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Study on Spatiotemporal Changes of Cultivated Land in the Major Grain-Producing Areas of the Middle and Lower Reaches of the Yangtze River

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ABSTRACT

Cultivated land is the primary form of rural land use and a critical resource for human survival. Investigating the spatiotemporal variation characteristics of cultivated land resources holds profound significance for strengthening cultivated land protection and optimizing spatial distribution patterns. This study used land-use data from four periods (1990, 2000, 2010, and 2023) in the Major Grain Producing Areas of the Middle and Lower Reaches of the Yangtze River. Using a land-use transition matrix and a dynamic degree model of land use, we analyzed the spatiotemporal evolution of cultivated land resources in this region. The results indicate: (1) Cultivated land resources exhibited uneven spatial distribution, with higher concentrations in the northeastern regions and lower densities in the southwestern areas. Between 1990 and 2023, except for Jiangxi Province, which experienced an increase of 454.32 km² in cultivated land area, all other provinces demonstrated decreasing trends. Specifically, Jiangsu, Anhui, Hubei, and Hunan provinces recorded reductions of 12,895.67 km², 8,207.89 km², 2,797.64 km², and 958.44 km², respectively. (2) Regarding the dynamics of cultivated land changes: From 1990 to 2000, while Hubei Province showed expansion tendencies, other provinces experienced contraction; between 2000 and 2010, Hunan Province underwent significant expansion while Jiangsu Province faced substantial reduction, with other provinces maintaining contraction trends; during 2010–2023, apart from dramatic expansion in Jiangxi Province, other provinces exhibited minor reduction tendencies. (3) Throughout the study period, significant conversions occurred between cultivated land and other land-use types. Cultivated land was primarily converted to forests and impervious surfaces, while newly added cultivated land mainly originated from forest conversion. Over the 33 years, the total cultivated land area in the study region decreased by 24,405.31 km².

KEYWORDS

Cultivated land resources; Land Use Transfer Matrix; Temporal and spatial changes

1. INTRODUCTION

Cultivated land resources constitute the most fundamental material basis for agricultural production, playing a critical role in food supply, ecological cycles, and resource-economic activities. They exert a profound impact on ensuring national food security, ecological security, and sustainable human development [1]. In recent years, China's rapid economic development and accelerated urbanization have led to a continuous reduction in cultivated land quantity and a sustained decline in its quality [2]. On one hand, cultivated land resources are being encroached upon by construction land during urban expansion; on the other hand, through implementation of the national policy on dynamic balance between cultivated land occupation and compensation, land use remediation initiatives, and continuous efforts in reclaiming other land-use types (such as forests, grasslands, and wetlands), the quantitative loss caused by urban construction has been partially offset[3].

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In addition, cultivated land occupied by industrialization and urbanization, including high-quality farmland, has fragmented cultivated land landscapes. This fragmentation phenomenon not only hinders large-scale agricultural operations and impedes agricultural modernization, but also compromises ecosystem integrity and increases disaster vulnerability[4,5]. As a populous nation with 1.4 billion people, China faces increasingly prominent human-land conflicts[6]. Meanwhile, due to factors such as ecological conversion of cultivated land and agricultural structural adjustments, significant changes have occurred in China's cultivated land in terms of quantity, quality, and spatial distribution[7]. Therefore, investigating the spatiotemporal dynamics of cultivated land resources, understanding their evolutionary patterns, and analyzing the characteristics of spatial distribution transformations are critical for protecting cultivated land and optimizing its spatial configuration. In light of this, the present study employed a land transition matrix and a land use dynamic degree model to analyze the spatiotemporal characteristics of cultivated land resources over 33 years (1990–2023) in the maior grain producing areas of the middle and lower reaches of the Yangtze River, aiming to provide scientific references for the utilization and conservation of cultivated land resources in these key agricultural areas.

2. STUDY AREA AND DATA SOURCES

2.1. Study Area

The main grain-producing areas in the middle and lower reaches of the Yangtze River are located in the Yangtze River Middle and Lower Plain, one of China's three major plains. This region serves as both a crucial national grain production base and an important area for the development of the Yangtze River Economic Belt. The region primarily comprises 71 prefecture-level cities across five provinces—Jiangxi, Hunan, Hubei, Anhui, and Jiangsu—covering a total area of approximately 806,800 km². Geographically, it is bounded by the sea to the east, the Three Gorges to the west, the Huaiyang Mountains to the north, and the Jiangnan Hills to the south, situated between 24°–35°N and 108°–122°E. As the region's primary water system, the Yangtze River traverses the entire area from west to east, providing abundant irrigation water for agricultural production while playing critical roles in shipping and aquaculture. The topography is characterized predominantly by plains and hills, with elevations ranging from 0 to 3,061 meters (Fig. 1). Most areas are relatively flat, with higher elevations in the southwest and lower elevations in the northeast. Prominent mountain ranges significantly enrich the regional topographic diversity, including well-known mountains such as Huangshan, Lushan, Dabie Mountains, Hengshan, and Wudang Mountains within the study area.

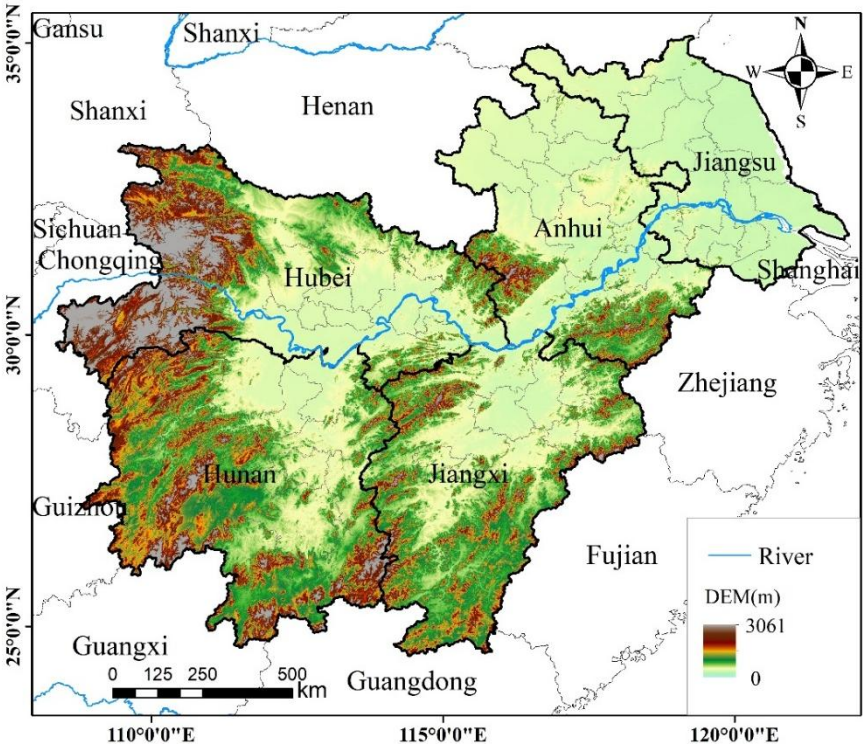

Figure 1. General location of the study area.

2.2. Source of Data

The administrative boundary data for the main grain-producing areas in the middle and lower reaches of the Yangtze River were obtained from the National Geographic Information Public Service Platform (https://www.tianditu.gov.cn/). In contrast, the land use data originated from the CLCD land cover dataset, publicly released by Wuhan University, with a spatial resolution of 30 meters [8]. Based on the ArcGIS 10.7 technical processing platform, all data were first reprojected to the WGS_1984 geographic coordinate system, followed by projection transformations that converted all geospatial data to the WGS_1984_Plate_Carree projected coordinate system.

3. RESEARCH METHODS

3.1. Dynamic Degree Model of Land Use

The Land Use Dynamic Degree model serves as a core tool for analyzing the magnitude and rate of area change across different land-use types, including cultivated land, forests, and impervious surfaces. This model effectively characterizes the dynamic evolution characteristics of cultivated land resources within specific time periods. Higher numerical values indicate stronger activity levels of cultivated land. In this study, the model was applied to systematically analyze the degree of change in cultivated land area at four temporal nodes within the study region, thereby depicting the trends and extent of variation in cultivated land area per unit time. The calculation formula is as follows:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

In the formula, K represents the dynamic degree of cultivated land during the study period, where U_a and U_b denote the areas of cultivated land at the beginning and end of the study period, respectively. T denotes the duration of the study period. When K > 0, it indicates an increasing trend in cultivated

land area during this phase; conversely, a decreasing trend occurs when K < 0. Meanwhile, the greater the absolute value of K, the more intense the fluctuation in cultivated land area.

3.2. Land Use Transfer Matrix

The core purpose of the land use transition matrix is to analyze the inflows and outflows of various land use types across different time periods. To comprehensively investigate the destinations of cultivated land reduction and its inflow sources within the study area, this research employed ArcGIS 10.7 to construct a land-use transition matrix characterizing the inflow and outflow dynamics of cultivated land across four distinct periods from 1990 to 2023. The resulting transition matrix is presented as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} \cdots & S_{1n} \\ S_{21} & S_{22} \cdots & S_{2n} \\ \cdots & \cdots \cdots & \cdots \\ S_{n1} & S_{n2} \cdots & S_{nn} \end{bmatrix} \quad (2)$$

Where S represents the area of different land-use types, n denotes the number of transitions between different land-use types during the transformation process, and S_{ij} indicates the area of land-use types at both the initial and final stages of the study.

4. RESULTS AND ANALYSIS

4.1. Cultivated Land Area and Its Spatial Distribution Characteristics

(1) Spatial Distribution Characteristics of Cultivated Land

To clearly illustrate the spatiotemporal evolution of cultivated land resources in the major grain-producing areas of the middle and lower reaches of the Yangtze River from 1990 to 2023, this study used ArcGIS 10.7 to extract cultivated land data for 1990, 2000, 2010, and 2023. These data were overlaid with the study area boundaries to generate spatial distribution maps of cultivated land (Fig 2). As shown in Fig 2, the distribution of cultivated land resources within the study area is uneven, exhibiting significant spatial heterogeneity. Cultivated land is more abundant in the northeastern region, primarily concentrated in Jiangsu Province and northern Anhui Province. In contrast, the central and western regions display a more scattered distribution, mainly in the plains of Hubei, Hunan, and Jiangxi Provinces. Although the spatial distribution of cultivated land remained relatively stable during the study period, the total area of cultivated land in the study area has declined overall due to temporal changes and socioeconomic development.

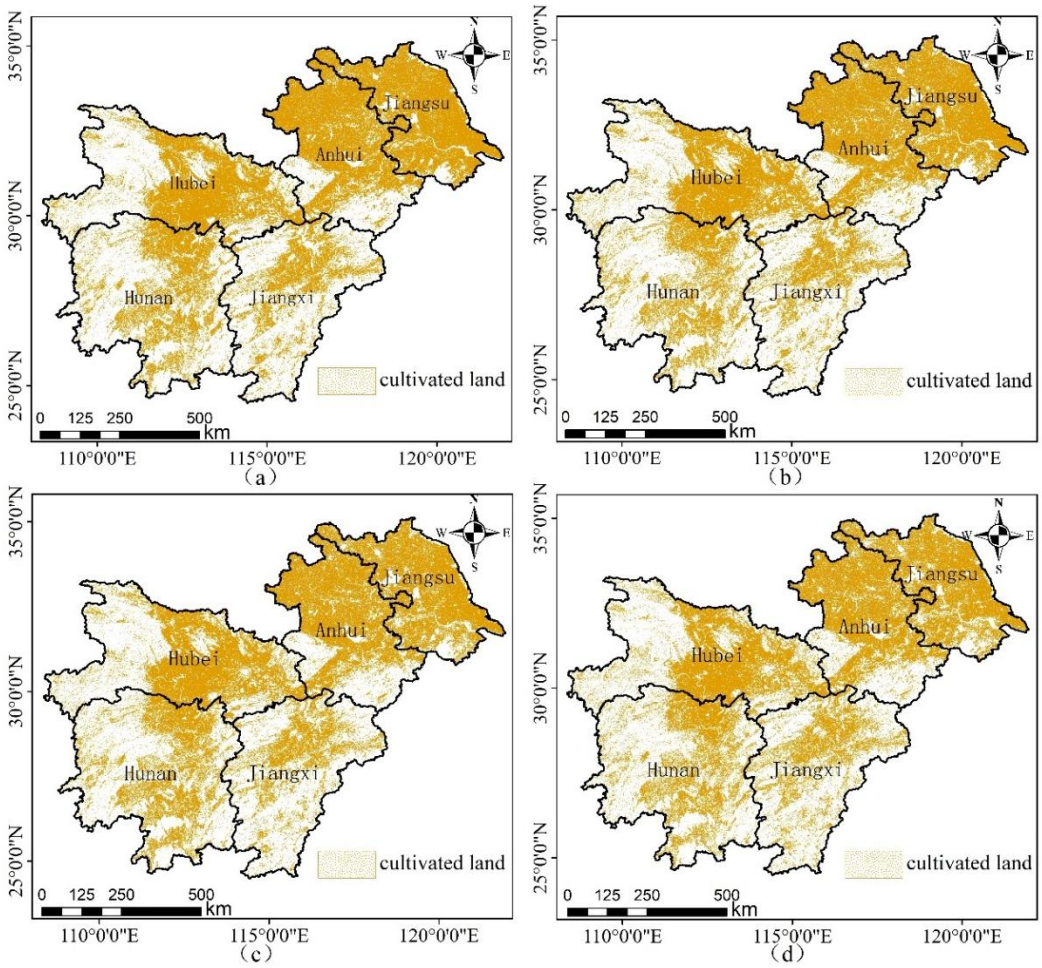

Figure 2. Spatial distribution map of cultivated land from 1990 to 2023

Note: (a) Spatial distribution of cultivated land in 1990; (b) Spatial distribution of cultivated land in 2000; (c) Spatial distribution of cultivated land in 2010; (d) Spatial distribution of cultivated land in 2023

(2) Characteristics of Cultivated Land Area Change

From the cultivated land area holdings across provinces in the study region from 1990 to 2023 (Fig 3), Anhui Province possessed the largest amount of cultivated land, while Jiangxi Province had the smallest distribution of cultivated land. Regarding changes in cultivated land area, except for Jiangxi Province, which increased by 454.32 km² during the study period, all other provinces experienced reductions. Among these, Jiangsu Province recorded the most significant decrease, with a reduction of approximately 12,895.67 km². As the province with the largest cultivated land area in the study region, Anhui Province lost 8,207.89 km² of cultivated land. Additionally, Hubei and Hunan Provinces experienced reductions of 2,797.64 km² and 958.44 km², respectively.

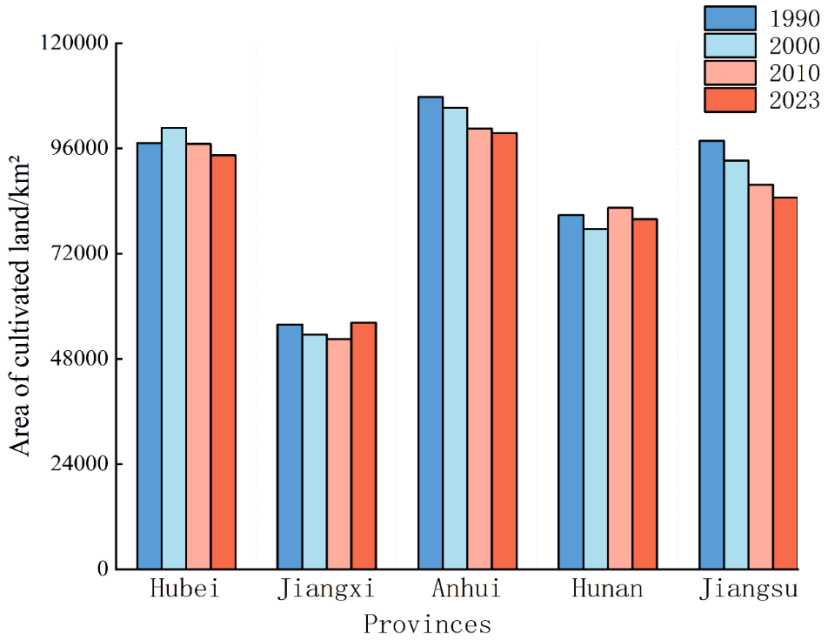

Figure 3. Map of cultivated land area changes by province from 1990 to 2023

The dynamic degree of cultivated land area changes in the study area (Table 1) indicates that Hubei Province experienced a cultivated land use dynamic degree of 0.35% during 1990-2000, demonstrating an expansion trend of cultivated land. The values of cultivated land use dynamic degree for the periods 2020-2010 and 2010-2023 were -0.36% and -0.21%, respectively, indicating a reduction trend in both periods. Notably, the magnitude of cultivated land reduction during 2020-2010 was almost equal to the expansion magnitude observed during 1990-2000, while the rate of change during 2010-2023 showed a significant weakening compared to the previous two periods. In Jiangxi Province, cultivated land exhibited continuous reductions during both 1990-2000 and 2000-2010 periods, with dynamic rates of -0.41% and -0.19%, respectively. However, the period 2010-2023 witnessed a notable increase in cultivated land, suggesting the effective implementation of land protection policies. Anhui Province experienced sustained cultivated land reduction throughout 1990-2023, with intensity ranking K2000-2010 > K1990-2000 > K2010-2023. The corresponding average annual change rates were -0.44%, -0.23%, and -0.08%, respectively. Hunan Province showed reductions in cultivated land area during the 1990-2000 and 2010-2023 periods, with dynamic degrees of -0.40% and -0.25%, respectively, while the 2000-2010 period recorded a strong expansion trend with a dynamic degree of 0.63%. Jiangsu Province demonstrated a similar continuous reduction in cultivated land area from 1990 to 2023 to Anhui Province, with intensity ranking K2000-2010 > K1990-2000 > K2010-2023. The average annual change rates for these periods were -0.59%, -0.46%, and -0.25%, respectively.

Table 1. Changes in the Dynamic State of Cultivated Land in the Study Area (%)

Area	1990-2000	2000-2010	2010-2023
Hubei	0.35	-0.36	-0.21
Jiangxi	-0.41	-0.19	0.55
Anhui	-0.23	-0.44	-0.08
Hunan	-0.40	0.63	-0.25
Jiangsu	-0.46	-0.59	-0.25

Overall, during the study period, cultivated land in the major grain-producing areas of the middle and lower reaches of the Yangtze River showed a decreasing trend. The cultivated land area decreased by 12,895.67 km² in Jiangsu Province, 8,207.89 km² in Anhui Province, 2,797.64 km² in Hubei Province, and 958.44 km² in Hunan Province, while Jiangxi Province experienced an increase of 454.32 km².

From the perspective of cultivated land dynamics, between 1990 and 2000, only Hubei Province saw cultivated land expand; all other provinces experienced declines. During 2000–2010, Hunan Province experienced a significant expansion of cultivated land, whereas Jiangsu Province saw a substantial reduction, with the remaining provinces showing consistent contraction. Between 2010 and 2023, apart from a dramatic expansion in Jiangxi Province, all other provinces showed slight reductions in cultivated land area.

4.2. Analysis of Cultivated Land Transfer Characteristics

From 1990 to 2000, the total amount of cultivated land transferred in the major grain-producing areas of the middle and lower reaches of the Yangtze River was 54,443.96 km². Among this, 22,724.75 km² represented inflows into cultivated land, while 31,719.21 km² constituted outflows from cultivated land, resulting in a net decrease of 8,994.47 km² in total cultivated land area. The primary destinations for cultivated land conversion were forests and impervious surfaces. As shown in Table 2, during 1990–2000, 16,905.61 km² of cultivated land in the study area was converted to forests. The main source of newly added cultivated land was forest conversion, with 18,642.97 km² of forest converted.

Table 2. Statistical Table of Cultivated Land Utilization Transfer Data in the Study Area from 1990 to 2000

Type of transfer out	Area (km²)	Type of transfer in	Area (km²)
cultivated land → forest	16905.61	forest →cultivated land	18642.97
cultivated land → shrub	61.30	shrub → cultivated land	158.62
cultivated land → grassland	303.79	grassland → cultivated land	706.47
cultivated land → water	4968.27	water → cultivated land	3166.25
cultivated land → barren	0.71	barren → cultivated land	38.76
cultivated land → impervious	9479.53	impervious → cultivated land	11.68
Total transfers out	31719.21	Transfer to total	22724.75

From 2000 to 2010, the total area of cultivated land conversion in the main grain-producing areas of the middle and lower reaches of the Yangtze River amounted to 56,564.88 km². Among this, newly added cultivated land accounted for 23,291.91 km², while converted-out cultivated land reached 31,719.21 km². The dominant pattern of cultivated land conversion remained outflow-oriented, resulting in a net decrease of 9,981.06 km² in cultivated land during this period. The primary destinations for cultivated land conversion were forests and impervious surfaces, with forest conversion accounting for 18,218.76 km² of newly added cultivated land, as shown in Table 3.

Table 3. Statistical Table of Cultivated Land Utilization Transfer Data in the Study Area from 2000 to 2010

Type of transfer out	Area (km²)	Type of transfer in	Area (km²)
cultivated land → forest	16874.31	forest →cultivated land	18218.76
cultivated land → shrub	28.27	shrub → cultivated land	84.22
cultivated land → grassland	231.51	grassland → cultivated land	479.51
cultivated land → water	5783.70	water → cultivated land	4429.39
cultivated land → barren	2.03	barren → cultivated land	4.63
cultivated land → impervious	10353.15	impervious → cultivated land	75.40
Total transfers out	33272.97	Transfer to total	23291.91

From 2010 to 2023, the total area of cultivated land conversion in the main grain-producing areas of the middle and lower reaches of the Yangtze River reached 90,951.67 km². Compared with the

previous two periods, cultivated land transitions exhibited higher activity. Specifically, 42,760.94 km² of land was converted from other land-use types to cultivated land, while 48,190.73 km² of cultivated land was transferred out to other land-use categories. The dominant conversion pattern remained outflow of cultivated land, resulting in a net reduction of 5,429.79 km² in cultivated land area. This decrease was smaller than that observed in the preceding two phases, indicating that the implementation of the cultivated land balance policy effectively protected arable land resources. The primary destinations for cultivated land outflow were forests and impervious surfaces. As shown in Table 4, between 2010 and 2023, 24,584.14 km² of cultivated land was converted to forests. The area of newly added cultivated land remained consistent with the previous two periods, primarily through conversion from forests, with 27,951.55 km² of forest land converted to cultivated land.

Table 4. Statistical Table of Cultivated Land Utilization Transfer Data in the Study Area from 2010 to 2023

Type of transfer out	Area (km²)	Type of transfer in	Area(km²)
cultivated land → forest	24584.14	forest →cultivated land	27951.55
cultivated land → shrub	5.53	shrub → cultivated land	50.14
cultivated land → grassland	115.49	grassland → cultivated land	387.86
cultivated land → water	3599.99	water → cultivated land	9763.19
cultivated land → barren	3.03	barren → cultivated land	6.83
cultivated land → impervious	19822.53	impervious → cultivated land	4601.37
Total transfers out	48190.73	Transfer to total	42760.94

Based on the analysis of cultivated land transfer across three distinct phases, significant conversions occurred between cultivated land and other land-use types within the study area. The most pronounced land-use transition was observed between cultivated land and forest coverage. However, in all three phases, the area converted from forest to cropland consistently exceeded the area transformed from cultivated land to forest.

5. SUMMARY

This study, based on four periods of land use data from the major grain-producing areas in the middle and lower reaches of the Yangtze River, analyzed the spatiotemporal characteristics of cultivated land resources in this region. The main conclusions are as follows:

(1) The cultivated land resources in the major grain-producing areas of the middle and lower Yangtze River region exhibit an uneven distribution pattern, generally characterized by higher concentrations in the northeastern part and lower densities in the southwestern part. From 1990 to 2023, except for Jiangxi Province, where cultivated land area increased by 454.32 km², all other provinces showed decreasing trends. Specifically, the cultivated land areas of Jiangsu, Anhui, Hubei, and Hunan decreased by 12,895.67 km², 8,207.89 km², 2,797.64 km², and 958.44 km², respectively.

(2) From the perspective of dynamic changes in cultivated land area, during 1990-2000, except for Hubei Province, which exhibited an expansion trend, all other provinces demonstrated a reduction trend. During 2000-2010, Hunan Province experienced relatively intense cultivated land expansion, while Jiangsu Province showed a significant reduction in amplitude, with the remaining provinces consistently showing a reduction trend. From 2010 to 2023, apart from Jiangxi Province's dramatic expansion of cultivated land, all other provinces showed minor reductions.

(3) During the study period, significant conversions occurred between cultivated land and other land-use types. The primary destinations of cultivated land loss were forests and impervious surfaces, while newly added cultivated land mainly originated from forest conversion. Over the 33 years, the total cultivated land area in the study region decreased by 24,405.31 km².

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