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Research on the Coupled and Coordinated Development of Intensive Land Use and Ecological Environment in East China

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Abstract: *To reveal the coupling and coordination effect between land intensive utilization and the ecosystem, alleviate land supply - demand pressure, and curb ecological degradation from extensive land use, the East China region, as the core for high - quality development, is crucial for land intensive utilization and ecological protection. This paper constructs a coupling coordination degree model for interdisciplinary research to analyze the interaction between land resource utilization efficiency and ecosystem health. Research shows that the coupling coordination degree of land intensive utilization and ecological environment protection in East China provinces and cities has been improving. Jiangsu and Shandong are in coupled and coordinated development; Zhejiang, Anhui, Fujian, and Jiangxi are approaching imbalance and decline; Shanghai is in mild imbalance and decline. The ranking of the comprehensive index of the land intensive utilization subsystem is: Jiangsu > Shandong > Zhejiang > Anhui > Fujian > Jiangxi > Shanghai. The ecological environment system subsystems fluctuate with significant provincial differences. Therefore, East China provinces and cities should adhere to the "three zones and three lines" policy, optimize spatial layout, upgrade industrial structure, strengthen ecosystem protection, and enhance ecological service functions.*

Keywords: *Land Intensive Utilization, Ecological Environment, Coupling Coordination, East China Region*

1. Introduction

Land is the fundamental material basis for human survival. The way and efficiency of its utilization play a crucial role in regional development. Under the circumstances of rapid economic development and increasing pressure on resources and the environment, the efficient and intensive utilization of land is a powerful means to implement the basic national policy of conservation and environmental protection, and an important guarantee for promoting the sustainable development of territorial space[1]. Meanwhile, the ecological environment, as the fundamental condition for human survival and development, its protection and improvement is also an important issue that the current society is facing. The intensive use of land and the ecological environment are interrelated and mutually influential. The coordinated development of these two aspects is of profound significance for regional sustainable development.

The East China region, a leading area in China's economic and cultural development, promotes national economic sustainability and social stability. On one hand, industrialization and urbanization have increased the demand for construction land, making the land supply - demand contradiction prominent and extensive land use still an issue. Thus, land utilization efficiency needs improvement. On the other hand, economic development has caused environmental problems. The growth of heavy and light industries, foreign capital influx, and export expansion have led to over - reliance on the "high - consumption, high - investment, low - added - value" export model[2], resulting in severe air, water, and land pollution and pressure on the ecological environment.

At present, domestic and foreign scholars have achieved certain results in research on land intensive utilization and ecological environment. Most existing studies focus on enhancing land intensive utilization, protecting the ecological environment and promoting economic and social stability. However, there are few research papers coupling and coordinating the development of land intensive utilization and the ecological environment as a related system. Moreover, the research methods have limitations, especially for studies in East China. Therefore, researching the coordinated development of

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land intensive utilization and ecological environment in East China is significant for the region's sustainable economic development.

2. Research Methods and Data Sources

2.1 Overview of the Study Area

East China is in the eastern part of China. It includes Jiangsu, Zhejiang, Shandong, Anhui, Fujian, Jiangxi, and Shanghai. But due to geographical and other factors, data collection is limited, so this study focuses on the "six provinces and one municipality" on the mainland. The terrain is diverse, mainly plains, hills, basins, and mountains, with higher elevations in the west and lower in the east[3]. It is one of the most densely - populated areas in China, with a large Han - dominated population and a high density of urban residents. It has municipalities, provincial capitals, a developed economy, and administrative divisions. The water system is well - developed with many lakes and a complex river network. With rapid economic growth and urbanization, the ecological environment faces many challenges. Industrial, domestic, and agricultural non - point source pollution are serious, and air and water pollution are severe in some areas, requiring improvements in air and surface water quality. Also, rapid urbanization and industrialization have led to over - exploitation of land, compression of ecological space, threats to ecosystem integrity and stability, and pressure on biodiversity.

2.2 Data Sources and Indicator Construction

In order to ensure the rigor, feasibility and accessibility of the data for this research, this article takes Jiangsu Province, Zhejiang Province, Shandong Province, Anhui Province, Fujian Province, Jiangxi Province and the municipality of Shanghai as the research units. The data are derived from the provincial statistical yearbooks and the China Statistical Yearbook over a span of 10 years, from 2014 to 2023.Based on the existing research results of scholars and in combination with the actual situation of East China, the indicators were refined and determined. As shown in Table 1, 13 indicators were established. Some of the indicator data were calculated based on the directly obtained original data.

Table 1 Evaluation Index System for Land Intensive Utilization and Ecological Environment in East China

Target Layer	Indicator Layer	Unit	Nature
Land Intensive Utilization	Population measurement	thousands of people	+
	Length of highway	Km	+
	Quantity of employment	thousands of people	+
	Expenditure in the general public budget	ten thousand yuan	+
	Per capita disposable income of residents	ten thousand yuan	+
	GDP	ten thousand yuan	+
	Public budget revenue	ten thousand yuan	+
	Total retail sales of consumer goods	ten thousand yuan	+
Ecological Environment System	Per capita water resources	L	-
	Urban green space area	m^2	-
	Green coverage rate of built-up areas	%	-
	Household garbage removal volume	ten thousand tons	-
	Sulfur dioxide emissions from waste gas	ten thousand tons	-

2.3 Research Methods

2.3.1 Data dimensionless processing

$$\text{Positive indicators(+):}\quad x'_{nij} = \frac{x_{nij} - \min(x_j)}{\max(x_j) - \min(x_j)} \times 0.9 + 0.1 \tag{1}$$

$$\text{Negative indicators(-):}\quad x'_{nij} = \frac{\max(x_j) - x_{nij}}{\max(x_j) - \min(x_j)} \times 0.9 + 0.1 \tag{2}$$

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In the formula: n is the year, i is the province, and j is the indicator. x'_{nij} The unnormalized values of the "represent n year, i province, j indicator" data, $x'_{nij} \in [0,1]$. x_{nij} represents the initial value of the data. $\max(x_{nij})$ represents the maximum value of the indicator among all evaluation objects. $\min(x_{nij})$ represents the minimum value of the indicator among all the evaluated objects.

2.3.2 Determining the weights of indicators using the entropy method

First, calculate the proportion of indicator j in the sample values of evaluation object i:

$$p_{nij} = \frac{x_{nij}'}{\sum_{i=1}^{n} x_{nij}'} \tag{3}$$

Secondly, calculate the information entropy of each indicator:

$$e_j = -k\sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \tag{4}$$

In the calculation formula, $k = 1/\ln(n)$

Subsequently, calculate the information utility value:

$$d_j = 1 - e_j \tag{5}$$

Finally, calculate the weight coefficients:

$$\omega_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

2.3.3 Comprehensive Evaluation Index

Based on the processing of the previous data, finally, the linear weighted method was used to conduct a comprehensive evaluation of the land intensive utilization and the ecological environment system in the East China region. The specific values of the evaluation indices for the land intensive utilization, the ecological environment system, and the composite system in the East China region were calculated. The formula is as follows:

$$W(u) = \sum_{j=1}^{n} \omega_j u_{ij}' \tag{7}$$

$$E(y) = \sum_{j=1}^{n} \omega_j y_{ij}' \tag{8}$$

$$T = \lambda W(u) + \mu E(y) \tag{9}$$

2.3.4 Coupling Coordination Degree Model

$$C = 2 \times \left[\frac{W(u) \cdot E(y)}{\left(W(u) + E(y)\right)^2} \right]^{\frac{1}{2}} \tag{10}$$

In the formula, C represents the degree of coupling, $0 \le C \le 1$. However, the degree of coupling can only represent the strength of the correlation among the two systems, but it cannot reflect the coordinated development status of the relationships among the two. In order to measure the degree of coordination between land intensive utilization and the ecological environment system in the eastern

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region of China, the coupling coordination degree model was introduced:

$$D = \sqrt{CT} \tag{11}$$

In the formula, D represents the degree of coupling coordination, $0 \le D \le 1$. C represents the coupling degree in Equation 11, T represents the comprehensive evaluation index of the land intensive utilization and ecological environment composite system in the eastern region as stated in Equation 10. The larger the value of D is, the stronger the coupling coordination degree will be. Therefore, the coupling and coordinated development between land intensive utilization and the ecological environment system in East China is better. According to the research of scholars, the stages of coupling coordination degree are divided as shown in Table 2:

Table 2 Coupling coordination stages and classification criteria

D	Degree of coupling and coordination	Coupling and coordination phase
$0 \le D < 0.1$	Disorder and decline category	Extreme dysregulation and depression
$0.1 \le D < 0.2$		Severe maladjustment and decline
$0.2 \le D < 0.3$		Moderate disordered decline
$0.3 \le D < 0.4$		Mild disordered decline
$0.4 \le D < 0.5$	Excessive category	Approaching maladjustment and decline
$0.5 \le D < 0.6$		Relatively coupled development
$0.6 \le D < 0.7$	Coordinated Development Category	Primary coupling development
$0.7 \le D < 0.8$		Intermediate coupling development
$0.8 \le D < 0.9$		Good coupling development
$0.9 \le D \le 1$		High-quality coupling development

3. Empirical Results and Analysis

3.1 Intensive Land Utilization and Comprehensive Development Level of Ecological Environment and Subsystems

3.1.1 From an overall perspective

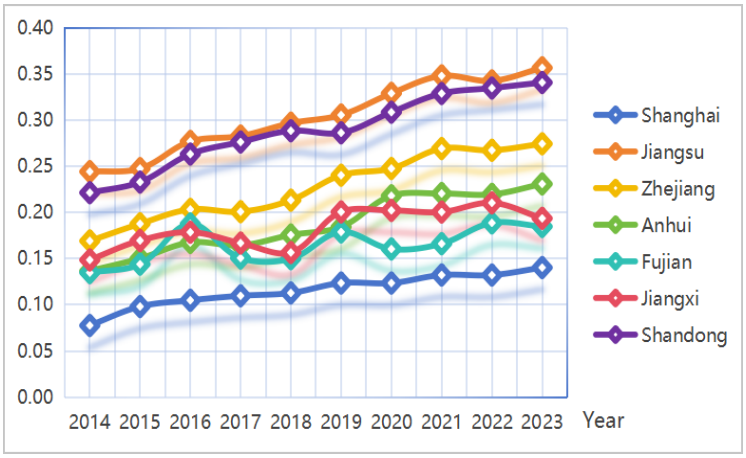

Figure 1: Trend of Land Intensive Utilization and Comprehensive Ecological Environment Coordination Index in Each Province of East China from 2014 to 2023

As shown in Figure 1, land-intensive resource use and ecological environment coordination in East China's provinces showed an upward trend from 2014 to 2023. This reflects improving coordination levels in land use and environmental protection. The index increased gradually from 2014 to 2018 and rapidly from 2019 to 2023, correlating with China's ecological civilization policy. Jiangsu Province, as an industrial hub, maintains economic and ecological balance through strict industrial land management for ecological projects.

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3.1.2 From the perspective of the land intensive utilization subsystem

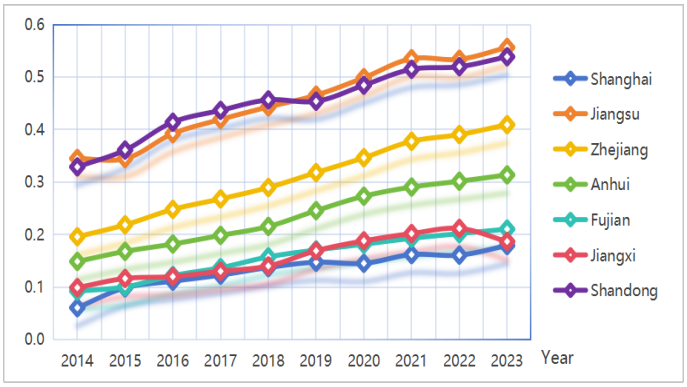

Figure 2: Trend of the comprehensive index of land intensive utilization system in each province of East China from 2014 to 2023

As shown in Figure 2, the intensive use of land resources has shown a continuous upward trend, with data from each province maintaining a highly consistent pace, presenting a stepwise growth pattern. Overall, the comprehensive index of the land intensive use subsystem ranks as follows: Jiangsu Province > Shandong Province > Zhejiang Province > Anhui Province > Fujian Province > Jiangxi Province > Shanghai. This system can be roughly divided into three tiers. First Tier: Shandong and Jiangsu. From 2014 to 2023, they were within the range of 0.33 to 0.56. Jiangsu and Shandong formed a dual-core tier, but Jiangsu was more stable, benefiting from its advanced management experience and efficient resource utilization strategies. Second Tier: Zhejiang and Anhui. From 2014 to 2023, they were within the range of 0.15 to 0.41. These two provinces are developing at a moderately high level with a relatively stable growth trend. Third Tier: Fujian, Jiangxi, and Shanghai. From 2014 to 2023, they were within the range of 0.06 to 0.21. These three provinces still face challenges in terms of land intensive use. The index value of Shanghai is relatively low and the growth trend is also relatively slow. This might be related to factors such as the tight land resources and high urbanization level in Shanghai[4].

3.1.3 From the perspective of the ecological environment subsystem

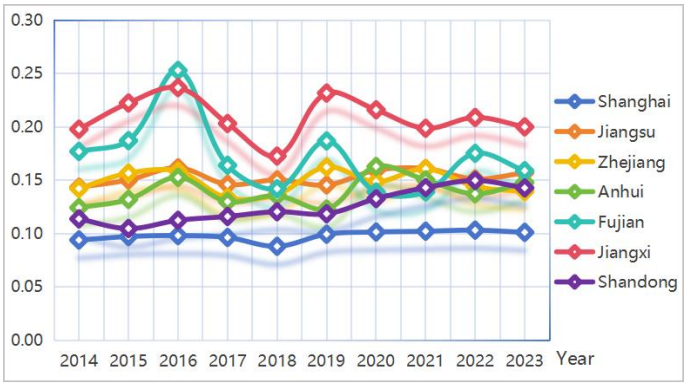

Figure 3: Trend of Comprehensive Environmental System Index of Each Province in East China from 2014 to 2023

As shown in Figure 3, from 2014 to 2023, the comprehensive ecological environment system index of all provinces in East China fluctuated, showing no obvious overall upward or downward trend, and the disparities among provinces were quite large. Jiangxi and Fujian had relatively better ecological environments, while Shanghai and Shandong faced greater ecological pressures. Fujian's index value reached a relatively high peak in 2016 and then declined slightly, but generally remained at a moderately high level. In policy, in June 2016, the Central Leading Group for Deepening Reform approved the "Implementation Plan for the National Ecological Civilization Pilot Zone (Fujian)", making Fujian China's first national ecological civilization pilot zone. In climate, in 2016, Fujian had evenly - distributed precipitation and a short hot season, reducing the occurrence of disasters like fires and pests. In industry, Fujian phased out outdated production capacities such as small coal mines and small cement plants and promoted the development of green industries like new energy and integrated circuits.

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3.2 Analysis of the Level of Coupled and Coordinated Development of Land Intensive Utilization and Ecological Environment System.

3.2.1 From the Perspective of Time

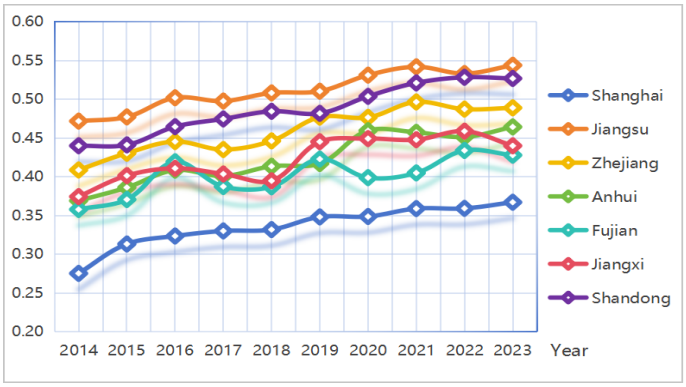

Figure 4: Trend of Changes in Land Intensive Utilization and Ecological Environment Coupling Coordination Degree in Each Province of East China from 2014 to 2023

As shown in Figure 4, overall, from 2014 to 2023, the coupling coordination degree between land intensive utilization and the ecological environment in all East - China provinces and cities was continuously rising, with remarkable overall progress. In the past decade, all these provinces and cities had positive growth in coupling coordination degrees, affirming regional sustainable development. Jiangsu, Zhejiang, and Shandong led the way. Jiangsu was at the forefront with an annual growth rate of 1.4%, maintaining a high level via industrial land renewal and ecological land preservation. Zhejiang had the fastest growth; it surpassed Shandong in 2021 by achieving full - coverage of the smart land management platform and increasing the inefficient land redevelopment contribution rate by 35%. In Shandong, the coupling coordination degree first decreased and then increased. In 2016, due to heavy chemical land rectification, it temporarily declined, facing transitional challenges but still maintaining a leading position.

3.2.2 At the mean level of data for the period from 2014 to 2023, regarding the coordinated development of land intensive utilization and the ecological environment system

Table 3 Mean values of coupling coordination development and main restrictive factors

Region	Mean Value Of Land Intensive Utilization Subsystem Development	Mean Value Of Ecological Environment Subsystem Development	Mean Value Of Comprehensive Coordination Index	Mean Value Of Coupling Coordination Degree	Coupling Coordination Development Stage	Main Constraints
Shanghai	0.1328	0.0982	0.1155	0.3355	Mild decline and deterioration	Ecological environment lagging type
Jiangsu	0.4533	0.1526	0.3030	0.5116	Strained integration of development	Ecological environment lagging type
Zhejiang	0.3063	0.1484	0.2273	0.4591	On the verge of imbalance and decline	Ecological environment lagging type
Anhui	0.2339	0.1397	0.1868	0.4227	On the verge of imbalance and decline	Ecological environment lagging type
Fujian	0.1569	0.1723	0.1646	0.4010	On the verge of imbalance and decline	Ecological environment lagging type
Jiangxi	0.1566	0.2089	0.1827	0.4225	On the verge of imbalance and decline	Ecological environment lagging type
Shandong	0.4508	0.1255	0.2881	0.4865	Strained integration of development	Ecological environment lagging type

As shown in Table 3, Jiangsu and Shandong have achieved a relatively good state of integrated and coordinated development between land intensive utilization and the ecological environment, and are in the coupled and coordinated development phase. They've implemented strategies like industrial upgrading and ecological restoration to create a three - dimensional driving force. However, Zhejiang,

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Anhui, Fujian, and Jiangxi face an average situation in this regard and are at a stage with a risk of imbalance and decline. To resolve the contradiction between ecological protection and land development, Zhejiang promoted the "hilly village" model and established a "Digital Land Resources Platform". Anhui set up a cross - provincial trading market for cultivated land indicators. Fujian strictly implemented a dual - control model for tourism land use[5]. Jiangxi is developing selenium - enriched functional agriculture and using technology for environmental governance. In contrast, Shanghai has a poor situation of coordinated development between land intensive utilization and the ecological environment and has entered a stage of mild imbalance and decline. Due to historical issues, industrial land transformation in Shanghai is difficult, pollution control costs are high, and land function transformation lags. Currently, Shanghai enforces strict regulatory management on limited land through progressive measures such as mandatory soil pollution testing and dynamic supervision of industrial performance.

4. Research Findings and Discussion

In this article, the coupling coordination model and a "comprehensive analysis + subsystem analysis" method were used to draw the following conclusions. Firstly, the overall index of land intensive utilization and comprehensive ecological environment coordination in the six provinces and one municipality of East China has been on the rise. Secondly, land resource intensive utilization has shown a continuous upward trend and can be divided into three tiers: the first tier includes Shandong and Jiangsu; the second tier, Zhejiang and Anhui; and the third tier, Fujian, Jiangxi, and Shanghai. Thirdly, the comprehensive index of the ecological environment system fluctuated from 2014 to 2023, with no clear overall trend and significant provincial variations. Fourthly, the coupling and coordination degree between land intensive utilization and the ecological environment in all East - China provinces and cities has been increasing, with positive growth in all regions. Fifthly, Jiangsu and Shandong are in a stage of coupled and coordinated development, while Zhejiang, Anhui, Fujian, and Jiangxi are approaching an imbalance and decline stage, and Shanghai is in a mild imbalance and decline stage. The research indicates that the coupling development of land intensive utilization and the ecological environment in Jiangsu and Shandong is relatively optimistic. Shandong proposed the "three controls and three enhancements" strategy, and Jiangsu adopted the "dual enhancement" approach and a "government - led + social participation" model for inefficient land redevelopment. Fujian should follow the "ecological province" strategy, Jiangxi focus on establishing demonstration counties, Zhejiang rely on digitalization and urban - rural renovation, and Anhui strengthen cultivated land protection and river - basin ecological management. In Shanghai, attention should be paid to concentrated land utilization, urban expansion, efficient industrial land allocation, comprehensive land improvement, and carbon sequestration. In the future, administrative barriers need to be further removed, cross - provincial ecological compensation and carbon sink trading markets established, to promote a higher - level dynamic balance between "land use efficiency" and "ecological capacity".

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