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Analysis of Spatiotemporal Evolution Characteristics of Cultivated Land in the Lower Reaches of the Yangtze River Economic Belt

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ABSTRACT

Analyzing spatiotemporal changes in cultivated land in the downstream region of the Yangtze River Economic Belt helps safeguard regional arable land resources. It provides guidance and reference for local governments in formulating relevant land policies. Using ArcGIS 10.8 software, combined with the land use transition matrix and gravity center shift model, can reveal the spatiotemporal distribution characteristics of cultivated land and its change patterns within the study area. The research findings indicate that cultivated land underwent conversion across all periods. Specifically, the areas of cultivated land converted out during 2000–2005, 2005–2010, 2010–2015, 2015–2020, and 2020–2023 were 10,868 km², 10,549 km², 10,000 km², 6,588 km², and 41,129 km², respectively. Notably, only during 2020–2023 was there a net gain in cultivated land area, with an inflow of 42,126 km² from land conversion. Between 2000 and 2023, the centroid of cultivated land also underwent a certain degree of migration. In the first phase from 2000 to 2010, the centroid of cultivated land area shifted northwestward by 6.68 km; in the second phase from 2010 to 2023, it gradually migrated southward.

KEYWORDS

Cultivated land resources; Transition Matrix; Center of gravity model; Temporal and spatial evolution

1. INTRODUCTION

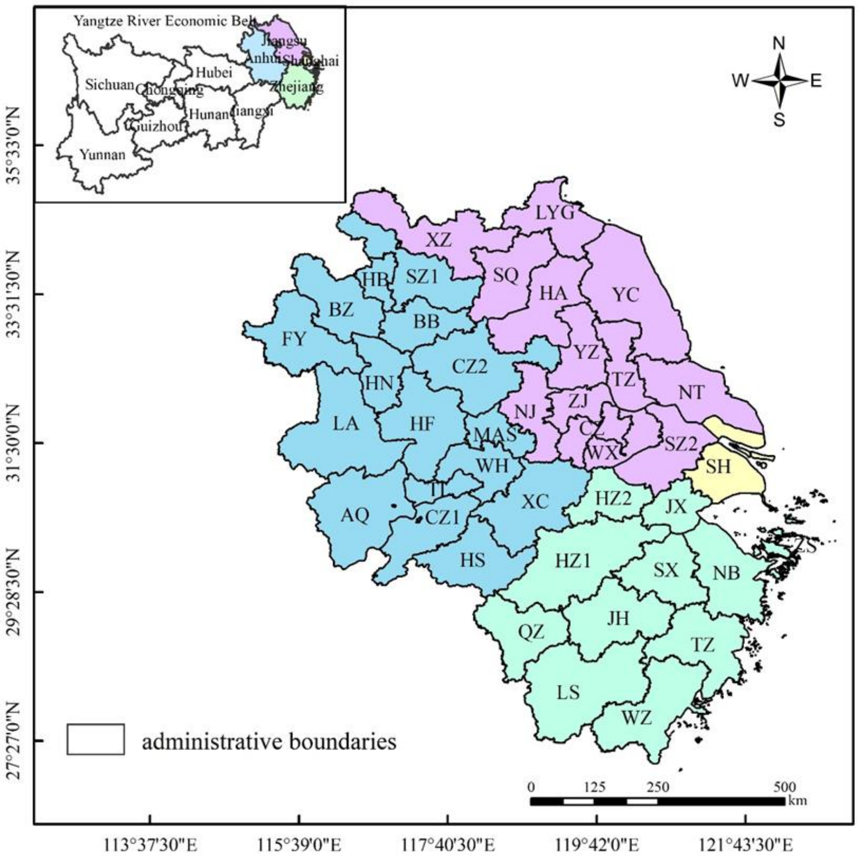
Cultivated land resources, as a critical resource for human survival and development, not only constitute an essential condition for human existence but also serve as a fundamental basis for the prosperity and development of nations and ethnic groups. However, with the accelerated urbanization process and rapid industrial development across various regions, cultivated land has undergone varying degrees of change. The pressure on cultivated land resources continues to intensify, and cropland conservation faces increasingly severe challenges. As a major agricultural country, China should place greater emphasis on protecting cultivated land to support sustainable development and green growth. The preservation of regional cultivated land quantity and improvement of its quality constitute important components of China's 15th Five-Year Plan. Therefore, within this broader context, analyzing the spatiotemporal evolution of cultivated land in the downstream region of the Yangtze River Economic Belt has significant reference value and practical significance for cultivated land conservation and management practices, promoting economic development and social progress, and advancing agricultural modernization. Domestic scholars have conducted extensive research on cultivated land, primarily focusing on the spatiotemporal patterns of its utilization and the driving mechanisms that influence it [1-6].

Li Yingchao et al. analyzed the spatiotemporal variation in cultivated land quantity in Henan Province and predicted cultivated land quantity [7]. Luo Fang et al. employed methods including a land-use transition matrix and kernel density analysis to investigate the spatiotemporal changes in cultivated land in Yibin City over a 38-year period, as well as their driving factors [8]. Yuan Chengcheng et al. employed GIS and mathematical index models to investigate the characteristics of changes in China's arable land from 2009 to 2018, focusing on quantity, spatial distribution, and site conditions [9]. Wang Jingyi et al. employed data mining techniques and selected the ARIMA model to investigate the trend in China's arable land area over nearly 21 years from 1996 to 2016, and identified its driving factors through correlation analysis [10]. Su Lijie et al. analyzed the quantity and quality of cultivated land resources in Guangzhou City using indicators such as the average annual change rate and the relative change rate of cultivated land [11]. A considerable number of scholars have employed the center of gravity shift model to determine the concentration level and transition trends of cultivated land, thereby providing recommendations for its rational utilization at the regional scale[12-15]. Based on this, the present study selects the downstream region of the Yangtze River Economic Belt as the research area. It employs a land-use transition matrix and a gravity center shift model to conduct comprehensive analyses of cultivated land dynamics from 2000 to 2023 in this region. The objective is to accurately characterize the spatial migration patterns of cultivated land in the downstream Yangtze River Economic Belt, thereby providing a scientific basis for sustainable utilization of regional cultivated land resources and promoting agricultural sustainability.

2. STUDY AREA AND DATA SOURCES

2.1. Study Area

The lower reaches of the Yangtze River Economic Belt (27°12′N–35°20′N, 114°54′E–122°12′E) encompass four provinces (municipalities): Shanghai, Jiangsu, Zhejiang, and Anhui. This downstream region constitutes the core area of the Yangtze River Economic Belt, located at the eastern estuary of the Yangtze River in China. The region features an expansive territory adjacent to both the Yellow Sea and the East China Sea, forming an estuarine zone where rivers meet the sea. Geomorphologically, it is the alluvial plain formed by the Yangtze River before it enters the East China Sea. In terms of spatial scale, the total land area covers approximately 350,300 km^2, accounting for 17.1% of the Yangtze River Economic Belt's total territory.



Note: AQ—Anqing; BB—Bengbu; BZ—Bozhou; CZ1—Chizhou; CZ2—Chuzhou; FY—Fuyang; HF—Hefei; HB—Huaibei; HN—Huainan; HS—Huangshan; LA—Lu'an; MAS—Ma'anshan; SZ1—Suzhou; TL—Tongling; WH—Wuhu; XC—Xuancheng; CZ—Changzhou; HA—Huaian; LYG—Lianyungang; NJ—Nanjing; NT—Nantong; SZ2—Suzhou; SQ—Suqian; TZ—Taizhou; WX—Wuxi; XZ—Xuzhou; YC—Yancheng; YZ—Yangzhou; ZJ—Zhenjiang; SH—Shanghai; HZ1—Hangzhou; HZ2—Huzhou; JX—Jiaxing; JH—Jinhua; LS—Lishui; NB—Ningbo; QZ—Quzhou; SX—Shaoxing; TZ—Taizhou; WZ—Wenzhou; ZS—Zhoushan

Figure 1. Overview of the Lower Reaches of the Yangtze River Economic Belt

2.2. Source of Data

The administrative boundary data for the downstream region of the Yangtze River Economic Belt were obtained from the Resources and Environment Science and Data Center, Chinese Academy of Sciences(https://www.resdc.cn/). The land-use data obtained from the research conducted by Professors Yang Jie and Huang Xin at Wuhan University served as the foundational dataset, covering a time series from 2000 to 2023 [16]. According to the requirements of this study, the land-use data were resampled to a 1 km × 1 km spatial resolution. The cultivated land data used in this research were extracted from the resampled land-use dataset.

3. RESEARCH METHODS

3.1. Land Use Transfer Matrix

Land-use transition refers to the area where initial land types are converted into terminal land types. It is used to characterize the transfer relationships among land-use areas between the initial and terminal periods, quantitatively revealing the mutual transformations of different land types across temporal phases within a region, while clarifying the sources and destinations of changes in each land-use category. Farmland change constitutes a core component of regional land-use evolution; employing a land transition matrix enables a comprehensive understanding of evolutionary characteristics of different land-use types across temporal phases, directly reflecting quantitative features and interconversion patterns among various land categories at the regional scale. This study uses a land-use transition matrix to analyze the dynamics of farmland inflow and outflow during the study period. The expression is as follows:

$$S_{ij}=\begin{bmatrix} S_{11} & S_{21} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ S_{31} & S_{32} & \cdots & S_{3n} \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix} \tag{1}$$

Where: Snn represents the unchanged area, located on the diagonal positions of the matrix; Sin (i≠, j), situated at the off-diagonal positions of the matrix.

3.2. Center of Gravity Transfer Model

The application of the barycenter model to calculate the migration trajectories of cropland resources and grain production centroids, combined with an analysis of spatial misalignment between grain production and cultivated land area, can reveal the spatiotemporal evolution characteristics of arable land and grain yield. The calculation formula is as follows:

$$X = \frac{\sum_{i=1}^{n} M_i X_i}{\sum_{i=1}^{n} M_i},\ Y = \frac{\sum_{i=1}^{n} M_i Y_i}{\sum_{i=1}^{n} M_i} \tag{2}$$

In the formula, (X, Y) denotes the center of gravity for cultivated land area and grain production within the study region; M_i (i=1, 2, 3…n) represents the element value of region i, which in this paper refers to either cultivated land area or grain production volume, while (X_i, Y_i) indicates the geographic center coordinates of region i. The calculation formula for the migration distance of the center of gravity is as follows:

$$D = \sqrt{(X_a - X_b)^2 + (Y_a - Y_b)^2} \tag{3}$$

D represents the distance of centroid migration; Xa and Ya denote the longitude and latitude of cultivated land (grain) in year a, respectively; Xb and Yb represent the longitude and latitude of cultivated land (grain) in year b, respectively.

4. RESULTS AND ANALYSIS

4.1. Analysis of the Characteristics of Cultivated Land Transfer

This study employed ArcGIS 10.8 to calculate land-use transitions across five distinct periods (2000–2005, 2005–2010, 2010–2015, 2015–2020, and 2020–2023) in the downstream region of the Yangtze River Economic Belt. The quantitative analysis elucidates the dynamics of land quantity conversion within the study area, as summarized in Table 1 below.

During the period from 2000 to 2005, significant changes in land use occurred within the study area. The total area of cultivated land converted to other land types reached 10,868 km², while the total area of other land types converted back to cultivated land was 3,104 km². The areas transferred out, ranked in descending order, were impervious surfaces (4,940 km²), forests (3,017 km²), water bodies (2,868 km²), and grasslands (43 km²). These four land-use types also experienced corresponding inflows through conversion from other types; however, all net conversion values relative to cultivated land remained negative. This indicates that urban development and expansion, along with increases in forest and water body areas during this period, were the primary drivers of the reduction in cultivated land area.

During the period from 2005 to 2010, a total of 10,549 km² of cultivated land was converted to other land-use types, while 3,869 km² of other land-use types were converted to cultivated land. The areas transferred out from cultivated land, ranked in descending order, were impervious surfaces (5,942 km²), forests (2,437 km²), water bodies (2,114 km²), grasslands (55 km²), and bare land (1 km²). During this period, impervious surfaces accounted for the highest proportion of land converted out of cultivated land, whereas forests represented the highest proportion of land converted into cultivated land.

During the period from 2010 to 2015, the total area of cultivated land converted to other land types was 10,000 km², while the total area of other land types converted to cultivated land was 6,356 km². The areas of cultivated land converted to impervious surfaces, water bodies, forests, and grasslands were 6,784 km², 1,795 km², 1,395 km², and 26 km², respectively. The land type with the largest conversion to cultivated land was forest (4,560 km²), followed by water bodies (1,761 km²). Due to the policy of returning farmland to forests, the primary source of newly added cultivated land during this stage was forests. The net conversion values for forests, grasslands, and bare land were positive, whereas those for impervious surfaces and water bodies were negative.

During the period from 2015 to 2020, a total of 6,588 km² of cultivated land was converted to other land-use types, while other land-use types contributed a total of 6,045 km² back to cultivated land during the same period. The areas transferred out, ranked in descending order, were impervious surfaces (3,688 km²), forests (1,949 km²), water bodies (945 km²), and grasslands (6 km²). Among these, the net conversion areas of forests, grasslands, water bodies, and bare land were all positive values, indicating that these land types contributed to the increase in cultivated land.

During the period from 2020 to 2023, the total area of cultivated land converted to other land types reached 41,129 km², while the area of other land types converted to cultivated land amounted to 42,126 km². This phase had the highest magnitudes of both inflow and outflow from cultivated land among all study periods. The outgoing land types from cultivated land, ranked by area from largest to smallest, were impervious surfaces, forests, water bodies, and grasslands. Notably, forests and water bodies exhibited positive net conversion values, whereas grasslands, bare land, and impervious surfaces showed negative net conversion values. These patterns indicate that the conversion between cultivated land and forests remained relatively stable during this stage, with forests providing some compensation for cultivated land loss. This trend essentially continued the conversion patterns observed in the previous phase, in which urban construction and ecological greening initiatives emerged as primary drivers of the reduction in cultivated land area.

Table 1. Table of Cultivated Land Transfer Inflow and Outflow in the Lower Reaches of the Yangtze River Economic Belt from 2000 to 2023

Unit: km²

Period	Transfer situation	Forest	Shrub	Grassland	Water	Barren	Impervious	Totally
2000—2005	Roll-out area	3017	0	43	2868	0	4940	10868
	Transfer-in area	1772	0	41	1273	1	17	3104
2005—2010	Roll-out area	2437	0	55	2114	1	5942	10549
	Transfer-in area	2205	1	25	1630	0	8	3869
2010—2015	Roll-out area	1395	0	26	1795	0	6784	10000
	Transfer-in area	4560	0	32	1761	1	2	6356
2015—2020	Roll-out area	1949	0	6	945	0	3688	6588
	Transfer-in area	3272	0	60	2708	1	4	6045
2020—2023	Roll-out area	10668	0	31	4227	3	26200	41129
	Transfer-in area	10915	0	21	6954	2	24234	42126

4.2. Analysis of the Evolutionary Characteristics of the Gravity Center of Cultivated Land

This study used ArcGIS 10.8 to calculate the centroids of cultivated land at six time points: 2000, 2005, 2010, 2015, 2020, and 2023 (Fig 2). Overall, from 2000 to 2023, the migration trajectory of the cultivated land centroid in the downstream region of the Yangtze River Economic Belt exhibited an inverted V pattern. The migration direction can be divided into two distinct phases: During the first phase (2000–2010), the centroid shifted northwestward from its initial location in Nanjing City, Jiangsu Province, in 2000 to Chuzhou City, Anhui Province, by 2010. In the second phase (2010–2023), the centroid gradually relocated southward back to Nanjing City. Over the same period (2000–2023), the spatial distribution of grain production demonstrated an overall shifting pattern characterized by "northward and westward movement," with the centroid migrating from Nanjing City, Jiangsu Province, to Chuzhou City, Anhui Province.

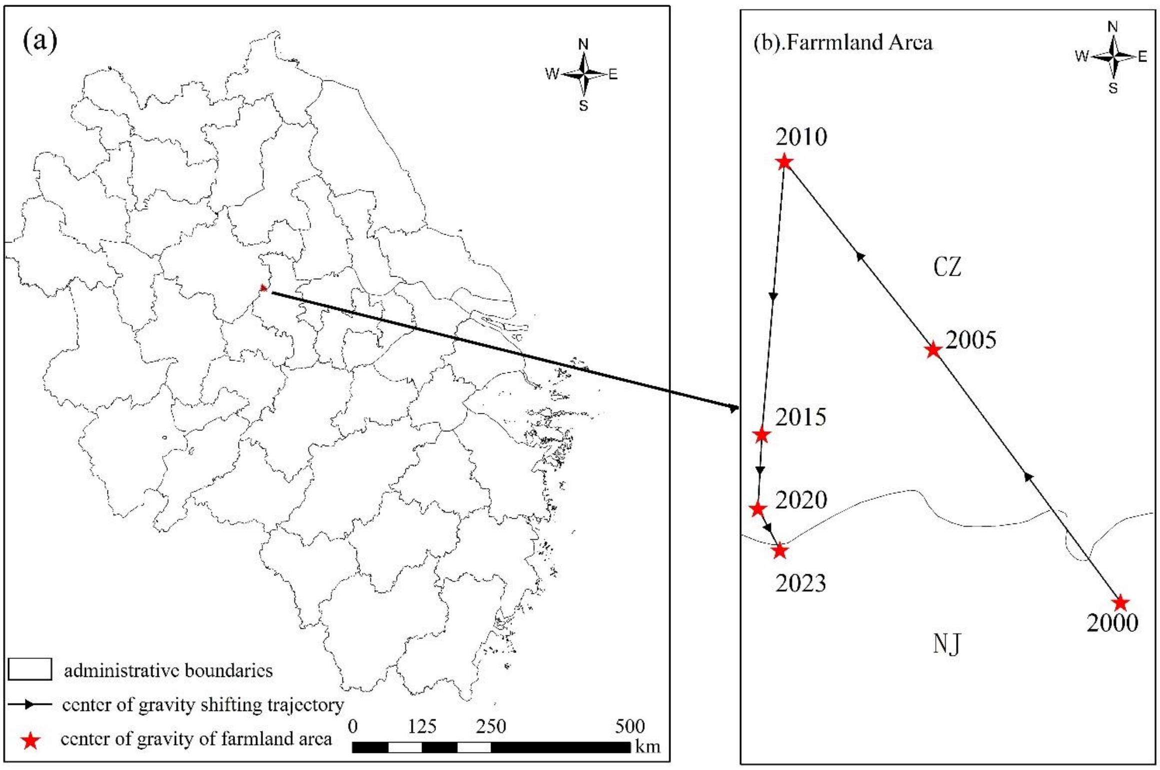


Figure 2. The Shift of the Gravity Center of Cultivated Land Resources in the Lower Reaches of the Yangtze River Economic Belt

To further analyze the migration dynamics of cultivated land area, the centroid coordinates for six periods and the corresponding migration distances and velocities across different time intervals were calculated (Table 2).

Table 2. The centroid coordinates and migration distance of cultivated land resources

Analysis of the Migration of the Gravity Center of Cultivated Land Area				
year	Coordinates	Phases	Distance (km)	Speed (km/a)
2000	118°35′35″E, 32°11′34″N	2000—2005	3.79	0.76
2005	118°34′23″E, 32°13′12″N			
2010	118°33′22″E, 32°14′25″N	2005—2010	2.89	0.58
2015	118°33′14″E, 32°12′39″N	2010—2015	3.30	0.66
2020	118°33′11″E, 32°12′10″N	2015—2020	0.89	0.18
2023	118°33′22″E, 32°11′54″N	2020—2023	0.60	0.20

From 2000 to 2023, the center of gravity of cultivated land shifted 4.16 km toward the northwest. During the study period, the cultivated land exhibited a fluctuating decrease in migration distance and velocity. Between 2000 and 2005, the shift in the center of gravity of cultivated land was more pronounced than in other periods, indicating significant spatial pattern changes driven by urbanization and rapid economic development during this phase. During this period, the cultivated land migrated 3.79 km, with an average rate of 0.76 km/a. From 2005 to 2010, the migration distance of the cultivated land center reached 2.89 km at a speed of 0.58 km/a. During 2010–2015, the center of gravity migrated 3.30 km at a velocity of 0.66 km/a. Compared to the previous stage, the migration characteristics of the cultivated land center underwent substantial changes, showing a decreasing trend in migration distance with a movement of 0.89 km at 0.18 km/a. The period from 2020 to 2023 witnessed minimal changes in cultivated land area, with the center of gravity shifting 0.60 km at a velocity of 0.2 km/a.

5. SUMMARY

Taking the downstream region of the Yangtze River Economic Belt as the study area, this research analyzed the spatiotemporal evolution of cultivated land using land-use data from six time periods (2000, 2005, 2010, 2015, 2020, and 2023). The main conclusions are as follows:

(1) From the perspective of cultivated land transfer characteristics, during the study period, the total area of cultivated land transferred out in the downstream region of the Yangtze River Economic Belt was distributed as follows: 10,868 km² (2000–2005), 10,549 km² (2005–2010), 10,000 km² (2010–2015), 6,588 km² (2015–2020), and 41,129 km² (2020–2023). The corresponding areas of cultivated land transferred in were: 3,104 km², 3,868 km², 6,356 km², 6,045 km², and 42,126 km², respectively.

(2) From the perspective of spatial change trends in cultivated land, the gravity center of cultivated land in the downstream region of the Yangtze River Economic Belt underwent significant migration during 2000–2023. Overall, this migration was primarily to the northwest.

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