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Spatio-Temporal Changes of Arable Land and Their Impacts on Grain Output in the Yangtze River Economic Belt from 1980 to 2020

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Abstract: The "Yangtze River Economic Belt Development Strategy" is one of China's three major national development strategies. Enhancing the protection and quality of arable land in the Yangtze River Economic Belt (YEB) is pivotal for fostering regional growth. In this study, land use data spanning the years 1980 to 2020 in the YEB were extracted from the national land use database maintained by the Resource and Environment Data Center of the Chinese Academy of Sciences. Employing Geographic Information System (GIS) spatial analysis techniques and arable land change metrics, the study delineated the spatiotemporal characteristics of arable land alterations across the YEB for the period. Additionally, using grain output data at the prefecture level from 2011 to 2020, the paper calculated provincial grain output to analyze the impact of arable land changes over the last four decades on grain output. The findings revealed that: (1) From 1980 to 2020, the total arable land area in the YEB decreased by approximately 41,775 square kilometers, with the most significant decrease occurring in the downstream region. (2) From 1980 to 1990, the primary factor contributing to the decrease in arable land area was the expansion of water bodies, while from 1990 to 2020, the principal reason for the reduction in arable land area was the expansion of construction land. (3) From 1980 to 2020, the decrease in arable land area resulted in a net reduction of approximately 25.12 million tons in total grain output, with the largest decline observed in the downstream regions and the smallest decline in the upstream regions. (4) Consistent with the trends in arable land area reduction, the main reason for the decline in grain output from 1980 to 1990 was the expansion of water bodies encroaching upon arable land, whereas from 2000 to 2010, the primary cause of arable land reduction was the expansion of construction land areas. In conclusion, the research suggested that over the past four decades, the primary driver behind the reduction in arable land within the YEB has been the expansion of construction land areas. Particularly noteworthy was the period from 2000 to 2010, during which the impact of arable land reduction on grain output was most pronounced. This period coincided with the rapid economic development and accelerated urbanization process within the YEB.

Keywords: food security; arable land; grain output; Yangtze River Economic Belt

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1. Introduction

Food security stands as a vital cornerstone to societal well-being, national security assurance, and the safeguarding of developmental interests [1,2]. It embodies a complex, multidimensional challenge that necessitates concerted efforts from the international communities, governments, businesses, and citizens alike [3]. Ensuring future generations' access to an ample, safe, and sustainable food supplies requires collaborative endeavors aimed at addressing the multifaceted aspects of global food security. Amid the Russo-Ukrainian conflict, the global food supply chain has been impacted [4], leading to increased volatility in the grain market and exacerbating food security concerns [5]. Linking food security with different dimensions of food security remains a challenge [6]; how to utilize limited arable land resources effectively and secure food sovereignty is an urgent task [7]. Food security has remained a focal point of international attention, as evidenced by reports such as the 2023 Global Risk Report and the Global Food Crisis Report. These reports underscore the persistent challenges expected in global food supply, predicting exacerbation of food crises and insecurity in the foreseeable future. The Food and Agriculture Organization of the United Nations anticipates a continuation of the global spread of food crises throughout 2024. Against this backdrop, China has implemented various policies aimed at safeguarding arable resources and ensuring food security, including measures such as balancing land occupancy and the implementation of initiatives like the "1.8 billion Mu Red Line" for arable land protection. In 2023, during the seventh session of the Standing Committee of the Fourteenth National People's Congress of China, the "Food Security Guarantee Law of the People's Republic of China" was passed. This legislative milestone underscores China's commitment to addressing the critical issue of food security through comprehensive legal frameworks. Despite efforts to maintain a balance between arable land occupancy and replenishment, spatial challenges persist, accompanied by severe land quality degradation, prominent environmental risks, and suboptimal grain production efficiency. Moreover, China continues to confront challenges such as rigid growth in overall food demand [8,9], frequent occurrences of extreme agricultural meteorological disasters, and turbulence in the international grain trade market [10,11]. Consequently, it becomes imperative to analyze food output security in China and elucidate the impact of arable land changes on grain output. This paper offers insights into potential strategies for enhancing food output security amidst evolving environmental and economic landscapes.

Since the initiation of the Reform and Opening-Up policy, urbanization has continuously expanded [12], encroaching upon arable land, resulting in the conversion of arable land and in significant changes in both the quantity and quality of China's arable land resources [13]. A substantial body of research has emerged from domestic and international scholars focusing on the interplay between arable land resources and food production [14,15]. The research has already been categorized into two primary themes. On the one hand, researchers studied the impact of arable land changes on the potential for grain production. Research conducted by Zhang et al. [16] utilized regional experimental yields of approved grain crop varieties in China as a basis for calculating the grain yield per unit area of various types of arable land, thereby further elucidating changes in food production potential. Additionally, Liu et al. [17] revealed the spatiotemporal dynamics of China's grain output in relation to changes in arable land, as well as analyzing the sensitivity of grain output to these changes. Liu's team [18] examined the spatial characteristics of China's arable land's potential for grain output and the impact of changes in arable land on this potential. Xu and his colleagues [19] analyzed the effects of changes in China's arable land on the potential for grain crop output. William M. Liefert et al. [20] conducted an analysis on the interrelationship between the increase in grain area in Russia and its potential for grain production. On the other hand, researchers investigated the relationship between arable land changes and food security. Deng and others [21] studied the changes in the area of China's arable land and its potential for agricultural output. Song and his team [22] have investigated the critical factors affecting China's food security, with a focus on changes in the productivity of arable land. Yang and his collaborators [23] have analyzed the impact of changes in China's arable land on the environment and the consequent effects on China's short-term and long-term grain supply. Nath et al. [24] conducted a comparative analysis of food security concerning arable land in India and China, concluding that a greater quantity of food is required to meet the demands of their respective populations. From the above studies, it is evident that those researchers primarily focused on the changes in arable land and the calculations of grain production potential and food security issues.

Against the backdrop of the current international food crisis and all kinds of food security, the significant impact of differences in quantity and quality of arable land resources among regions on grain output is evident [25,26]. The guarantee of fundamental agricultural output cannot be ensured if we neglect food security.

As one of China's three major development strategies, the development of the YEB holds significant importance for the nation's overall progress. In July 2013, President Xi Jinping proposed the establishment of the "Golden Waterway" throughout the entire Yangtze River basin during his investigation visit to Wuhan City. Subsequently, numerous symposiums on the development of the YEB have been conducted. In October 2023, President Xi Jinping convened a symposium in Nanchang City, Jiangxi Province, to further promote the high-quality development of the YEB, emphasizing its pivotal role in supporting and serving China's modernization endeavors. Based on the above analysis, this study focused on the YEB as the study region, and integrated land-use data from 1980, 1990, 2000, 2010, and 2020, to analyze the spatiotemporal changes in arable land over the past four decades. Furthermore, using data on grain yield per unit area from 2011 to 2020, the study computed grain output from 1980 to 2020, systematically analyzing the impact of changes in arable land quantity on grain output. This research holds strategic significance in further understanding the dynamics of arable land supply and demand, its relationship with grain security, and in consolidating the foundation of grain output and ensuring food security. Moreover, it provides theoretical support for the national layout of food security to some extent.

2. Materials and Methods

2.1. Study Area

The YEB, relying on the Golden Waterway of the Yangtze River, is a critical region designed to promote economic development from the coastal areas upstream, forming a primary national development axis along the Yangtze River, incorporating the coasts of the Yellow Sea and the Bohai Sea. It encompasses four provinces and municipalities in the upstream regions of the YEB (Yunnan, Guizhou, Sichuan, and Chongqing), three provinces in the midstream regions (Hubei, Hunan, Jiangxi), and four provinces and municipalities in the downstream regions (Shanghai, Jiangsu, Zhejiang, Anhui) (Figure 1). As one of China's three major development strategies, it spans an area of approximately 2.05 million square kilometers, accounting for 21.4% of China's total area. According to data from China's Statistical Yearbook 2023, the Gross Domestic Product (GDP) of the YEB region was approximately 55.98 trillion yuan, representing 46.51% of the national GDP; the year-end permanent population was 608 million, constituting 43.13% of the national population; the total cultivated area was 0.68 million square kilometers (with grain crops covering 0.40 million square kilometers), making up 39.96% of the nation's total cultivated area (and 33.68% of the grain crop area); grain output reached 242 million tons, accounting for 35.18% of the national grain output. It has rich water resources, and numerous tributaries including 45 tributaries with a catchment area exceeding 10,000 square kilometers. It also has eight significant tributaries such as the Yalong, Min, Jialing, Wu, Xiang, Yuan, Han, and Gan rivers, with catchment areas of over 80,000 square kilometers. Significant lakes in this area include Lake Tai, Lake Chao, Dongting Lake, and Poyang Lake. Moreover, it encompasses six major grain-producing bases, including the Chengdu Plain, the Jianghan Plain, the Poyang Lake Plain, the Dongting Lake Plain, the Tai Lake Plain, and the Jianghuai region, which collectively represent two-thirds of the country's nine major grain-producing bases.

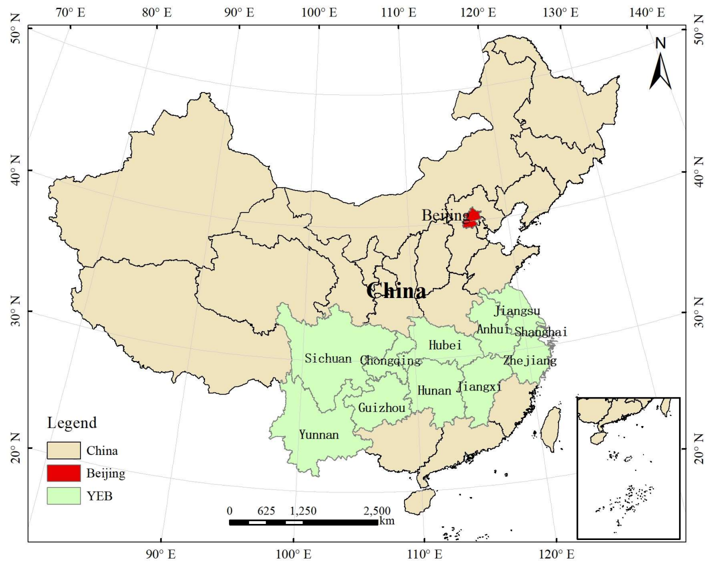

Figure 1. Sketch of the study area.

2.2. Data Sources

The paper used the land-use data for 1980, 1990, 2000, 2010, and 2020 from the National Land Use Database of the Resource and Environment Data Center of the Chinese Academy of Sciences. This database, established through years of accumulation with the support of significant scientific and technological projects such as the National Key Technologies R&D Program and the Knowledge Innovation Program of the Chinese Academy of Sciences, encompasses a multi-temporal dataset of land-use status across the national terrestrial region at a 1:100,000 scale [27–30]. The dataset, primarily derived from Landsat TM/ETM and Landsat 8 remote sensing imagery, was generated through manual visual interpretation. It classifies land use into six primary categories: arable land (AL), forest land (FL), grassland (GL), water bodies (WB), construction land (CL), and unused land (UL), further subdivided into 25 secondary categories. For this study, forest and grassland categories were consolidated into a single category termed "forest and grassland (F&GL)". Field investigations have confirmed that the accuracy of comprehensive evaluation of primary-level land use types exceeds 94.3%; this level of precision was up to the cartographic accuracy requirements for users at the 1:10,000 scale [31,32]. In this study, GIS technology was employed to extract the spatial distribution of arable land from the land-use status datasets for the years mentioned above, facilitating the analysis of the impact of changes in arable land on grain output in the YEB from 1980 to 2020.

Statistical data encompassed the average grain output of the past decade (2011–2020), with 130 prefecture-level cities in the YEB. If the annual data of individual prefecture-level cities were missing, the provincial average annual grain output in the data from the same year was used as an alternative. The average grain output data for these cities was derived from official websites, including statistical yearbooks and bulletins on national economic and social development for each year from 2011 to 2020.

2.3. Methods

(1) Analysis Methodology for Arable Land Changes

This study employed ARCGIS10.8 software and utilized Geographic Information Systems (GIS) spatial analysis techniques [18] to extract the quantity and spatial patterns characteristics of arable land from the land use datasets of five periods: 1980, 1990, 2000, 2010, and 2020. Subsequently, the study obtained the characteristics of the area, quantity and spatial pattern of arable land change in the five periods from 1980 to 2020, as well as the characteristics of the conversion between arable land and other land-use types.

(2) Metrics for Arable Land Change Analysis

To thoroughly investigate the characteristics of arable land changes in the YEB and to elucidate the rate and intensity of these changes, this paper employed four indices: net change in arable land area, average annual net change in arable land area, annual rate of change, and dynamic degree [33]. The formula for calculating the cropland change rate is as follows:

$$K_i = \left\{ \left(\sum_j^n \frac{|\Delta S_{ij}|}{S_i} \right) \right\} \times \frac{1}{t} \times 100 \quad (1)$$

where S_i is the total area of arable land at the monitoring start time; $|\Delta S_{ij}|$ is the net change area after the conversion between arable land and other land use types j during the monitoring period from the beginning to the end; t is the period; The annual change rate of arable land reflects the annual change rate of arable land in the study sample area corresponding to the period t.

The dynamic degree of arable land is calculated by:

$$D_i = \left\{ \left(\sum_j^n \frac{|\Delta S_{ij}|}{S_a} \right) \right\} \times \frac{1}{t} \times 100\% \quad (2)$$

where S_a is the total area of the study area; $|\Delta S_{ij}|$ is the absolute value of the area of conversion between arable land and other land use types j during the period from the beginning to the end of monitoring; t is the period; The dynamic attitude of arable land reflects the intensity of arable land change in the study area corresponding to this period.

(3) Method for Calculating Grain Output

In order to assess the changes in grain output in the YEB more accurately, this study calculated the grain output over the last four decades. The study utilized arable land area data for 1980, 1990, 2000, 2010, and 2020, combined with the average annual grain output from 130 municipal cities from 2011 to 2020. Drawing on the previous, the formula for calculating grain output [34,35] is as follows:

$$\mathrm{P_{sum}} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{P_i} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{Y_i} \times \mathrm{A_i} \quad (3)$$

where $\mathrm{P_{sum}}$ denotes the total grain output of arable land at the provincial level, $\mathrm{P_i}$ denotes the grain output of the i prefecture-level city, $\mathrm{Y_i}$ denotes the grain output per unit area of the *i* prefecture-level city, and $\mathrm{A_i}$ denotes the arable land area of the i prefecture-level city. The study involved subtracting the grain output of the YEB for the years 1980, 1990, 2000, 2010, and 2020 to ascertain the variations in grain output for each period.

Meanwhile, based on the analysis of changes in arable land, the study obtained the data of changes in land-use categories for 130 prefecture-level cities from 1980 to 2020 and collected the data for the periods of 1980–1990, 1990–2000, 2000–2010, and 2010–2020. By using Formula (3), the impact of land conversion on grain output for each period was calculated. By aggregating the changes in grain output at the prefecture level for each type of land conversion in each province, the final provincial-level changes in grain output due to each type of land conversion could be determined.

3. Results

3.1. Spatiotemporal Characteristics of Arable Land Changes

3.1.1. The Overall Situation of Arable Land Changes from 1980 to 2020

From 1980 to 2020, the total arable land area in the YEB decreased by approximately 41,775 square kilometers. Approximately 82,516 square kilometers of arable land were converted to other land-use types, while approximately 40,741 square kilometers of other land-use types were converted to arable land (Table 1). The primary mechanism of arable land reduction was the expansion of construction land, accounting for the conversion of approximately 36,844 square kilometers of arable land. Subsequently, afforestation and grassland restoration contributed to the conversion of 3.65 units of arable land into forest and grassland, reflecting a notable expansion of water bodies. Conversely, the primary reason of arable land increase was through the reclamation of forest and grassland, with approximately 35,588 square kilometers of forest and grassland being reclaimed for arable purposes. Furthermore, the other reason of arable land increase was a notable shrinkage of water bodies. In summary, the primary driver of arable land reduction in the YEB over the past four decades has been the expansion of construction land, while the increase in arable land has mainly resulted from the reclamation of forest and grassland.

Table 1. Arable land conversion matrix of different provinces in the YEB from 1980 to 2020 (square kilometers).

Province	Decrease					Increase					Net Change
	AL → F&GL	AL → WB	AL → CL	AL → UL	Total	F&GL → AL	WB → AL	CL → AL	UL → AL	Total	
Yunnan	−7588	−436	−2164	−20	−10,208	7879	140	200	31	8250	−1958
Guizhou	−5038	−253	−1116	−1	−6408	5251	21	22	2	5296	−1112
Sichuan	−11,941	−797	−4042	−21	−16,801	11,721	385	463	15	12,584	−4217
Chongqing	−2009	−253	−1724	−5	−3991	2530	32	15	2	2579	−1412
Hubei	−1604	−2937	−2763	−42	−7346	1594	310	273	53	2230	−5116
Hunan	−3956	−1054	−2057	−31	−7098	2712	505	178	16	3411	−3687
Jiangxi	−2074	−507	−1916	−31	−4528	2365	518	197	0	3080	−1448
Shanghai	−50	−70	−2166	−1	−2287	22	177	24	30	253	−2034
Jiangsu	−130	−1437	−9680	−39	−11,286	538	337	286	0	1161	−10,125
Zhejiang	−1828	−475	−4928	−1	−7232	639	440	106	0	1185	−6047
Anhui	−317	−715	−4288	−11	−5331	337	216	159	0	712	−4619
total	−36,535	−8934	−36,844	−203	−82,516	35,588	3081	1923	149	40,741	−41,775

The abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL in the table represent arable land conversion to: forest and grassland, water body, construction land, and unused land, respectively. The abbreviations F&GL → AL, WB → AL, CL → AL, and YL → AL in the table represent forest and grassland, water body, construction land, and unused land, conversion to arable land, respectively.

In terms of spatial distribution, from 1980 to 2020, the expansion of construction land areas within the YEB exhibited notable characteristics. In particular, the downstream region of the YEB exhibited the largest expansion of construction land areas, accounting for approximately 57.17% of the total increase within the belt. The regions with the largest proportion of the construction land expansion within the upstream and midstream regions of the YEB were primarily located around provincial capital cities (Figure 2). The conversion of arable land to forest and grassland predominantly occurred in the upstream region of the YEB, followed by the midstream region. The area of arable land converted to forest and grassland within these two regions accounted for over 90% of the total arable land conversion to forest and grassland within the YEB. The conversion of forest and grassland to arable land primarily occurred in the upstream region of the YEB, with some minor changes observed in the midstream region as well. In the upstream region, the area of forest and grassland converted to arable land accounted for approximately 70% of the total conversion within the YEB. The expansion of water bodies in regions characterized by the concentrated distribution of rivers and lakes within the YEB was associated with the abundant presence of water resources throughout the YEB.

In terms of regional distribution, the downstream regions of the YEB experienced the most substantial decrease in arable land area from 1980 to 2020, accounting for approximately 54.36% of the total reduction across the YEB. Specifically, Jiangsu Province accounted for approximately 24.25% of the total arable land reduction within the YEB. The city with the most substantial reduction in arable land was Suzhou City, Jiangsu Province. This phenomenon can be attributed primarily to the rapid economic development of Suzhou City, leading to the conversion of arable land to construction land. In Zhejiang Province, the reduction in arable land area accounted for approximately 14.27% of the total decrease in arable land area in the YEB. This trend correlated with the rapid economic development in the downstream area, which necessitated extensive construction and development. Conversely, the reduction in arable land area was relatively minor in the upstream and midstream regions of the belt, with Guizhou Province contributing about 2.67% and Jiangxi

Province about 3.39% to the total reduction. The decrease of arable land reduction in these areas was not only related to the pace of economic development but also to the regional topography and landscape. Additionally, individual cities of the upstream regions of the YEB, such as Zigong City in Sichuan Province and Tongren City in Guizhou Province, there was evident of an increase in arable area. The expansion of arable land area in these cities was primarily attributed to the conversion of forest and grassland into arable land.

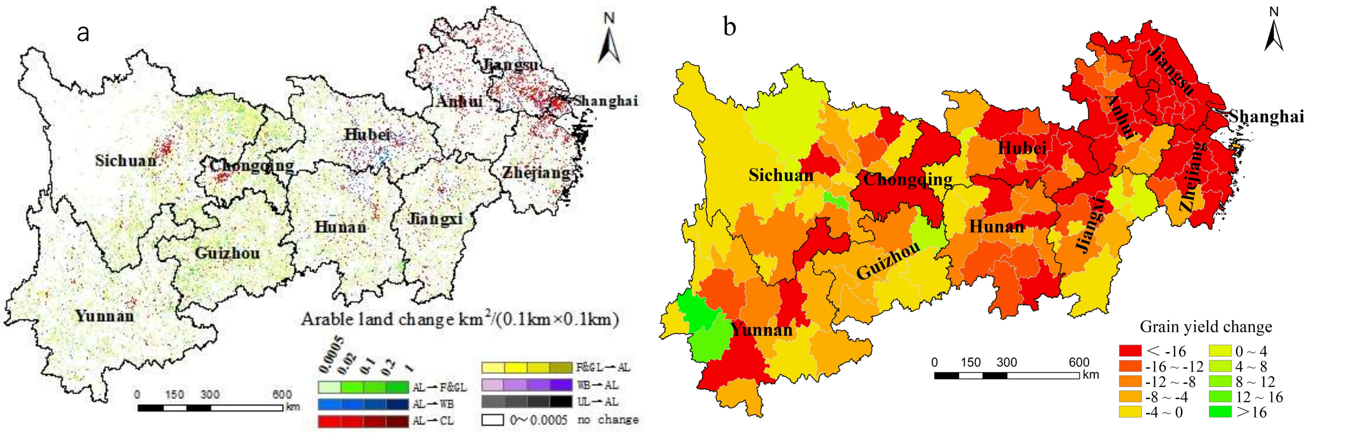

Figure 2. (**a**) Spatial distribution of arable land conversion types in the YEB from 1980–2020. (**b**) Changes of grain output in each province during 1980–2020. (The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1).

3.1.2. The Changes in Arable Land from 1980 to 1990

From 1980 to 1990, the total arable land area in the YEB decreased by approximately 3924 square kilometers. Approximately 5374 square kilometers of arable land were converted to other land-use types, while approximately 1450 square kilometers of other land-use types were converted into arable land. Regionally, the midstream region of the YEB witnessed the most significant reduction in arable land, accounting for approximately 50.90% of the total decrease during this period (Figure 3). The primary drivers for the reduction in arable land area from 1980 to 1990 were the expansion of water bodies and construction land, accounting for approximately 52.98% and 29.45% of the total arable land reduction within the YEB, respectively. Conversely, the main factor contributing to the increase in arable land was the reduction of water bodies, which represented approximately 61.58% of the newly added arable land area. Among them, the city with the greatest reduction in arable land area was Wuhan City, Hubei Province. This was primarily attributed to the proliferation of rivers and lakes in Wuhan City, leading to the expansion of water bodies and consequently the reduction of arable land. The city with the greatest increase in arable land area was Zigong City in Sichuan Province, which is attributed to the conversion of forest and grassland into arable land. In summary, the fluctuations in arable land area during this period were predominantly influenced by the expansion and contraction of water bodies.

During the period of 1980–1990, noticeable disparities existed in both the extent and rate of arable land changes in the YEB (Figure 3). In terms of net change area and average net change area, the province experiencing the most considerable reduction in arable land was Hubei Province, followed by Anhui Province. Regarding arable land dynamics, the most notable changes in arable land occurred in Sichuan Province, followed by Hubei Province. Analysis of the annual average change rate revealed that Shanghai City exhibited the most pronounced rate of arable land change. Generally, regions with substantial decreases in arable land area during this period were primarily those containing large lakes, such as Dongting Lake, Poyang Lake, and Tai Lake. In regions experiencing rapid economic development, the expansion of construction areas has begun to emerge. The tabulated data for the four indicators are provided in the Appendix A.

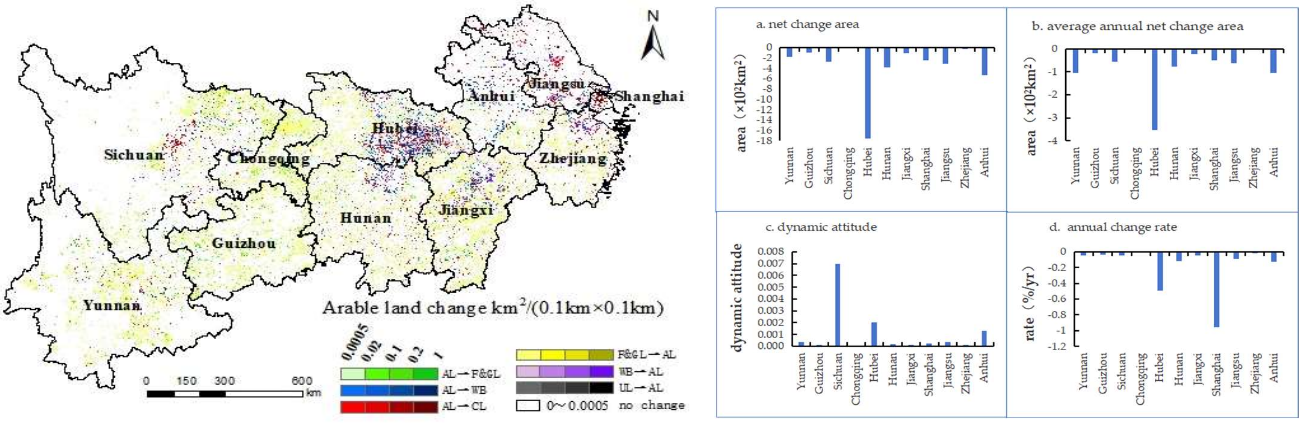

Figure 3. Spatial distribution of arable land conversion types in the YEB from 1980–1990. Statistics of arable land change in the YEB during 1980–1990. (The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1).

3.1.3. The Changes in Arable Land from 1990 to 2000

From 1990 to 2000, the total arable land area in the YEB decreased by approximately 7608 square kilometers. Approximately 58,016 square kilometers of arable land were converted to other land-use types, and approximately 50,408 square kilometers of other land-use types were converted to arable land. The most significant reduction of the arable land was in the downstream regions of the YEB, accounting for approximately 63.27% of the total decrease in arable land area during this period (Figure 4). The main reasons for the reduction in arable land from 1990 to 2000 were the occupation of forest and grassland and the expansion of construction land, accounting for approximately 67.28% and 23.33% of the total arable land reduction within the YEB, respectively. The primary reason for the increase in arable land area from 1990 to 2000 was the conversion of forest and grassland areas to arable land areas, accounting for approximately 76.32% of the total increase in arable land area. During this period, the city with the most significant reduction in arable land area was Hangzhou City, Zhejiang Province. The decrease in arable land area during this period was primarily attributed to the expansion of construction land. The city with the greatest increase in arable land area was Tongren City in Guizhou Province, which is attributed to the conversion of forest and grassland into arable land.

From 1990 to 2000, the spatial pattern of arable land changes in the YEB exhibited both similarities and differences compared to the period from 1980 to 1990 (Figure 4). In terms of area change, diverging from the pattern observed between 1980–1990, the most significant reduction in arable land area within the YEB during this period occurred in the downstream region. With regard to the dynamism of arable land change, Sichuan Province continued to exhibit the greatest fluctuations in arable land, consistent with the trends observed from 1980 to 1990. Furthermore, the annual rate of change in arable land area was most pronounced in Shanghai. Notably, during this period, both Zhejiang and Jiangsu Provinces experienced a significant negative growth in their annual change rates, indicating a substantial decrease in arable land areas. In summary, the downstream regions of the YEB witnessed the most significant reduction in arable land area during this period. This trend was primarily attributed to the expansion of construction land areas, leading to a marked decrease in the availability of arable land in these regions. The tabulated data for the four indicators are provided in the Appendix A.

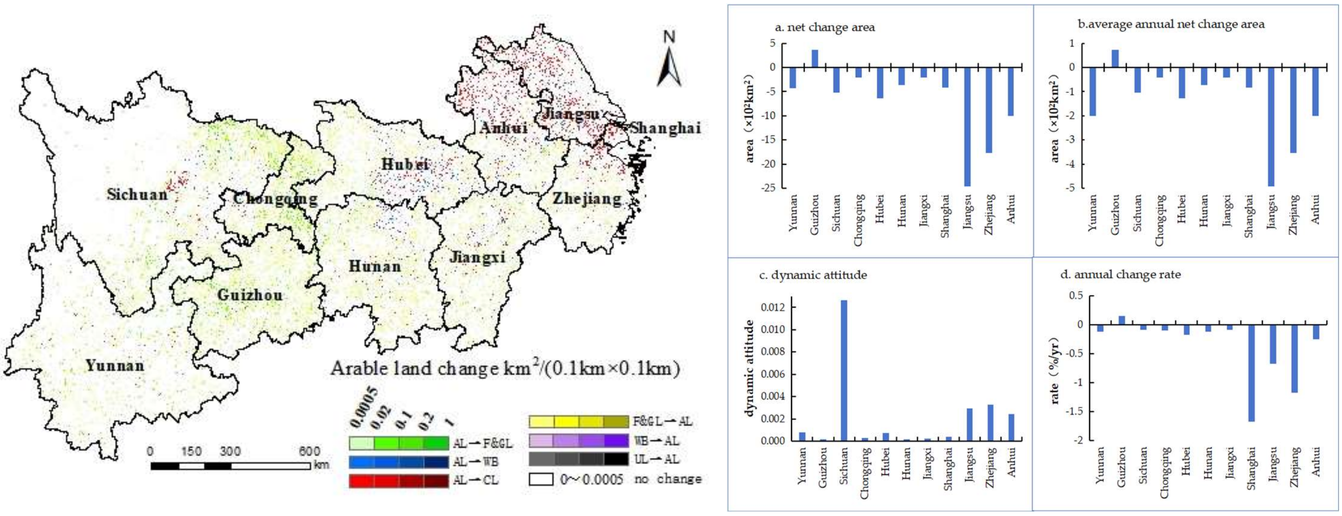

Figure 4. Spatial distribution of cultivated land conversion types in the YEB during 1990–2000. Statistics of arable land change in the YEB during 1990–2000. (The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1).

3.1.4. The Changes in Arable Land from 2000 to 2010

During the period of 2000–2010, the total arable land area in the YEB decreased by approximately 19,097 square kilometers. Approximately 84,024 square kilometers of arable land were converted to other land use types, and approximately 64,927 square kilometers of other land types were converted to arable land. The study observed the most significant decrease in arable land area in the downstream regions of the YEB, accounting for approximately 53.29% of the total reduction (Figure 5). The primary drivers for the reduction in arable land during this period were the expansion of forest and grassland areas and of construction land areas, accounting for approximately 60.40% and 29.03% of the total arable land decrease, within the YEB, respectively. Conversely, the main reason for the increase in arable land was the reduction of forest and grassland, accounting for approximately 78.69% of the total arable land increase. Notably, the main factor for the decrease in arable land area continued to be the expansion of construction land areas, which contributed approximately 80.18% to arable land loss compared to the previous period. This analysis underscores the significant impact of urbanization and land development on the arable land dynamics within the YEB, with a marked acceleration in the rate of arable land conversion to construction land areas between 2000 and 2010. During this period, the city that experienced the most significant decrease in arable land area was Suzhou City, Jiangsu Province. According to data from the National Bureau of Statistics, Suzhou's GDP once ranked amongst the top ten nationally among prefecture-level cities. The rapid economic development inevitably led to the expansion of construction land, resulting in the occupation of a large amount of arable land. In addition, the city with the most substantial increase in arable land area was Baoshan City in Yunnan Province. Due to geographical factors, Baoshan City has experienced relatively limited expansion of construction land, with some forest and grassland areas being converted into arable land.

From 2000 to 2010, the spatial pattern of arable land changes in the YEB exhibited both similarities and differences compared to the period from 1990 to 2000 (Figure 5). In terms of area change, the downstream regions of the YEB continued to witness the most significant reduction in arable land. However, compared to the previous period, both the upstream and downstream regions of the YEB experienced varying degrees of change in individual provinces. Regarding dynamic degree changes, Sichuan Province continued to display the greatest fluctuations in arable land, consistent with the patterns observed from 1980 to 1990. Moreover, there were varying degrees of change in the dynamicity of the downstream regions of the YEB compared to the previous period. In terms of the annual change rate, the downstream regions maintained the most pronounced change rate. In contrast, the change rates in the Hubei and Hunan provinces, situated in the midstream area of the YEB, were significantly greater than in the previous period. Overall, during this period, the downstream regions of the YEB continued to experience the most significant decrease in arable land reduction, indicating ongoing pressures from urbanization and land-use transformation in these economically vibrant zones. The tabulated data for the four indicators are provided in the Appendix A.

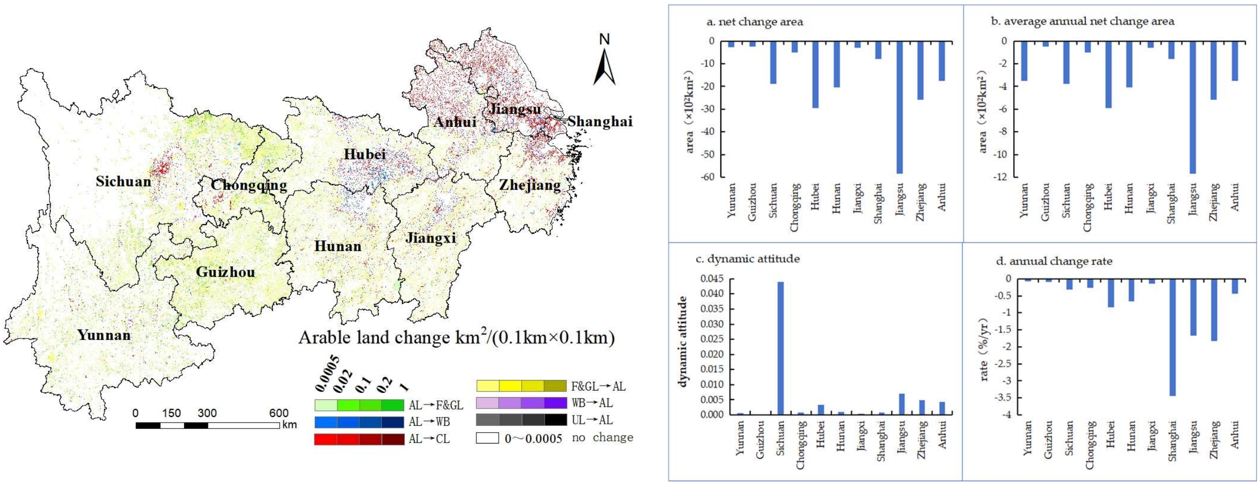

Figure 5. Spatial distribution of cultivated land conversion types in the YEB from 2000–2010. Statistics of arable land change in the YEB during 2000–2010. (The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1).

3.1.5. The Changes in Arable Land from 2010 to 2020

From 2010 to 2020, the total arable land area within the YEB decreased by approximately 11,109 square kilometers. Approximately 45,420 square kilometers of arable land were converted to other land use types, while approximately 34,311 square kilometers of other land-use types were converted to arable land. Regionally, both the upstream and downstream areas of the YEB witnessed significant reductions in arable land area, which accounted for approximately 42.30% and 44.77% of the total arable land reduction, respectively (Figure 6). The primary drivers behind the decrease in arable land during this period were the expansion forest and grassland areas, and of construction land areas, accounting for approximately 59.45% and 33.06% of the total arable land reduction within the YEB, respectively. The primary reason for the arable land increase from 2010 to 2020 was the conversion of forest and grassland to arable land, accounting for approximately 80.22% of the increase in arable land. Overall, the main factor driving arable land changes during this period was the expansion of construction land areas, indicating ongoing pressures from urbanization and land development within the YEB. During this period, the city witnessing the most significant reduction in arable land area was Chongqing City. This phenomenon can be attributed to the rapid economic development of the municipality, leading to substantial expansion in construction land, which in turn encroaches upon arable land. Conversely, the city experiencing the most substantial increase in arable land area was Jingzhou City, Hubei Province. This trend may be associated with the reduction in rivers and lakes within Jingzhou City, which affected the distribution of arable land.

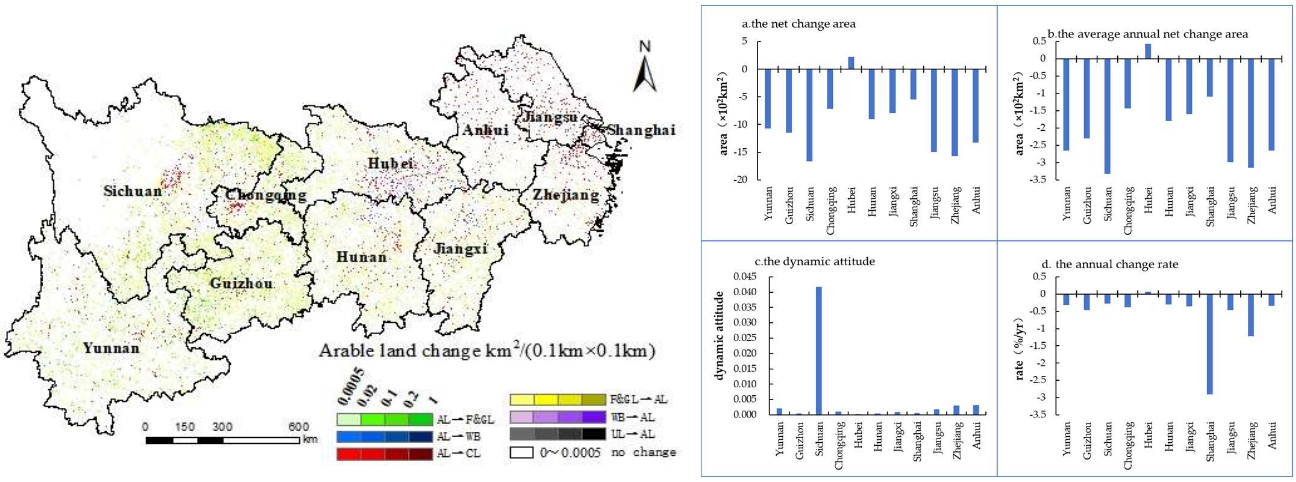

Figure 6. Spatial distribution of cultivated land conversion types in the YEB from 2010–2020. Statistics of arable land change in the YEB during 2010–2020. (The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1).

Between 2010 and 2020, the spatial pattern of arable land changes exhibited specific disparities compared to the previous three periods (Figure 6). Regarding area change, there was an increase in arable land area in Hubei Province, while at the same time other provinces experienced varying degrees of reduction in arable land area. Regarding arable land dynamics, Sichuan Province continued to exhibit the most significant variation, consistent with the patterns observed in the previous three periods. The annual change rate in the arable land area remained most pronounced in the downstream regions of the YEB. Overall, each province witnessed varying degrees of arable land area changes during this period. Sichuan Province consistently demonstrated the highest degree of arable land dynamics, while Shanghai Municipality consistently showed the highest variability in arable land annual change rate since 1980. The tabulated data for the four indicators are provided in the Appendix A.

3.2. The Impact of Arable Land Changes on Grain Output

Based on the calculation method for grain production, the variations in arable land from 1980 to 2020 in the YEB were used to determine the corresponding changes in grain output. The overall variations in grain production from 1980 to 2020 were classified into ten categories (Figure 2b), including: <−16, −16 to −12, −12 to −8, −8 to −4, −4 to 0, 0 to 4, 4 to 8, 8 to 12, 12 to 16, and >16. Similarly, the results of grain production for the periods 1980–1990, 1990–2000, 2000–2010, and 2010–2020 were categorized into ten levels (Figure 7), including: <−4, −4 to −3, −3 to −2, −2 to −1, −1 to 0, 0 to 1, 1 to 2, 2 to 3, 3 to 4, and >4. The unit of grain output is ten thousand tons. In these classifications, red indicates a decrease in grain output and green represents an increase.

3.2.1. Basic Characteristics of Grain Output Change from 1980 to 2020

From 1980 to 2020, the total grain output in the YEB decreased by approximately 25.12 million tons, increased by approximately 20.64 million tons, increased by approximately 45.76 million tons (Table 2). Among all types of land use conversions from 1980 to 2020 within the YEB, the primary driver behind the decrease in total grain production was the encroachment of construction land on arable land. The reduction in arable land area resulted in a decline in grain output, with the conversion of arable land for construction land accounting for approximately 48.37% of the total decrease in grain production. Additionally, the reduction of arable land area occupied by forest and grass land accounted for approximately 38.27% of the total decrease in grain output. The expansion of construction land areas was a consequence of urbanization, while the cultivation of forest and grassland came at the expense of ecological degradation. The expansion of construction land was an outcome of urbanization, while the conversion of forest and grassland entailed a sacrifice of the ecological environment. From 1980 to 2020, the increase in grain output resulting from the conversion of forest and grassland to arable land accounted for approximately 84.16% of the total increase in grain output in the YEB.

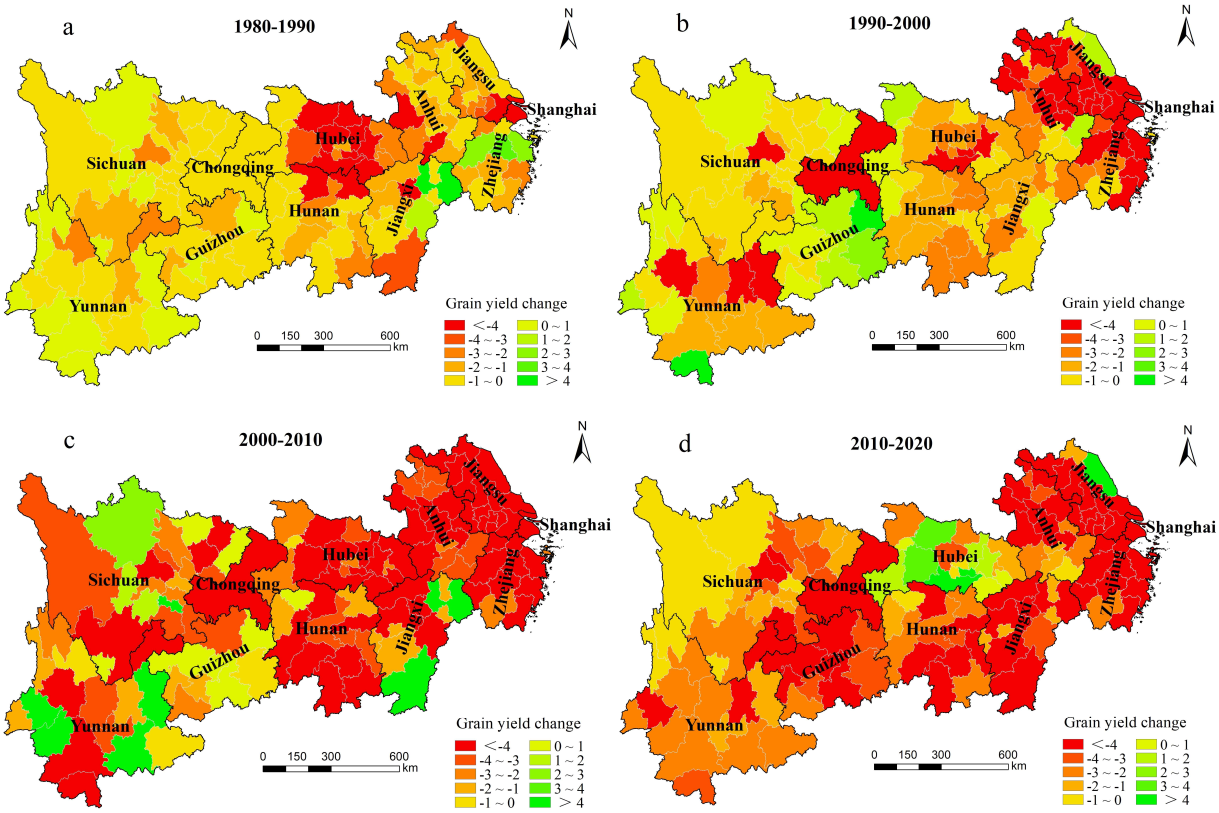

Figure 7. (**a**) Changes of grain output in each province during 1980–1990. (**b**) Changes of grain output in each province during 1990–2000. (**c**) Changes of grain output in each province during 2000–2010. (**d**) Changes of grain output in each province during 2010–2020.

Table 2. Statistics on the impact of arable land change on grain output from 1980 to 2020 (million tons).

Province	Decrease					Increase					Net Change
	AL → F&GL	AL → WB	AL → CL	AL → UL	Total	F&GL → AL	WB → AL	CL → AL	UL → AL	Total	
Yunnan	−3.45	−0.20	−1.00	−0.01	−4.66	3.65	0.06	0.09	0.01	3.82	−0.84
Guizhou	−1.88	−0.09	−0.42	0.00	−2.39	1.96	0.01	0.01	0.00	1.98	−0.41
Sichuan	−6.11	−0.42	−2.30	−0.01	−8.84	6.00	0.21	0.26	0.01	6.48	−2.37
Chongqing	−1.05	−0.13	−0.90	0.00	−2.08	1.32	0.02	0.01	0.00	1.34	−0.73
Hubei	−0.86	−1.71	−1.61	−0.02	−4.21	0.85	0.18	0.16	0.03	1.22	−2.99
Hunan	−2.31	−0.63	−1.25	−0.02	−4.21	1.58	0.30	0.11	0.01	2.00	−2.21
Jiangxi	−1.22	−0.31	−1.16	−0.02	−2.71	1.39	0.31	0.12	0.02	1.84	−0.88
Shanghai	−0.03	−0.05	−1.40	0.00	−1.48	0.01	0.11	0.02	0.00	0.14	−1.33
Jiangsu	−0.09	−0.99	−6.59	−0.03	−7.70	0.31	0.21	0.19	0.00	0.70	−7.00
Zhejiang	−1.07	−0.29	−3.00	0.00	−4.37	0.37	0.27	0.06	0.00	0.70	−3.66
Anhui	−0.18	−0.43	−2.51	−0.01	−3.12	0.19	0.13	0.09	0.00	0.41	−2.71
total	−18.26	−5.25	−22.14	−0.12	−45.76	17.64	1.81	1.11	0.08	20.64	−25.12

The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1.

From 1980 to 2020, variations existed in the reduction of grain output among provinces within the YEB. (Figure 2). Jiangsu Province exhibited the most substantial decrease in total grain output, accounting for approximately 27.85% of the total reduction in grain output in the YEB, followed by Zhejiang Province, accounting for approximately 14.58% of the total decrease. Both Jiangsu and Zhejiang provinces are situated in the downstream region of the YEB, where the expansion of construction land areas has significantly encroached upon arable land. Moreover, Jiangsu Province's arable land was suitable for grain cultivation, with relatively high output per unit area compared to some regions within the YEB. Conversely, the provinces of Guizhou, Chongqing, and Yunnan experienced the most minor decrease in total grain output, accounting for approximately 1.65%, 2.92%, and 3.35% of the total decrease in the YEB, respectively. These provinces belong to the upstream region of the YEB, where there is limited area available for grain cultivation due to the terrain and topography of the Yunnan-Guizhou Plateau, which resulted in a comparatively smaller proportion of grain output decline.

Over the period from 1980 to 2020, among the cities in the YEB, Suzhou City in Jiangsu Province experienced the most significant decrease in grain output (Figure 2). Despite being renowned for its agriculturally favorable land for grain cultivation, Suzhou City ranked third in terms of grain production per unit area among the 130 cities in the YEB. However, due to a considerable reduction in arable land area, the overall grain output in Suzhou City witnessed a notable decline. Conversely, only a few municipal-level cities observed an increase in grain output. Notably, Aba Tibetan and Qiang Autonomous Prefecture and Suining City in Sichuan Province, Tongren City in Guizhou Province, and Baoshan City and Lincang City in Yunnan Province exhibited slight increments in grain output. The primary drivers behind the increased grain output were the relatively limited expansion of construction land in these upstream provinces along the YEB. Additionally, the topography of these cities and the conversion of forest and grassland into arable land may have contributed to the observed increase in grain output.

3.2.2. Effects of Arable Land Change on Grain Output from 1980 to 1990

From 1980 to 1990, there was a decrease of approximately 3.15 million tons and an increase of approximately 0.85 million tons in the total grain output within the YEB, resulting in a net decrease of approximately 2.30 million tons. (Table 3). Among the various land-use conversions during this period, the decrease and increase in total grain output were primarily attributed to the expansion and contraction of water bodies. This phenomenon was attributed to the abundant presence of rivers and lakes in addition to the main stream of the Yangtze River. The expansion of rivers and lakes led to reduction in arable land quantity, thus contributing to the decrease in total grain output during the period.

Table 3. Statistics on the impact of arable land change on grain output from 1980 to 1990 (million tons).

Province	Decrease					Increase					Net Change
	AL → F&GL	AL → WB	AL → CL	AL → UL	Total	F&GL → AL	WB → AL	CL → AL	UL → AL	Total	
Yunnan	−0.07	−0.03	−0.02	0.00	−0.12	0.03	0.01	0.00	0.00	0.04	−0.08
Guizhou	−0.06	0.00	0.00	0.00	−0.06	0.02	0.00	0.00	0.00	0.02	−0.04
Sichuan	−0.04	−0.04	−0.13	0.00	−0.20	0.04	0.01	0.00	0.00	0.05	−0.16
Chongqing	−0.01	0.00	0.00	0.00	−0.01	0.01	0.00	0.00	0.00	0.01	0.00
Hubei	−0.02	−0.90	−0.17	−0.01	−1.09	0.01	0.03	0.00	0.02	0.06	−1.03
Hunan	−0.05	−0.14	−0.09	0.00	−0.29	0.03	0.02	0.00	0.00	0.06	−0.23
Jiangxi	−0.09	−0.12	−0.06	−0.02	−0.28	0.08	0.10	0.00	0.02	0.21	−0.07
Shanghai	0.00	−0.01	−0.20	0.00	−0.22	0.00	0.05	0.00	0.00	0.06	−0.16
Jiangsu	−0.01	−0.15	−0.11	0.00	−0.27	0.01	0.05	0.00	0.00	0.06	−0.21
Zhejiang	−0.09	−0.05	−0.09	0.00	−0.23	0.03	0.17	0.00	0.00	0.21	−0.02
Anhui	−0.04	−0.26	−0.09	0.00	−0.40	0.00	0.08	0.00	0.00	0.09	−0.31
total	−0.47	−1.70	−0.96	−0.03	−3.15	0.25	0.54	0.01	0.04	0.85	−2.30

The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1.

From 1980 to 1990, variations in total grain output were observed among provinces within the YEB. The range of changes in total grain output among cities was mainly between

−10,000 to 10,000 tons (Figure 7). Whilst individual cities in Zhejiang and Jiangsu provinces experienced slight increases in grain output, the grain output changes in other provinces remained below 10,000 tons. The most significant decrease in grain output were observed among cities in Hubei Province, particularly in regions surrounding Dongting Lake, where the expansion of the lake resulted in a reduction in arable land area. Additionally, the total grain output in the upstream regions of the YEB remained relatively stable, with notable decreases observed in the grain output of certain urban areas within Hunan Province, Anhui Province, Jiangsu Province, and Shanghai Municipality.

During the period from 1980 to 1990, Wuhan City in Hubei Province experienced the most significant decrease in grain output among the cities in the YEB (Figure 7). As the provincial capital, Wuhan City witnessed substantial expansion of construction land, resulting in significant encroachment upon arable land. Despite boasting relatively high grain output per unit area, the expansion of construction land in Wuhan City led to a decline in overall grain output. Conversely, during this period, certain cities in the northeastern part of Jiangxi Province and northern part of Zhejiang Province, including cities such as Shangrao, Ningbo, and Shaoxing, experienced a relative increase in grain output. In these cities, the expansion of construction land was relatively limited, and the relatively high grain output per unit area contributed to an increase in total grain output.

3.2.3. Effects of Arable Land Change on Grain Output from 1990 to 2000

From 1990 to 2000, there was a decrease of approximately 31.92 million tons and an increase of approximately 27.12 million tons in the total grain output within the YEB, resulting in a net decrease of approximately 4.80 million tons (Table 4). Among the various land-use conversions, the primary drivers behind the decrease in grain output were the cultivation of forest and grassland and the expansion of construction land areas, accounting for approximately 63.82% and 26.02% of the reduction in grain output within the YEB, respectively. During this period, the occupation of forest and grassland and the expansion of construction land were significantly greater compared to the 1980–1990 period. This period witnessed the rapid economic development of the YEB, accompanied with accelerated urban expansion. Concurrently, the occupation of forest and grassland also contributed to the decrease in grain output.

Table 4. Statistics on the impact of arable land change on grain output from 1990 to 2000 (million tons).

Province	Decrease					Increase					Net Change
	AL → F&GL	AL → WB	AL → CL	AL → UL	Total	F&GL → AL	WB → AL	CL → AL	UL → AL	Total	
Yunnan	−1.68	−0.03	−0.16	0.00	−1.88	1.61	0.02	0.05	0.00	1.69	−0.19
Guizhou	−2.02	−0.01	−0.03	0.00	−2.06	2.18	0.01	0.01	0.00	2.20	0.14
Sichuan	−3.73	−0.22	−0.57	0.00	−4.52	3.79	0.18	0.26	0.00	4.23	−0.29
Chongqing	−2.12	−0.04	−0.11	0.00	−2.28	2.11	0.04	0.02	0.00	2.17	−0.11
Hubei	−2.40	−0.79	−0.75	−0.02	−3.95	2.45	0.53	0.59	0.01	3.57	−0.38
Hunan	−3.25	−0.32	−0.35	0.00	−3.93	3.20	0.26	0.24	0.00	3.71	−0.21
Jiangxi	−2.50	−0.27	−0.37	−0.01	−3.14	2.47	0.26	0.29	0.01	3.02	−0.12
Shanghai	−0.01	−0.04	−0.33	0.00	−0.37	0.01	0.03	0.07	0.00	0.11	−0.27
Jiangsu	−0.18	−0.56	−2.99	0.00	−3.73	0.24	0.33	1.43	0.00	2.00	−1.73
Zhejiang	−1.91	−0.18	−0.71	0.00	−2.80	1.22	0.17	0.35	0.00	1.75	−1.05
Anhui	−1.00	−0.30	−1.96	0.00	−3.26	1.05	0.29	1.34	0.00	2.68	−0.59
total	−20.81	−2.77	−8.31	−0.04	−31.92	20.33	2.11	4.65	0.03	27.12	−4.80

The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1.

From 1990 to 2000, the changes in total grain output among provinces within the YEB diverged from those observed during 1980–1990, with a noticeable increase in regions experiencing a decrease in grain output (Figure 7). Plain regions such as Sichuan, Hubei, Anhui, Jiangsu, and Shanghai exhibited the most pronounced decreases in grain output, primarily concentrated in areas characterized by significant expansion of urban construction land. Some regions of Yunnan and Guizhou provinces witnessed a slight increase in grain output, attributed to the cultivation of forest and grassland, which increased the arable land area in those regions.

During the period from 1990 to 2000, Suzhou City in Jiangsu Province experienced the most significant decrease in grain output among cities in the YEB (Figure 7). Additionally, Shanghai and Chongqing, as two municipalities directly under the central government, also witnessed relatively large decreases in grain output. This phenomenon can be attributed to the rapid economic development in these municipalities, leading to extensive expansion of construction land and subsequent encroachment upon arable land. Conversely, the cities with the greatest increase in grain output during this period were Tongren City in Guizhou Province and Jinghong City in Yunnan Province. Both of these cities are located in the upstream region of the YEB. Tongren City benefits from rivers such as the Wu River for irrigation of grain crops, while the Lancang River flowing through Jinghong City provided abundant water resources for the region. The topography of these cities, coupled with the conversion of forest and grassland into arable land, may have also contributed to the observed increase in grain output.

3.2.4. Effects of Arable Land Change on Grain Output from 2000 to 2010

From 2000 to 2010, the total grain output within the YEB experienced a net decrease of approximately 11.66 million tons, with a decrease of approximately 45.89 million tons offset by the increase of approximately 34.23 million tons (Table 5). Among the various land-use conversions, the primary contributors to the decrease in grain output were the cultivation of forest and grassland and the expansion of construction land areas, which accounted for approximately 56.14% and 32.44% of the reduction in grain output, respectively. The cultivation of forest and grassland led to an increase in grain output, while the expansion of construction land led to a decrease in grain output. The main driver behind the increase in total grain output during this period was the cultivation of forest and grassland, contributing approximately 75.78% of the increase in grain output. The upstream regions of the YEB witnessed a decrease in grain output primarily due to the national policy of returning farmland to forests or grasslands. In the midstream regions, the decline in grain output is attributed to the national policy of returning farmland to forests and grasslands and the expansion of urbanization. Meanwhile, in the downstream regions, the decrease in grain output was mainly driven by urbanization expansion. The primary reason for the decrease in grain output was the national policy of returning farmland to forests and grasslands, and urbanization during this period.

Table 5. Statistics on the impact of arable land change on grain output from 2000 to 2010 (million tons).

Province	Decrease					Increase					Net Change
	AL → F&GL	**AL → WB**	**AL → CL**	**AL → UL**	**Total**	**F&GL → AL**	**WB → AL**	**CL → AL**	**UL → AL**	**Total**	
Yunnan	−3.64	−0.06	−0.49	−0.01	−4.19	3.89	0.06	0.15	0.01	4.11	−0.08
Guizhou	−3.19	−0.05	−0.08	0.00	−3.31	3.19	0.01	0.02	0.00	3.22	−0.09
Sichuan	−5.20	−0.26	−1.06	−0.01	−6.52	5.07	0.18	0.28	0.01	5.54	−0.98
Chongqing	−2.08	−0.09	−0.37	0.00	−2.55	2.22	0.04	0.03	0.00	2.29	−0.26
Hubei	−2.51	−1.30	−1.31	−0.02	−5.13	2.31	0.56	0.54	0.02	3.44	−1.70
Hunan	−4.55	−0.53	−0.78	−0.02	−5.87	3.92	0.43	0.30	0.01	4.66	−1.22
Jiangxi	−2.97	−0.33	−0.80	−0.01	−4.10	3.16	0.38	0.34	0.01	3.90	−0.21
Shanghai	−0.01	−0.04	−0.60	0.00	−0.65	0.01	0.06	0.07	0.00	0.14	−0.51
Jiangsu	−0.21	−0.95	−5.16	−0.04	−6.35	0.33	0.38	1.64	0.00	2.35	−4.00
Zhejiang	−1.29	−0.32	−1.88	0.00	−3.49	1.34	0.22	0.35	0.00	1.91	−1.58
Anhui	−0.97	−0.38	−2.38	0.00	−3.72	0.96	0.31	1.41	0.00	2.68	−1.04
total	−26.61	−4.29	−14.89	−0.11	−45.89	26.41	2.63	5.14	0.06	34.23	−11.67

The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1.

The changes in grain output among provinces within the YEB during the 2000–2010 period differed from those observed during the 1980–1990 and 1990–2000 periods, with a further increase in regions experiencing a significant decrease in total grain output

(Figure 7). The areas experiencing a decline in grain output during the 1990–2000 period, provinces like Hunan, Jiangxi, and Zhejiang, witnessed a notable decrease in grain output during the 2000–2010 period. The decline in grain output in Hunan and Jiangxi provinces was primarily attributed to the national policies of returning farmland to forest or grassland and returning farmland to lakes, whilst it was mainly due to the continuous expansion of construction land areas in Zhejiang Province.

During the period from 2000 to 2010, the most significant decrease in grain output was experienced by Suzhou City in Jiangsu Province among cities in the downstream region of the YEB. According to data from the National Bureau of Statistics, Suzhou City has consistently ranked among the top ten cities in terms of GDP in recent years, reflecting its rapid economic development. The expansion of construction land accompanying this economic growth inevitably encroached upon arable land, particularly as there was a relatively high average grain output per unit area in Suzhou City. Consequently, the extensive occupation of arable land inevitably led to a decrease in grain output. Conversely, there were several cities during this period where grain output increased, such as Shangrao City and Ganzhou City in Jiangxi Province, Qujing City and Lincang City in Yunnan Province, and Zigong City and Aba Prefecture in Sichuan Province. The increase in grain output in these cities can be attributed to the less pronounced expansion of construction land and the cultivation of forest and grassland for agricultural purposes.

3.2.5. Effects of Arable Land Change on Grain Output from 2010 to 2020

From 2010 to 2020, the total grain output in the YEB experienced a net decrease of approximately 6.32 million tons, with a decline of approximately 23.86 million tons offset by an increase of approximately 17.54 million tons (Table 6). Among various land use conversions, the primary contributors to the decline in total grain output were still the cultivation of forest and grassland and the expansion of construction land areas, accounting for approximately 56.06% and 36.11% of the reduction in grain output within the YEB, respectively. During this period, the proportion of grain output reduction attributed to the expansion of construction land areas increased. The main reason behind the increase in grain output during this period remained the cultivation of forest and grassland, contributing approximately 77.79% of the total increase in grain output. The continuous encroachment of farmland due to the national policy of returning farmland to forests and grasslands, as well as urbanization, remained the primary drivers behind the decrease in grain output during this period.

Table 6. Statistics on the impact of arable land change on grain output from 2010 to 2020 (million tons).

Province	**Decrease**					**Increase**					**Net Change**
	AL → F&GL	**AL → WB**	**AL → CL**	**CL → UL**	**Total**	**F&GL → AL**	**WB → AL**	**CL → AL**	**UL → AL**	**Total**	
Yunnan	−2.23	−0.16	−0.56	0.00	−2.95	2.27	0.06	0.12	0.00	2.46	−0.50
Guizhou	−1.68	−0.06	−0.35	0.00	−2.10	1.65	0.01	0.01	0.00	1.67	−0.43
Sichuan	−5.04	−0.31	−1.21	0.00	−6.57	5.01	0.25	0.38	0.01	5.64	−0.93
Chongqing	−0.77	−0.08	−0.54	0.00	−1.39	0.93	0.02	0.07	0.00	1.02	−0.37
Hubei	−1.04	−0.43	−1.04	−0.01	−2.52	1.19	0.71	0.72	0.01	2.64	0.12
Hunan	−1.46	−0.13	−0.59	0.00	−2.17	1.39	0.10	0.12	0.01	1.62	−0.55
Jiangxi	−1.10	−0.11	−0.62	0.00	−1.83	1.11	0.08	0.15	0.00	1.35	−0.48
Shanghai	−0.03	−0.03	−0.45	0.00	−0.51	0.01	0.07	0.05	0.00	0.13	−0.38
Jiangsu	−0.02	−0.11	−1.34	0.00	−1.47	0.06	0.15	0.19	0.03	0.42	−1.05
Zhejiang	−0.26	−0.05	−1.08	0.00	−1.39	0.22	0.07	0.11	0.00	0.40	−0.99
Anhui	−0.06	−0.07	−0.83	0.00	−0.96	0.06	0.02	0.11	0.00	0.19	−0.77
total	−13.69	−1.52	−8.62	−0.03	−23.86	13.90	1.54	2.04	0.06	17.54	−6.32

The specific explanations for the abbreviations AL → F&GL, AL → WB, AL → CL, and AL → UL, and F&GL → AL, WB → AL, CL → AL, and YL → AL, are provided in Table 1.

The changes in total grain output among provinces within the YEB from 2010 to 2020 differed from those observed in the previous three periods (Figure 7). During this period, with the exception of some cities in Hubei and Jiangsu provinces, grain output generally declined. During the period from 2010 to 2020, notable increases in grain output occurred in the vicinity of Dongting Lake in Hubei Province. Among them, Jingzhou City exhibited the most significant increase in grain output. In recent years, ecological restoration projects have to some extent alleviated the rate of shrinkage of Dongting Lake. However, the conversion of water bodies into arable land has also contributed to an increase in the arable land area [36], thereby enhancing grain output. Additionally, some regions such as Yancheng City in Jiangsu Province witnessed an increased grain output. Yancheng City, located near the sea and with three plains and numerous rivers, boasts favorable conditions for grain cultivation. Apart from these areas, the overall trend in grain output in the YEB during this period remained negative. Conversely, a multitude of cities experienced a decrease in grain output during this period, with few exceptions mentioned above. Generally, regions with more developed economies tend to have less arable land. Grain output is fundamental to survival and the reduction of arable land is detrimental to the overall development of the region. Therefore, it is significant to strengthen the protection of arable land in the YEB.

4. Discussion

Over the span of four decades from 1980 to 2020, the YEB, serving as a vital core region for China's economic development and an essential agricultural production base, experienced significant changes in the quantity and spatial pattern of arable land amidst rapid urbanization and industrialization processes. In light of the aforementioned research findings, a discussion of these outcomes is warranted.

The term "sown area of grain crops" refers to the total arable land within a specific region (usually a country or region) allocated for the cultivation of grain crops. This metric is crucial for assessing agricultural output and food supply within a country or region. The magnitude of sown area directly impacts grain output and supply, thereby exerting significant influence on food security and economic development. Based on the publicly available data from the National Bureau of Statistics regarding the sown area of grain crops in the 11 provinces and cities within the YEB from 1980 to 2020, it was observed that, with the exception of Yunnan, Guizhou, and Anhui provinces, the sown area of grain crops in the remaining eight provinces and cities demonstrated a decreasing trend (Figure 8). It stated that the sown area of grain crops within the YEB predominantly exhibited a decreasing trend. This trend of decreasing sowing area for grain crops in most regions aligned with the findings of arable land reduction presented in this study, lending scientific credibility to the study's findings. Furthermore, several previously published articles have utilized the land use dataset employed in this study. Many of these articles have garnered considerable recognition from peers and have achieved high citation counts. Additionally, the land-use data from the dataset covering the period of 1980–2020 have been publicly disseminated in journals such as the "Journal of Geography", indicating the validation of the arable land dataset utilized in this study. It is worth noting that the distinguishing features of this study's analysis of spatiotemporal changes in arable land differ from those of previously published articles in two key aspects: firstly, while the timespan of previously published articles generally covered specific periods within 1980–2020, this study analyzed the entire duration from 1980 to 2020; secondly, no other scholars have yet conducted a detailed analysis of the spatiotemporal changes in arable land in the YEB using the same dataset.

The term "grain crop yield per unit area" refers to the quantity of grain crops produced per unit of land area, typically measured per hectare. "Grain output" serves as a pivotal indicator for assessing agricultural productivity and food supply capability within a given region. Its magnitude is directly influenced by factors including arable land area, climatic conditions, planting techniques, and agricultural management practices. An analysis of the grain yield per unit and total production data for 11 provinces and municipalities within the YEB, as published by the National Bureau of Statistics for the period 1980–2020, revealed a consistent trend of increase in grain yield per unit across the provinces and municipalities over this period (Figure 9). However, total grain output showed an increasing trend across the region, except for Shanghai and Zhejiang in the lower reaches of the YEB. As illustrated in Figure 8, the sowing area of grain crops mainly showed a decreasing trend from 1980 to 2020. These suggested that the increase in grain production was primarily attributed to improvements in the yield per unit of grain crops, reflecting advancements in agricultural quality and productivity through technological means.

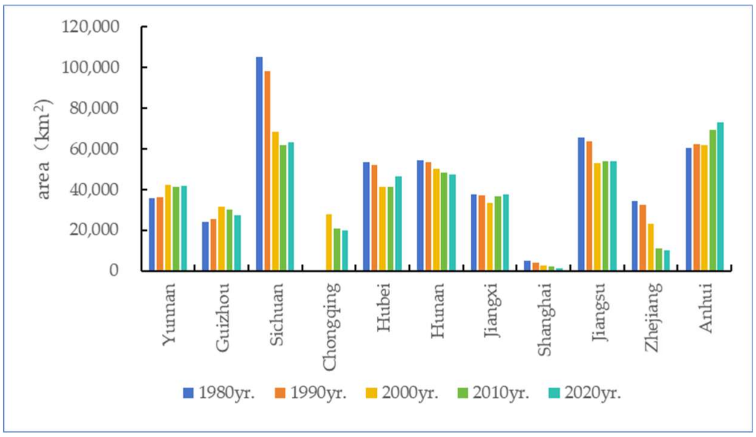

Figure 8. Grain crop sowing area statistics from 1980 to 2020 in the YEB.

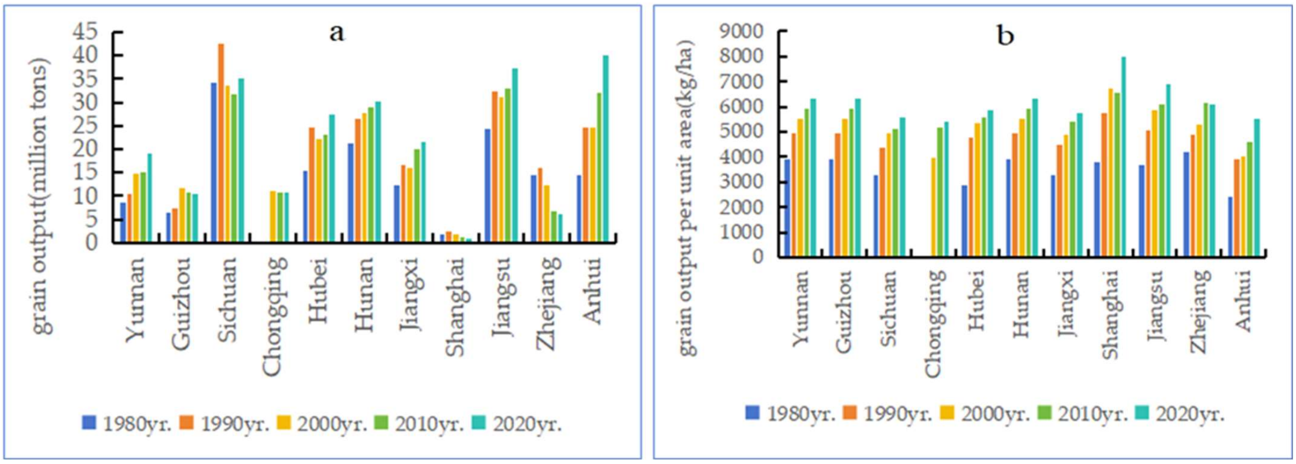

Figure 9. (**a**) Grain output per unit area of the YEB from 1980 to 2020. (**b**) Grain output statistics of the YEB from 1980 to 2020.

This study primarily examined the changes in grain output by considering the variations in arable land area in the YEB from 1980 to 2020. It focused solely on the average grain crop yields of 130 cities in the YEB over the past decade to explore the four-decade evolution of grain output. A reduction in arable land area inevitably led to a decrease in grain output. And moreover, due to the extensive temporal span of this study, obtaining accurate historical data on average grain output yields for earlier periods is challenging. Consequently, precise calculations using average grain output yield data from different periods were not feasible, resulting in inherent inaccuracies in the grain output calculations of this study. Furthermore, grain output is influenced by factors such as the quality of arable land and the variety of grain crops, aspects not fully accounted for in this study. Addressing these limitations, future research endeavors will endeavor to incorporate these influencing factors into grain output calculations, thereby enhancing the precision of the results.

Additionally, due to limitations in data availability and timeframe constraints, there are several shortcomings in this research. For instance: (1) The study in this paper only focused on the spatiotemporal changes of primary land-use types of arable land converting into other primary land-use types. It did not delve into the relationship between secondary land-use types of arable land, such as paddy fields and drylands, converting into other primary land-use types. (2) Due to constraints in data acquisition, this study only utilized grain output data at the municipal level for calculations. It did not compute provincial-level grain output from the perspective of grain output data at the county level, which could offer a more detailed analysis of grain output at the provincial level.

5. Conclusions

Based on the temporal and spatial changes of arable land and the effects of arable land changes on grain output, this paper analyzed the characteristics of cultivated land changes and grain impacts in the YEB in a recent 40-year period. The main conclusions of the research were as follows:

(1) The total area of arable land has significantly decreased in the YEB. From 1980 to 2020, the arable land area decreased by approximately 41,775 square kilometers, with the downstream region experiencing the most significant reduction in the YEB. The city with the greatest reduction in arable land was Suzhou City, Jiangsu Province. Expanding construction land was the primary factor contributing to the relatively lower arable land area in the YEB.

(2) There were similarities and differences in the reduction of arable land area and in its causes in different periods in the YEB. From 1980 to 1990, the arable land area decreased by approximately 3924 square kilometers in the YEB, mainly due to the expansion of water bodies. From 1990 to 2020, the arable land area was decreased primarily due to the expansion of construction land. The period from 2000 to 2010, witnessed the most significant decrease in arable land area, coinciding with the rapid economic development and urbanization expansion, which extensively occupied arable land.

(3) There was a decrease in the total arable land area in the YEB. The net decrease in grain output caused by the reduction in arable land area from 1980 to 2020 was approximately 25.12 million tons. The city with the greatest reduction in grain output was also Suzhou City, Jiangsu Province. The expansion of construction land occupied a significant amount of arable land in the downstream region of the YEB. Moreover, the arable land in most of the downstream provinces was suitable for grain cultivation, with relatively high per-acre grain output, thus the changes in the quantity and quality of arable land significantly reduced the total grain output. The upstream region of the YEB experienced the most minor decrease in grain output due to the limited arable land area influenced by the terrain of the Yunnan-Guizhou Plateau.

(4) There were differences in the reduction of total grain output in the YEB in different periods. In the decades from 1980 to 2020, the net decrease in total grain output in the YEB was approximately 2.30 million tons, 4.80 million tons, 11.66 million tons, and 6.32 million tons, respectively. Similarly to the reduction in arable land area, the decrease in grain output from 1980 to 1990 was due to the occupation of arable land by expanding water bodies, while from 2000 to 2010, the expansion of construction land resulted in the most significant decrease in grain output.

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Appendix A

Table A1. Statistical table of net area change in the YEB from 1980 to 2020 ($\times 10^2$ km^2).

Provinces	1980–1990	1990–2000	2000–2010	2010–2020
Yunnan	−1.823	−4.258	−2.775	−10.737
Guizhou	−0.952	3.634	−2.343	−11.480
Sichuan	−2.785	−5.250	−18.740	−16.652
Chongqing	−0.003	−2.036	−4.986	−7.167
Hubei	−17.588	−6.347	−29.445	2.197
Hunan	−3.856	−3.593	−20.407	−9.013
Jiangxi	−1.095	−2.069	−3.062	−7.945
Shanghai	−2.503	−4.153	−7.834	−5.464
Jiangsu	−3.086	−24.663	−58.554	−14.945
Zhejiang	−0.283	−17.684	−25.865	−15.736
Anhui	−5.275	−10.062	−17.590	−13.287

Table A2. Statistical table of average annual net change area in the YEB from 1980 to 2020 ($\times 10^2$ km^2).

Provinces	1980–1990	1990–2000	2000–2010	2010–2020
Yunnan	−1.055	−2.012	−3.518	−2.657
Guizhou	−0.190	0.727	−0.469	−2.296
Sichuan	−0.557	−1.050	−3.748	−3.330
Chongqing	−0.001	−0.407	−0.997	−1.433
Hubei	−3.518	−1.269	−5.889	0.439
Hunan	−0.771	−0.719	−4.081	−1.803
Jiangxi	−0.219	−0.414	−0.612	−1.589
Shanghai	−0.501	−0.831	−1.567	−1.093
Jiangsu	−0.617	−4.933	−11.711	−2.989
Zhejiang	−0.057	−3.537	−5.173	−3.147
Anhui	−1.055	−2.012	−3.518	−2.657

Table A3. Statistical table of dynamic change in the YEB from 1980 to 2020.

Provinces	1980–1990	1990–2000	2000–2010	2010–2020
Yunnan	0.000	0.001	0.001	0.002
Guizhou	0.000	0.000	0.000	0.000
Sichuan	0.007	0.013	0.044	0.042
Chongqing	0.000	0.000	0.001	0.001
Hubei	0.002	0.001	0.003	0.000
Hunan	0.000	0.000	0.001	0.000
Jiangxi	0.000	0.000	0.000	0.001
Shanghai	0.000	0.000	0.001	0.001
Jiangsu	0.000	0.003	0.007	0.002
Zhejiang	0.000	0.003	0.005	0.003
Anhui	0.001	0.002	0.004	0.003

Table A4. Statistical Table of annual change rate in the YEB from 1980 to 2020 (%/yr).

Provinces	1980–1990	1990–2000	2000–2010	2010–2020
Yunnan	−0.052	−0.123	−0.081	−0.313
Guizhou	−0.039	0.147	−0.094	−0.465
Sichuan	−0.046	−0.087	−0.313	−0.283
Chongqing	0.000	−0.105	−0.258	−0.376
Hubei	−0.488	−0.180	−0.845	0.066
Hunan	−0.123	−0.115	−0.657	−0.300
Jiangxi	−0.048	−0.091	−0.135	−0.353
Shanghai	−0.959	−1.671	−3.440	−2.898
Jiangsu	−0.085	−0.683	−1.678	−0.468
Zhejiang	−0.019	−1.174	−1.824	−1.221
Anhui	−0.128	−0.246	−0.436	−0.337

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