective weights to determine the impact of each indicator. The subjective weighting method is based on the experience of researchers or experts so lacks objectivity. In the objective weighting method, mathematical models and methods are used to calculate weights with a scientific basis.

3.2 Equivalent Factor Method

The equivalent factor method is used to construct the value of ecosystem service based on quantifiable standards for different types of ecosystems [6]. The calculation formula is as follows.

$$VC_i = \sum_{f=1}^{m} EC_f \times E_a \tag{2}$$

$$ESV_f = \sum_{i=1}^{n} LA_i \times VC_{fi} \tag{3}$$

$$ESV = \sum_{i=1}^{n} LA_i \times VC_i \tag{4}$$

where EC_f represents the value equivalent of ecosystem services for item f of a certain type of land use, E_a represents the value of one standard unit of ecosystem service value equivalent factor, VC_i represents the ecosystem service value coefficient for the i-th land use type, LA_irepresents the area of the i-th type of land use, VC_{fi} is the coefficient representing the value of ecosystem services in item f for the i-th land use type, ESV_f is the ecological value of the f-th ecosystem service, and ESV represents the ecosystem service value of the study area.

3.3 Implicit Form Index for Land Use

We established an implicit form index system of land use from the perspectives of economy, society, ecology, and environment (Table 1). In terms of economy, two indicators were selected: per capita fixed asset investment and per capita fiscal expenditure [7]. Social service expenditure was used to characterize the social aspect and reflect the development of social livelihood. At the ecological level, the consumption of land was measured by the value of each ecosystem service. From an environmental perspective, the average emission of pollutants was used to characterize the ecological effects of sewage, exhaust gas, and solid waste on land use.

Table 1. Index system of implicit forms of land use

Perspective	Calculation Method	Direction
Economy	Total fixed assets investment/area under jurisdiction	+
	Area of jurisdiction/GDP	-
Society	Total expenditure on social services/jurisdictional area	+
Ecology	Equivalent factor method	-
Environment	Total emissions/jurisdictional area	-

3.4 Coupling Coordination Model

The coupling coordination model is used to estimate the degree of coordination between land use forms and ecological security. Based on this, the stability and sustainability of system operation are evaluated [8]. The calculation formula are as follows.

$$C=\left[f(x)\cdot g(y)/\left(\frac{f(x)+g(y)}{2}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

$$T=af(x)+\beta g(y) \quad (6)$$

$$D=(C\cdot T)^{\frac{1}{2}} \quad (7)$$

where C represents the coupling degree, T is the degree of coordination, and D represents the coupled scheduling in the range of [0,1]. The larger the value, the better the coordination between the implicit form of land use and ecological security, and vice versa. A and β are undetermined parameters and equally important for collaborative development, taking $a = \beta = 0.5$ [9]. The uniform distribution function method [10] was used to classify the coordination degree D between the implicit form of land use and ecological security in the study area, as shown in Table 2.

Table 2. Coupling coordination level classification table

Coordination Type	Coupling Degree	Coordination Type	Coupling Degree
Extreme imbalance	0.00−0.09	Bare coordination	0.49−0.59
Severe imbalance	0.09−0.19	Primary coordination	0.59−0.69
Moderate imbalance	0.19−0.29	Middle coordination	0.69−0.79
Mild imbalance	0.29−0.39	Good coordination	0.79−0.89
Endangered imbalance	0.39−0.49	Superior coordination	0.89−1.00

4. Results and Discussion

4.1 Spatial and Temporal Characteristics

The implicit form of land use in the study area showed an overall upward trend with an average growth of 10.45% from 2000 to 2005, 5.40% from 2005 to 2010, and -0.04% from 2010 to 2015 (Fig. 1). This indicated that the growth rate slowed down over the past 15 years, and decreased from 2010 to 2015. However, the implicit form of land use was still at a relatively high level. The implicit form index of land use in the Huai River Basin was 0.74−0.83, and Jiangsu Province showed a high value since 2010. The number of provinces with median values of 0.64−0.73 was 1 in 2000 and 2 in 2005 and continued to increase by 2010. The number of provinces with low values (0.54−0.63) decreased from 4 in 2000 to 2 in 2005. All provinces in the Huai River Basin showed higher values than the low-value range.

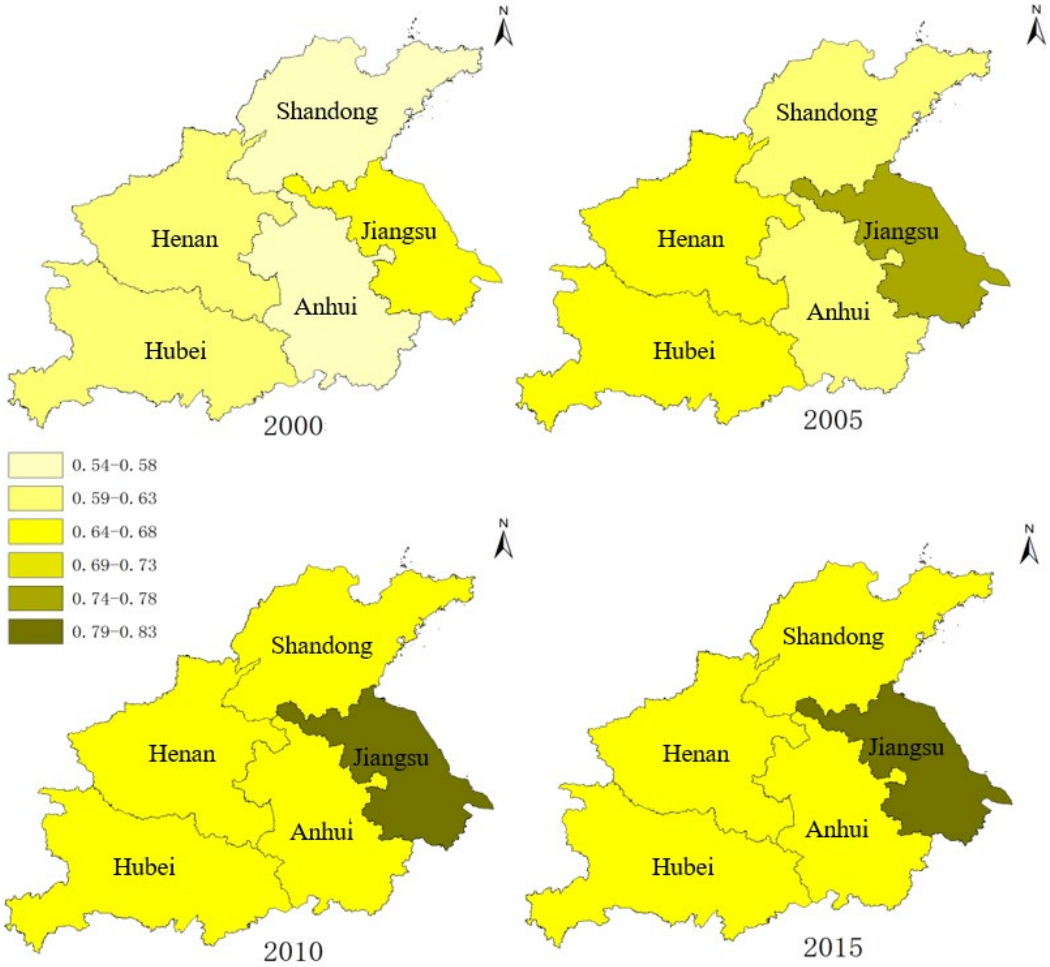

Fig. 1. Spatiotemporal characteristics of implicit forms of land use in Huai River Basin.

From 2000 to 2015, there were significant differences in the implicit form of land use in the study area. Jiangsu Province ranked first and has been in a high-level state. The average growth rate of the form index of land use during these 15 years was 6.98%. Jiangsu is the fastest-growing province in the study area with a high growth rate. The form index of land use in Shandong Province ranks last, but with the rapid development of the social economy, the form index of land use steadily increased. From 2000 to 2015, the average form index of land use increased by 6.53%, showing the highest growth rate among several provinces. The index of land use in Henan increased by an average of 2.67% in the past fifteen years, which was the lowest growth rate among the provinces, but the index was high. The average growth rate of the form index in Anhui and Hubei provinces was 5.79 and 4.39%, respectively showing a relatively high growth rate.

4.2. Change in Implicit Form of Land Use

Fig 2 shows a line graph of the form index of land use in the study area from 2000 to 2015 [9, 11]. By comparing the form index of land use in different times and spaces, the change patterns were explored, and a land use transformation model was established based on the patterns. The implicit transformation of land use was divided into three stages: slow transformation period (a form index of below 0.3), intense transformation period (a form index of 0.3−0.8), and stable transformation period (a form index of 0.8) [12]. Due to the high level of the form index in the study area from 2000 to 2015, we did not explore the "slow transformation period", but mainly focused on the other two stages. Due to rapid economic growth and social development, the implicit form of land use entered a period of intense transformation with a significant increase in growth rate. After entering the period of stable transformation, the growth rate began to slow down. The Huai River Basin was developed in two stages, completing the land use transformation in the stable transformation period". The development cycle did not end, and the development of new science and technology has driven the new land use transformation [13].

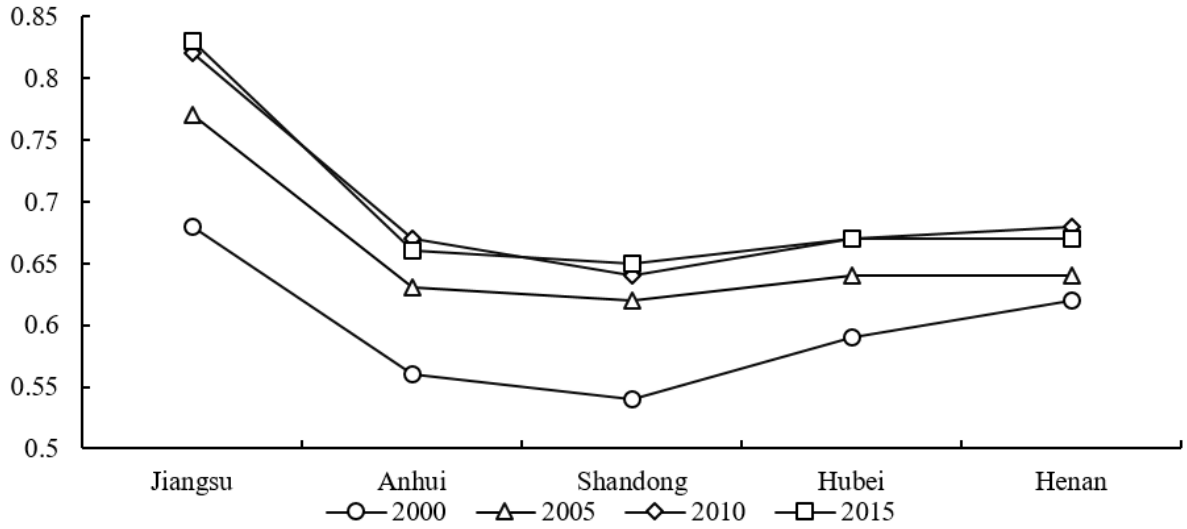

Fig. 2. Form Index of implicit land use from 2000 to 2015.

4.3. Spatial and Temporal Changes in Land Ecological Security

There were significant differences in the ecological security index among provinces in the research area. The ecological security index in Jiangsu Province was the lowest value. With insufficient forest coverage, a small proportion of grassland and forest in the Huai River Basin showed a fragile ecological environment. However, Hubei Province had large forests with a large proportion of grassland and forest land in the Huai River Basin. The ecological environment was excellent, and the ecological security index was high. From 2000 to 2005, except for Anhui Province where the proportion of forest land and grassland in the Huai River Basin remained unchanged, the proportion in the other four provinces decreased. From 2005 to 2010, the proportion in Hubei Province increased rapidly, while the proportion of forest land and grassland in Jiangsu and Anhui provinces increased slightly. From 2010 to 2015, the proportion in the five provinces of the Huai River Basin decreased slightly, but the change was small. The proportion remained roughly stable (Fig. 3). The changes in the ecological security index were closely related to the stages of implicit transformation of land use. Before entering the period of intense transformation, the increase in urban construction land reduced forest and grassland areas, and the deterioration of the ecological environment decreased the ecological security index. The faster the economic development speed, the faster the decline in the ecological security index. In the later stage, people gradually realized the deterioration of the ecological environment and began to pay attention to environmental protection and pollution control. The ecological security index was improved for harmonized development. Several cities entered a period of stable transformation with increasing ecological security index for the ecological environment.

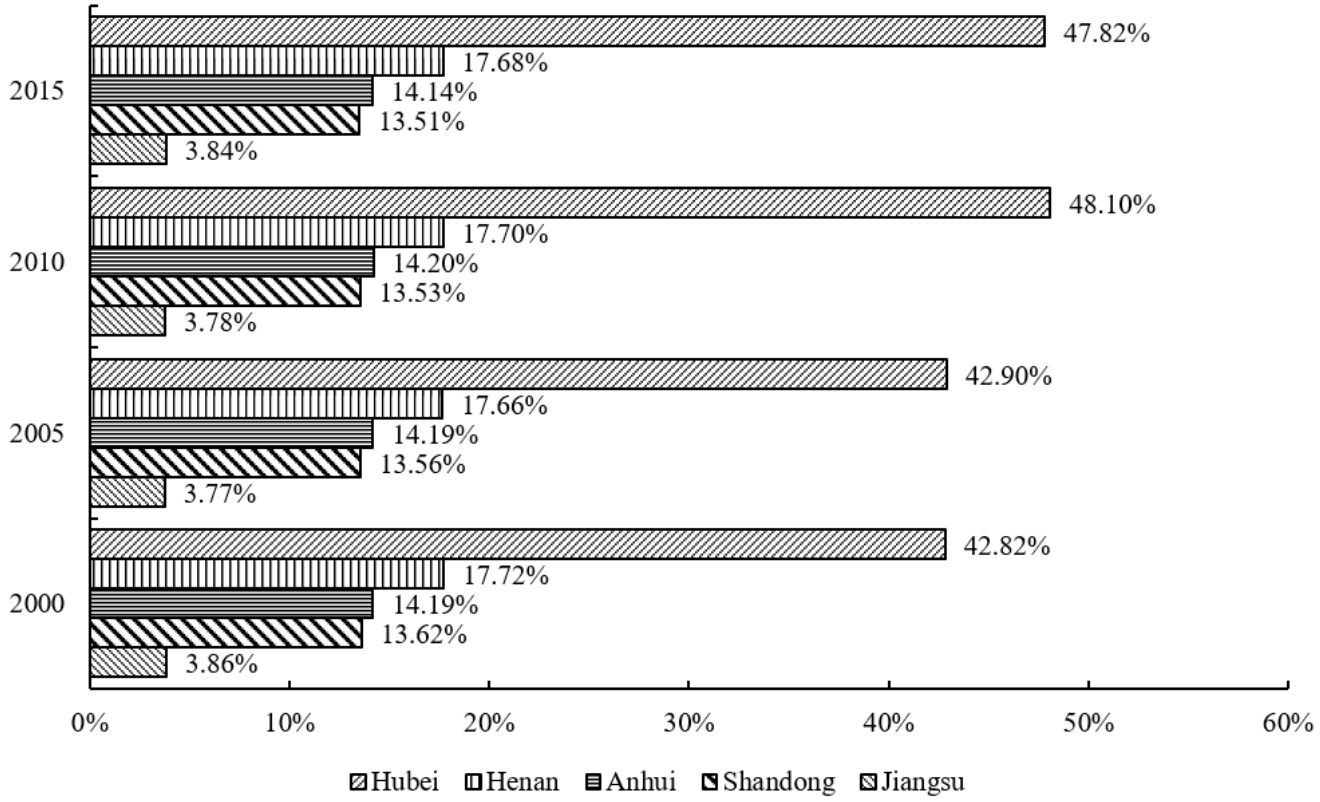

Fig. 3. Proportion of forest and grassland in provinces in Huai River Basin.

4.4 Coupling and Coordination of Implicit Land Use and Ecological Security

There were significant differences in the level of coupling and coordinated development in the study area, and the implicit forms of land use and land ecological security in different provinces were in transition from imbalance to coordination (Fig. 4). The coupling coordination between implicit land use and ecological security increased from 2005 to 2010, and the annual coordination rate slowed from 2010 to 2015 with decreases in several provinces. Jiangsu was a coordinated state from 2005 to 2010, but by 2014 it was imbalanced. While developing its economy, environmental protection and green waters and mountains need to be preserved. In Shandong Province, coupling and coordination of implicit land use and ecological security were imbalanced in 2005 but coordinated in 2010, while Hubei was imbalanced. The ecological environment improved to be at a coordinated level. Henan was imbalanced with improvement, while Anhui remained imbalanced. Although the coordination degree increased, it was still low. The form index of land use in the region was not high enough compared with the ecological security index. Thus, it is crucial to achieve harmonious development between humans and nature by strengthening economic construction in the ecological environment.

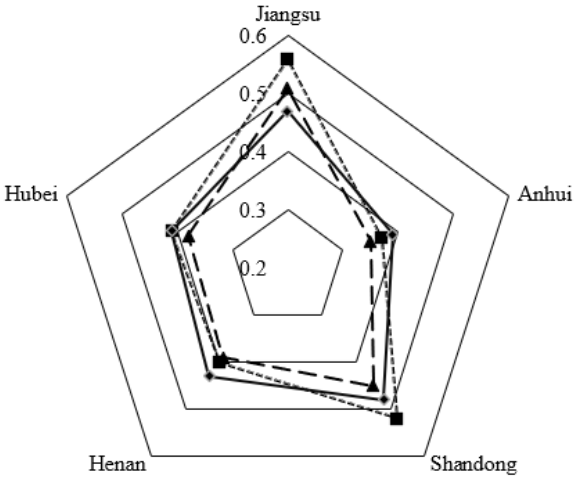

Fig. 4. Changes in the coupling of implicit land use and ecological security.

5. Conclusions

We investigated the spatiotemporal characteristics and their changes in the form index of implicit land use using an equivalent factor method and a coupling coordination model. The coupling coordination between land use and ecological security was explored by analyzing the transformation of implicit land use. It was important to optimize the spatial pattern of the Huai River Basin and develop the area as eco-friendly. The form index of land use in the five provinces increased during 2005−2015, and the degree of implicit land use was high with spatiotemporal differentiation. The transformation of land use showed a cycle, and the transformation was fast but became slower. The level of coupling and coordinated development in the provinces varied greatly, and the implicit land use and ecological security in each province were imbalanced but became improved.

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