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# Spatiotemporal Evolution of Cultivated Land Non-Agriculturalization and Its Drivers in Typical Areas of Southwest China from 2000 to 2020

**Yan Chen [1], Shiyuan Wang [1] and Yahui Wang [1,2,3,*]**

[1] School of Geographical Sciences, Southwest University, Chongqing 400715, China; z6655736@email.swu.edu.cn (Y.C.); xh618618@email.swu.edu.cn (S.W.)
[2] New Liberal Arts Laboratory for Sustainable Development of Rural Western China, Chongqing 400715, China
[3] Chongqing Jinfo Mountain Karst Ecosystem National Observation and Research Station, School of Geographical Sciences, Southwest University, Chongqing 400715, China
* Correspondence: wangyh1210@swu.edu.cn

**Abstract:** Cultivated land resources are crucial to food security and economic development. Exploring the spatiotemporal pattern of cultivated land non-agriculturalization and its drivers is a prerequisite for cultivated land conservation. This paper used GlobeLand30 data to reveal the spatial and temporal pattern, the shift of the gravity center and the drivers of cultivated land non-agriculturalization by employing spatial analysis, gravity center model and the geographical detector model. The results show a dramatic increase in the non-agriculturalization of cultivated land in the period of 2010–2020 compared to 2000–2010. Spatially, the cultivated land non-agriculturalization mainly occurred in areas with high urbanization levels, such as eastern Sichuan Province and western Chongqing Municipality, while the cultivated land non-agriculturalization in other areas was small-scale and spatially scattered. Furthermore, the speed of cultivated land non-agriculturalization showed spatial unevenness, and the gravity center of cultivated land non-agriculturalization shifted towards the northeast at a distance of 123.21 km. The cultivated land non-agriculturalization was affected by GDP per capita, population density, GDP per unit of land and total retail sales of social consumer goods. The key drivers for the cultivated land non-agriculturalization in the study area were the continuous expansion of urban space and the large-scale cultivation of economic fruit trees. The government should promote small-scale machinery suitable for agricultural cultivation in the mountainous and hilly areas of Southwest China, and appropriately develop economic fruit groves and livestock farming to reduce the phenomenon of cultivated land non-foodization.

**Keywords:** non-agriculturalization of cultivated land; spatiotemporal pattern; drivers; geographical detector model; mountainous and hilly areas; Southwest China

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## 1. Introduction

The expansion of urban land is widely recognized and has a profound impact on the global environment as well as on socio-economic development. Land cover change due to urban expansion may not only lead to land waste, environmental pollution and reduced biodiversity [1] but also contribute to carbon emissions and increase the risk of climate change [2,3]. The conversion of cultivated land to construction land under the influence of urban expansion has been the main reason for the decline in cultivated land [4]. The non-agriculturalization of cultivated land is a phenomenon that arises in the context of rapid socio-economic and urbanization development, which is reflected in the transformation of the use of cultivated land from agricultural cultivation to urban construction, reforestation and seedling planting [5]. The non-agriculturalization of cultivated land caused by the conversion of cultivated land to construction land has often caused damage to the cultivated layer that is difficult to recover, resulting in a series of negative impacts on cultivated land resources and the ecological environment [6].

Under the Shared Socio-Economic Pathway (SSP), projections indicate that by 2100, approximately 50–63% of construction land will take up cultivated land and global urban land expansion will result in a direct loss of 1–4% of crop production, affecting between 122 million and 1389 million people [7]. Cultivated land is the foundation of food production, and the proper management and use of every inch of valuable cultivated land is a prerequisite for holding the initiative in food security [8]. China had entered a phase of rapid industrialization and urbanization since 1995, resulting in a reduction of 0.21 Mha of cultivated land nationwide from 2005 to 2015, directly threatening the food security of China [9]. The area under grain cultivation in China decreased by $9.70 \times 10^5$ $hm^2$ in 2019 alone, which not only posed a serious threat to national food security but also posed a huge risk to social stability, agricultural landscape, and ecosystem health [10,11]. The Chinese government has taken a series of measures to respond to the shrinking of cultivated land and the threat to food security, including delimiting a red line for cultivated land protection, reclaiming off-site cultivated land and adjusting the quota supply of land for construction, which are of great significance in ensuring the harmonious and sustainable development of China's economy and society [12,13].

China's sustained population growth and dietary structure changes have increased the demand for food, but industrialization and urban construction have led to a sharp decline in the amount of cultivated land [14]. In the past few years, scholars' work on the non-agriculturalization of cultivated land mainly involves the spatial and temporal configuration and evolutionary characteristics [15,16], the driving forces and mechanisms [17–19], the impact on the economic, social and ecological environment [20,21] and the prediction of trends [22,23]. The scale of research is concentrated at the national, provincial and municipal levels at the macro-regional scale, while relatively little research has been done at the micro-level [24]. The existing studies mainly focus on the relationship between the amount of cultivated land non-agriculturalization and regional resource endowments, economic development, population, government actions, agricultural technology, and other factors, but there is a lack of research on the spatial and temporal evolution of cultivated land non-agriculturalization and the process of gravity center shift [25]. In addition, most of the studies on the non-agriculturalization of cultivated land are focused on the plains of eastern and central China. There is a relative lack of attention to the non-agriculturalization of cultivated land in the western hilly areas [26,27].

Southwest China is a typical mountainous and hilly region, which is a paramount production base for agricultural products such as grain, meat, oil, fruit and tobacco in China. Protecting and utilizing the cultivated land resources in this region is of great significance to guarantee national food security [28]. However, the fragmented topography of Southwest China has resulted in a shortage of cultivated land suitable for farming and difficulties in popularizing the use of large farm machinery, eventually leading to low agricultural production efficiency. Furthermore, the expansion of cities and towns in the past few years has taken up a large amount of high-quality cultivated land resources, and the quantity and quality of cultivated land have continued to decline, resulting in a weak increase or even decrease in grain production [29]. Currently, very little research has been done on the non-agriculturalization of cultivated land in southwest China. It is vital to analyze the process of cultivated land non-agriculturalization in southwest China and its causes in order to improve food production capacity and ensure national food security [30].

Therefore, we selected Sichuan Province, Chongqing Municipality, Guizhou Province, and Yunnan Province in Southwest China as study areas, then we used multi-period global land cover data in 2000, 2010, and 2020 as support to reveal the spatial and temporal evolution characteristics of the cultivated land non-agriculturalization and the driving factors behind them in typical areas of southwest China with the help of spatial analysis, gravity center model and the geographical detector model. It will not only provide a scientific basis for the conservation of regional cultivated land resources and sustainable land use but also provide a theoretical basis and research ideas to promote the management of non-agriculturalization and non-foodization of cultivated land. And the outcomes from

this research are an invaluable knowledge base for cultivated land management, livelihood security and food security in all regions.

## 2. Study Area, Data and Methods

### *2.1. Study Area*

Southwest China (97°21′E–110°11′E, 21°08′N–33°41′N) covers Sichuan Province, Guizhou Province, Yunnan Province, and Chongqing Municipality, with a total area of 1.139 million square kilometers, accounting for about 11.82% of China's land area. The topography of the study area is high in the west and low in the east, with a variety of landform types such as plateau, plain, basin and hills, and its karst landform development is quintessential. The climate is dominated by a subtropical monsoon climate, with an average annual temperature of about 15 °C and average annual precipitation of over 1200 mm.

In 2021, the total GDP of Sichuan, Guizhou and Yunnan Provinces as well as Chongqing Municipality amounted to 12,847 billion yuan, accounting for 11.23% of the national total GDP, with a total population of 201 million, accounting for approximately 14.27% of the national total population. Southwest China is the key area to achieve coordinated development among regions, which has a very paramount impact on forming a pattern of high-quality development in the western region and promoting high-quality development of China's economy. The implementation of development strategies such as the Large-scale development of western China has promoted the equalization of basic public services and contributed to the narrowing of the development gap between the southwestern region and eastern region in China since 2005. The Chengdu–Chongqing region within the Southwest is a densely populated region with convenient transportation and a leading level of economic development within the area. The Chengdu–Chongqing economic circle is the "fourth growth pole" of China's economic development after the Yangtze River Delta region, Beijing–Tianjin–Hebei region and Pearl River Delta region, and it has great significance in leading the linkage development of other urban clusters and expanding inter-regional cooperation in Southwest China. Figure 1 shows the location of the study area.

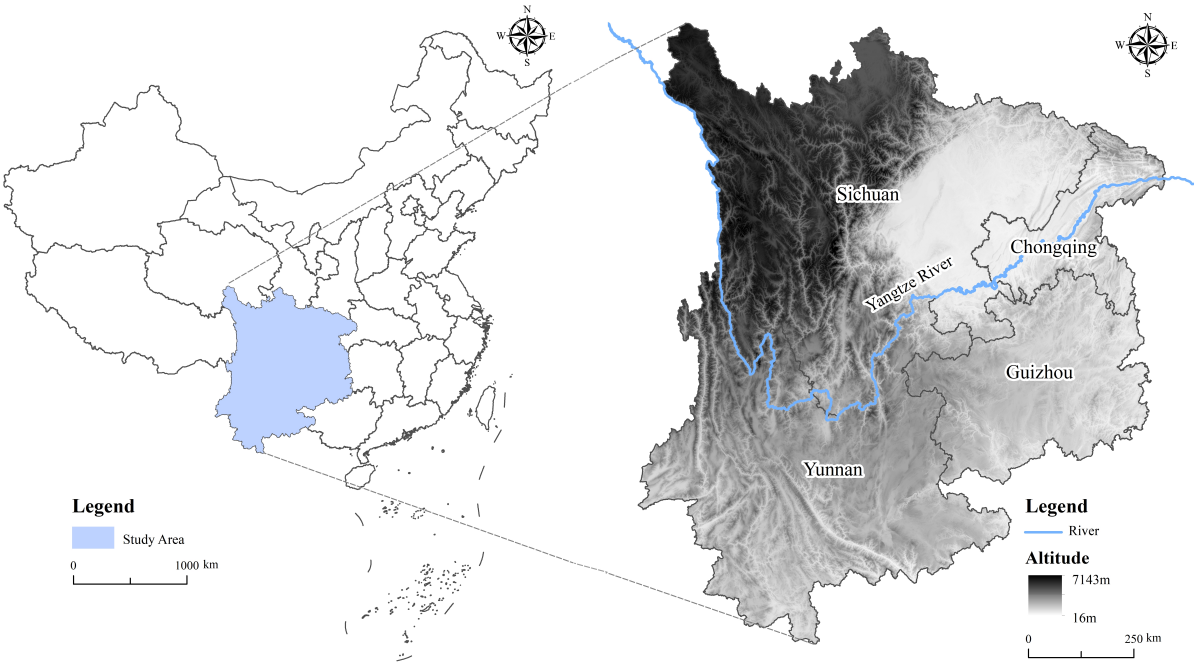



**Figure 1.** The geographical location of the study area.

### *2.2. Data*

This paper used the GlobeLand30 (http://www.globallandcover.com, accessed on 29 July 2021), a 30 m spatial resolution global land cover data developed in China to

analyze the spatial and temporal changes and the shift of the gravity center for the non-agriculturalization of cultivated land. GlobeLand is currently available in versions 2000, 2010 and 2020. The classified images used for GlobeLand30 data interpretation are mainly 30 m multispectral images, including TM5, ETM+, OLI multispectral images from the U.S. Land Resources Satellite (Landsat) and multispectral images from the Chinese Environmental Disaster Reduction Satellite (HJ-1). In addition, the 2020 version of the data also uses the 16 m resolution Gaofen-1 (GF-1) multispectral images. The global land cover data, GlobeLand30, is interpreted from remote sensing imagery, and the types of land cover in the classification system include cropland, forest, grassland, shrubland, wetlands, water, tundra, artificial ground, bare ground, glaciers and permanent snow. The overall accuracy of GlobeLand30 for 2010 is 83.50% with a Kappa coefficient of 0.78, and the overall accuracy of GlobeLand30 for 2020 is 85.72% with a Kappa coefficient of 0.82. The general accuracy of global land cover data is high and meets the research accuracy requirements.

For research purposes, this paper used the CNLUCC classification system to reclassify the global land cover data GlobeLand30. The China Multi-period Land Use Land Cover Change (CNLUCC) remote sensing monitoring dataset is derived from the Resource and Environment Science Data Registration and Publication System (http://www.resdc.cn/DOI, accessed on 22 June 2022), and it is a 1:100,000 scale multi-period land use and land cover thematic database constructed by manual visual interpretation using Landsat remote sensing imagery from the United States Land Satellite as the main information source. The database uses a two-level classification system, and Level 1 is divided into six categories: cultivated land, forest land, grassland, water, construction land and undeveloped land, while Level 2 is further divided into 25 categories based on the Level 1 types. The construction land includes urban land, rural settlements and construction land for factories, mines, airports and transport roads. Figure 2 shows a flow chart of the data processing and analysis.

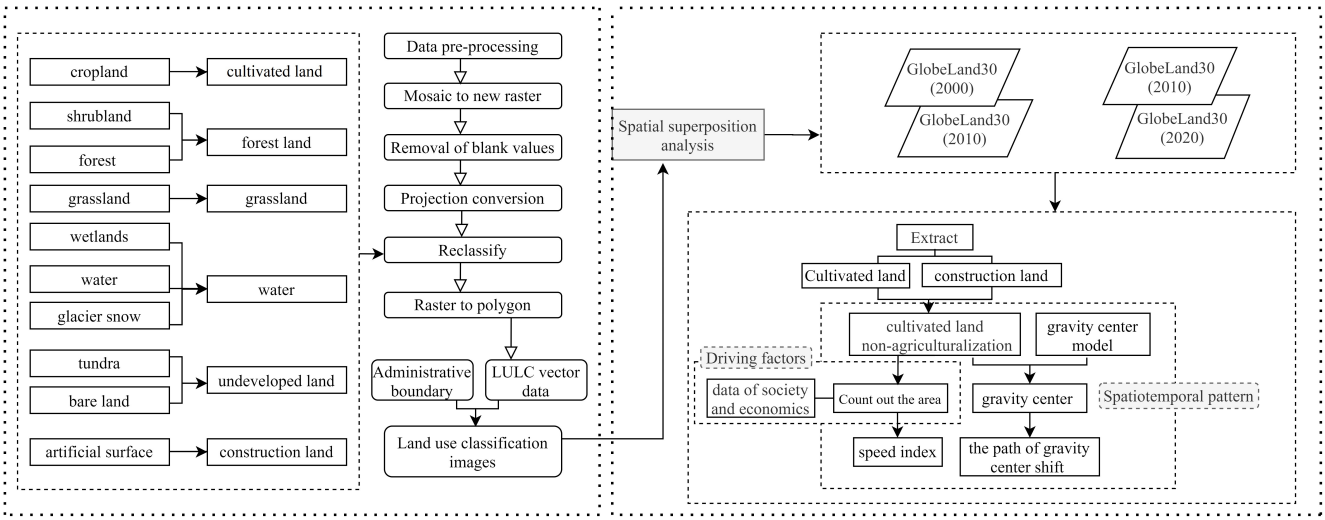



**Figure 2.** Flow chart of data processing and analysis.

We selected indicators such as population density, GDP per capita, the GDP share of primary industry, the GDP share of non-agricultural industry, total retail sales of social consumer goods, total agricultural machinery power and disposable income of rural residents to explore the drivers of cultivated land non-agriculturalization in the study area by using the economic and social data of 30 prefecture-level cities in Chongqing Municipality, Sichuan Province, Yunnan Province and Guizhou Province in 2000, 2010 and 2020. These data were obtained from the 2001–2021 Sichuan Provincial Statistical Yearbook, Yunnan Provincial Statistical Yearbook, Guizhou Provincial Statistical Yearbook, Chongqing Statistical Yearbook, Guiyang Statistical Yearbook, and Kunming Statistical Yearbook. Topographic data were derived from a digital terrain elevation model made

from radar images acquired by the SRTM system with an accuracy of 90 m. The cultivated land area, cultivated land area per capita and GDP per unit of land were calculated from the global land cover data combined with the above statistical yearbook data.

### 2.3. Methods

#### 2.3.1. Spatial Analysis

Spatial analysis is a technique that makes it possible to obtain the spatial location, distribution, morphology and evolution of geographical objects. We used the reclassification tool and spatial overlay analysis function of ArcGIS 10.4 to extract the areas where cultivated land was converted to construction land between 2000–2010 and 2010–2020.

Firstly, we removed the null values of the global land cover data for the three periods of 2000, 2010 and 2020, so that the global land cover data for the three periods had the same number of valid image elements. Next, we used the reclassification function of ArcGIS 10.4 to reclassify the global land cover data into six types according to the CNLUCC classification system, including cropland, forest land, grassland, water, construction land and undeveloped land. Table 1 shows the meaning of each type in the GlobeLand30 classification system and the CNLUCC classification system, as well as the methodology for reclassification in this paper. We then converted the raster image data to vector data and cropped it within the study area to obtain land use type maps for the study area for 2000, 2010 and 2020. Finally, we overlaid the land use type maps and extracted the portion of cultivated land converted to construction land as areas of non-agriculturalization of cultivated land in the study area for 2000–2010 and 2010–2020.

**Table 1.** The meaning of LULC classification and the method of reclassification.

| GlobeLand30 Classification System | | CNLUCC Classification System | |
|---|---|---|---|
| **Type** | **Meaning** | **Type** | **Meaning** |
| cropland | Land for growing crops | cultivated land | Land for growing crops |
| forest | Land with tree cover and more than 30% canopy cover | forest land | Forestry land for growing trees, shrubs, bamboos, etc. |
| shrubland | Land with shrub cover and more than 30% scrub cover | | |
| grassland | Land covered by natural herbaceous vegetation with more than 10% cover | grassland | All types of grassland with herbaceous vegetation and a cover of 5% or more |
| water | Areas covered by liquid water at the terrestrial scale | water | Refers to land with natural terrestrial waters and water facilities |
| glacier snow | Land covered by permanent snow, glaciers and ice caps | | |
| wetlands | Land located in the border zone between land and water, with shallow standing water or excessively wet soil | | |
| artificial surface | Surface formed by man-made construction activities | construction land | Refers to urban and rural settlements and the land outside them for industrial, mining and transport purposes |
| bare ground | Land with natural cover of less than 10% vegetation cover | undeveloped land | Land that is currently undevelopd, including hard-to-use land |
| tundra | Land covered by lichens, mosses, perennial hardy herbs and shrubs in boreal and alpine environments | | |

#### 2.3.2. the Speed Index

There is significant geographical variability among cities, consequently, the degree of cultivated land non-agriculturalization is also different. The speed index can measure the extent of change in the non-agriculturalization of cultivated land [25,31]. We used

the speed index of cultivated land non-agriculturalization to reveal the spatially uneven pattern of cultivated land non-agriculturalization in a typical region of southwest China. The expression for the index is as follows:

$$v_i = \frac{F_i^{20} - F_i^{00}}{F_i^{00}} \quad (1)$$

$v_i$ in the expression is the speed index of cultivated land non-agriculturalization in the city $i$, $F_i^{20}$ is the area of cultivated land in 2020 in the city $i$. $F_i^{00}$ is the area of cultivated land in 2000 in the city $i$.

2.3.3. Gravity Center Model

The gravity center model is a paramount analytical tool for studying the spatial changes of factors in the process of regional development. The spatial transfer path of the cultivated land non-agriculturalization can be visualized by finding the gravity center of the cultivated land non-agriculturalization in the study area. The expression of the gravity center model is as follows:

$$X = \frac{\sum_1^n x_i}{n} \quad (2)$$

$$Y = \frac{\sum_1^n y_i}{n} \quad (3)$$

In the expression, $X$ and $Y$ are the latitude and longitude coordinates of the spatial gravity center of cultivated land non-agriculturalization; $x_i$ and $y_i$ are the longitude and latitude coordinates of the spatial unit $i$ where cultivated land non-agriculturalization has occurred; $n$ is the number of space units.

Let the coordinates of the gravity center of cultivated land non-agriculturalization in years $k$, $k+l$ be $P_k(x_k, y_k)$, $P_{(k+l)}(x_{(k+l)}, y_{(k+l)})$. The direction that the gravity center $P_k$ moved towards $P_{(k+l)}$ is represented as:

$$\theta = \arctan[(y_{k+l} - y_k)/(x_{k+l} - x_k)] \quad (4)$$

The distance that the gravity center $P_k$ moved towards $P_{(k+l)}$ is denoted as:

$$d = \sqrt{(x_{k+l} - x_k)^2 + (y_{k+l} - y_k)^2} \quad (5)$$

2.3.4. Geographical Detector Model

We used the geographical detector model to explore the driving factors of cultivated land non-agriculturalization. The geographical detector is a statistical method for detecting spatial heterogeneity and revealing the driving forces behind it. The basic assumption of the geographical detector model is that if the independent variable has a significant effect on the dependent variable, then the two should have similar spatial distributions [32]. The geographical detector model includes factor detection, interaction detection, risk zone detection and ecological detection, and factor detection and interaction detection are often used in driving factor analysis [33,34]. Factor detection reveals the influence magnitude of the independent variable $X$ on the dependent variable $Y$ and is measured by the $q$ value, the expression is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \quad (6)$$

In the expression: the $q$ value indicates that the independent variable explains $100 \times q\%$ of the dependent variable, and the $q$ value ranges from [0,1]. A larger $q$ value indicates that the factor has a stronger explanatory power for the dependent variable. $h = 1, \ldots, L$ is the classification of factor $X$, $N_h$ and $N$ are the numbers of units in layer $h$ and the whole region, respectively, $\sigma_h^2$ and $\sigma^2$ are the variances of layer $h$ and the whole region, respectively.

The factors influencing the cultivated land non-agriculturalization include natural, economic and social institutional factors [19]. Factors such as cultivated land resource endowment, geographical location, soil and climate are significantly correlated with the cultivated land non-agriculturalization among the natural factors [35]. GDP per capita, disposable income of rural residents, investment in secondary and tertiary fixed assets, the proportion of non-agricultural industries in GDP, urbanization rate, and the characteristics of agriculture and agricultural development are important influencing factors of cultivated land non-agriculturalization among the economic factors [36,37]. We took 30 prefecture-level cities in the study area as the research objects and selected population density, GDP per capita, the GDP share of primary industry, the GDP share of non-agricultural industry, cultivated land area, cultivated land area per capita, GDP per unit of land, total retail sales of social consumer goods, total agricultural machinery power, and disposable income of rural residents as indicators based on the existing research results. Afterward, we calculated the change amount of each index during 2000–2010 and 2010–2020 and used the natural breakpoint method to discretize each factor. In addition, since the study area is located in the mountainous areas of Southwest China, topographic factors were added to the model. According to the World Conservation Monitoring Center (UNEP-WCMC), mountainous areas can be classified if they meet the following requirements. ① Altitude greater than 2500 m. ② Altitude between 1500–2500 m and slope greater than 2°. ③ Altitude between 1000–1500 m and slopes greater than 5° or local altitude differences greater than 300 m. ④ Altitude between 300–1000 m and local altitude difference greater than 300 m [38]. We used the digital elevation model for the study area to count the proportion of mountainous areas in each prefecture-level city. Then, we discretized the proportion of mountainous areas and added them to the model as topographic factors. Table 2 shows the symbols and classification numbers of the driving factors

**Table 2.** Driving factors and number of discretization types.

| Driving Factors | Factor Symbols | Number of Types (2000–2010) | Number of Types (2010–2020) |
|---|---|---|---|
| Population density | *X*1 | 5 | 7 |
| GDP per capita | *X*2 | 4 | 3 |
| The GDP share of the primary industry | *X*3 | 4 | 4 |
| The GDP share of the non-agricultural industry | *X*4 | 4 | 3 |
| Cultivated land area | *X*5 | 4 | 5 |
| Cultivated land area per capita | *X*6 | 4 | 5 |
| GDP per unit of land | *X*7 | 6 | 6 |
| Total retail sales of social consumer goods | *X*8 | 4 | 3 |
| Total power of agricultural machinery | *X*9 | 5 | 5 |
| Disposable income of rural residents | *X*10 | 4 | 3 |
| Percentage of mountainous area | *X*11 | 3 | 3 |

## 3. Results

### *3.1. Spatiotemporal Pattern of Cultivated Land Non-Agriculturalization*

There are spatial differences in the endowment and distribution of cultivated land resources within each prefecture-level city. Cultivated land in the study area is mainly concentrated in the western part of Chongqing and the eastern part of Sichuan, which is within the Sichuan Basin and has flat topography. Nevertheless, the landscape of Yunnan and Guizhou provinces is mostly plateau, hilly and mountainous, accordingly, the cultivated land is highly fragmented and scattered, Figure 3 represents the distribution of cultivated land and non-cultivated land in the study area at different periods.

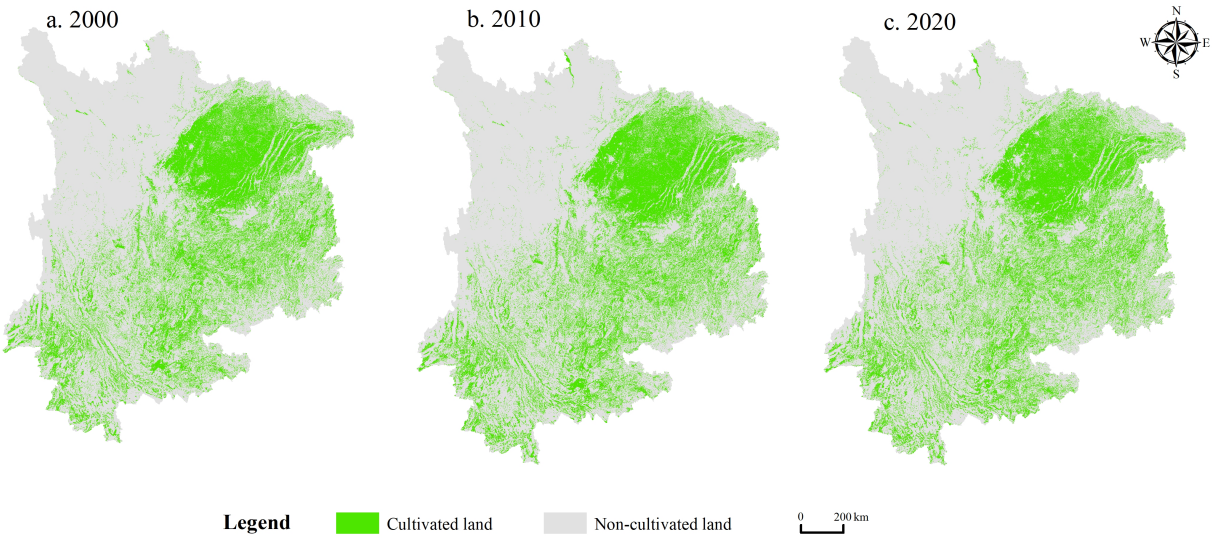



**Figure 3.** Distribution of cultivated and non-cultivated land.

Table 3 presents the proportion of non-agriculturalized cultivated land in the study area for each period. The results manifest that the non-agriculturalized area of cultivated land was 15.82 × $10^4$ $hm^2$ from 2000 to 2010, while it increased significantly to 87.03 × $10^4$ $hm^2$ from 2010 to 2020. The ratio of the cultivated land non-agriculturalization increased from 0.497% to 2.710%. The reason for this is that since 2000, the implementation of policies such as the "Large-scale development of western China" and the "Poverty Alleviation" campaign has promoted the rapid economic growth of the southwest region, and attracted a large labor force, resulting in a sharp increase in the demand for construction land, which has exacerbated the phenomenon of cultivated land non-agriculturalisation. From 2004 to 2011, the Central Committee of the Communist Party of China and the area and State Council issued eight consecutive documents on the theme of "agriculture, rural areas, and farmers", which led to a small increase in the amount of cultivated land in the southwest region and to some extent alleviated the non-agriculturalization of cultivated land. The accelerated rate of urbanisation in the western region and the implementation of the Grain for Green Project has led to an increase in the area of cultivated land occupied by construction land, forestry land and grass land after 2010, meanwhile, the phenomenon of low food efficiency aggravated, and farmers were less motivated to grow food, all these led to the non-agriculturalization of cultivated land intensified again.

**Table 3.** Area and proportion of non-agriculturalization of cultivated land in each period.

| | 2000–2010 | 2010–2020 |
|---|---|---|
| Area of non-agricultural cultivated land ($hm^2$) | 15.82 × $10^4$ | 87.03 × $10^4$ |
| The ratio of cultivated land non-agriculturalization area to cultivated land area (%) | 0.497 | 2.710 |

The prefecture-level cities in the study area were divided into five levels: lowest area, lower area, medium area, higher area and highest area according to the degree of cultivated land non-agriculturalization. As shown in Figure 4, the results demonstrate that there is significant spatial variability in the non-agriculturalization of cultivated land. Chengdu and Chongqing were consistently the highest areas for cultivated land non-agriculturalization, while higher areas include the cities of Dali, Kunming and Guiyang. The extent of cultivated land non-agriculturalization in the study area showed a tendency to spread from large cities to small surrounding cities. In addition, the results show that the high areas of cultivated land non-agriculturalization were mostly medium and large cities with a high level of development, moreover, most of them were located within the Chengdu–Chongqing economic circle, the city group in central Yunnan and the city group

in central Guizhou. The low areas of cultivated land non-agriculturalization were mostly cities with poor cultivated land resource endowment and in the primary or intermediate stages of economic development. The number of areas where the degree of cultivated land non-agriculturalization belongs to the medium area or the high area increased from 2000 to 2020. Besides, there was a trend that the medium areas and high areas of cultivated land non-agriculturalization moved toward the eastern part of the study area.

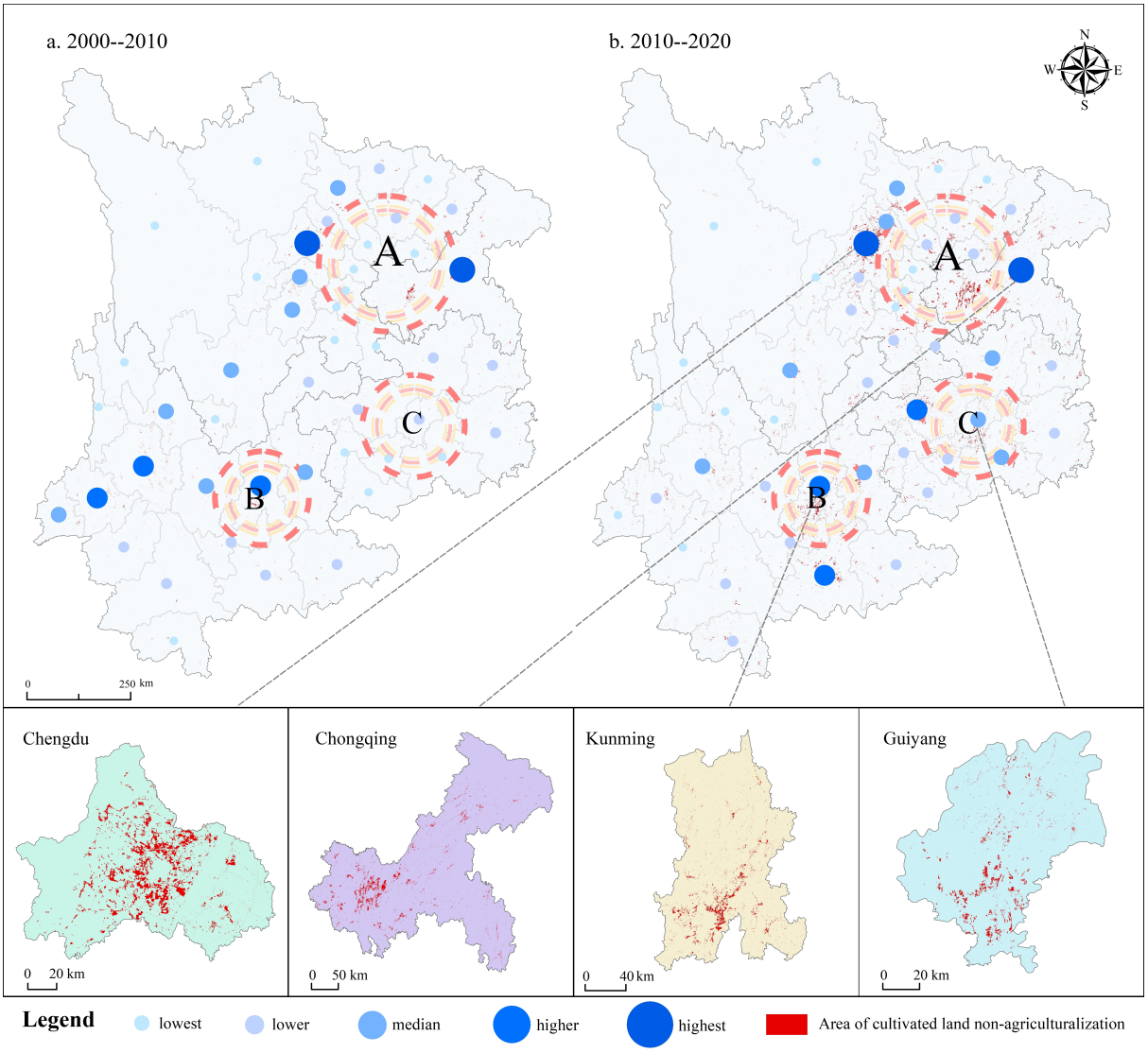



**Figure 4.** The grade map for the non-agriculturalization area of cultivated land. (**a**) Spatial distribution of the level of cultivated land non-agriculturalization during 2000–2010, (**b**) Spatial distribution of the level of cultivated land non-agriculturalization during 2010–2020.

We calculated the speed index of cultivated land non-agriculturalization for each city during the period 2000 to 2020, as shown in Figure 5. On the whole, the spatial discrepancy in the non-agriculturalization of cultivated land was obvious. The speed index of cultivated land non-agriculturalization was lower in Chongqing, eastern Sichuan Province, eastern Yunnan Province, and western Guizhou Province, while the speed index of cultivated land non-agriculturalization was relatively higher in border cities. It is easy to find through the results that the three provincial capitals, Chengdu, Kunming, Guiyang and Chongqing Municipality, all have a relatively high degree of non-agriculturalization of cultivated land. The pie chart in Figure 5 indicates the ratio of the area of cultivated land non-

agriculturalization in the latter decade to the former decade for each prefecture-level city. Only the non-agriculturalized area of cultivated land in Dehong Dai Jingpo Autonomous Prefecture of Yunnan Province decreased from $0.39 \times 10^4$ hm$^2$ to $0.31 \times 10^4$ hm$^2$, while the non-agriculturalized area of cultivated land in the rest of the regions showed a notable increase from 2000 to 2020. Locally, the area of cultivated land non-agriculturalization increased from $2.75 \times 10^4$ hm$^2$ to $16.46 \times 10^4$ hm$^2$ in Chongqing and from $2.45 \times 10^4$ hm$^2$ to $10.63 \times 10^4$ hm$^2$ in Chengdu from 2000 to 2020. These two cities had a much larger area of cultivated land non-agriculturalization than the other cities in the study area. Chongqing and Chengdu are the core cities of southwest China. The rapid improvement of their economic level and urbanization had led to the continuous growth of the inflowing population and a further expansion of the demand for construction land, resulting in an increase in the non-agriculturalized area of cultivated land in the two cities after 2000.

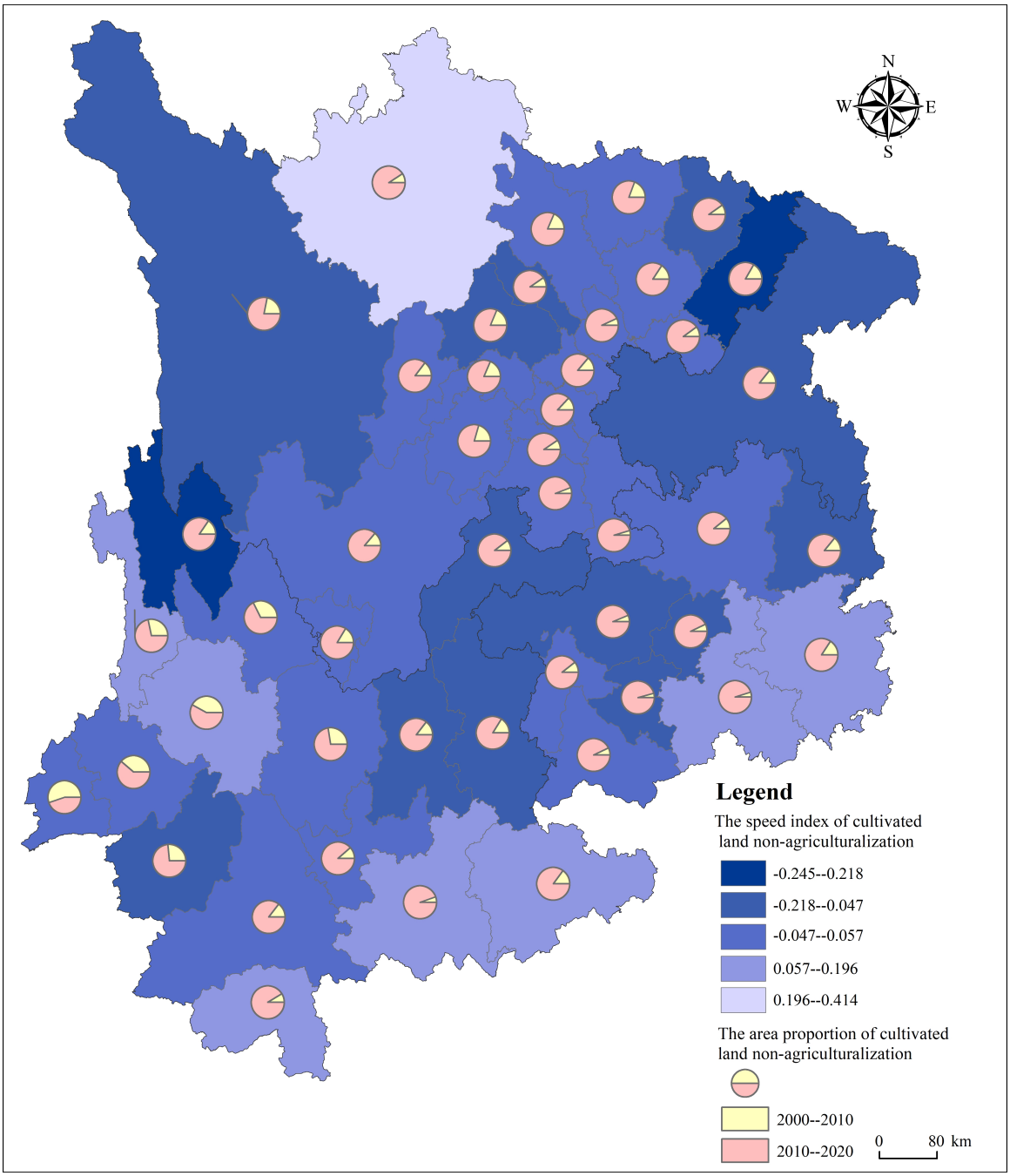



**Figure 5.** Map of the speed index for cultivated land non-agriculturalization.

We used the Zonal Geometry tool of ArcGIS to figure out the gravity center of the cultivated land non-agriculturalization in Southwest China in 2000–2010 and 2010–2020. Then, we calculated the direction and distance of the gravity center movement. Finally, we obtained the path of the gravity center shift of the cultivated land non-agriculturalization from 2000 to 2020 (as shown in Figure 6). The results manifest that the gravity center of cultivated land non-agriculturalization moved from Zhaotong City in Yunnan Province to Bijie City in Guizhou Province, the direction of the movement was roughly northeastward, and the distance of the movement was 123.21 km.

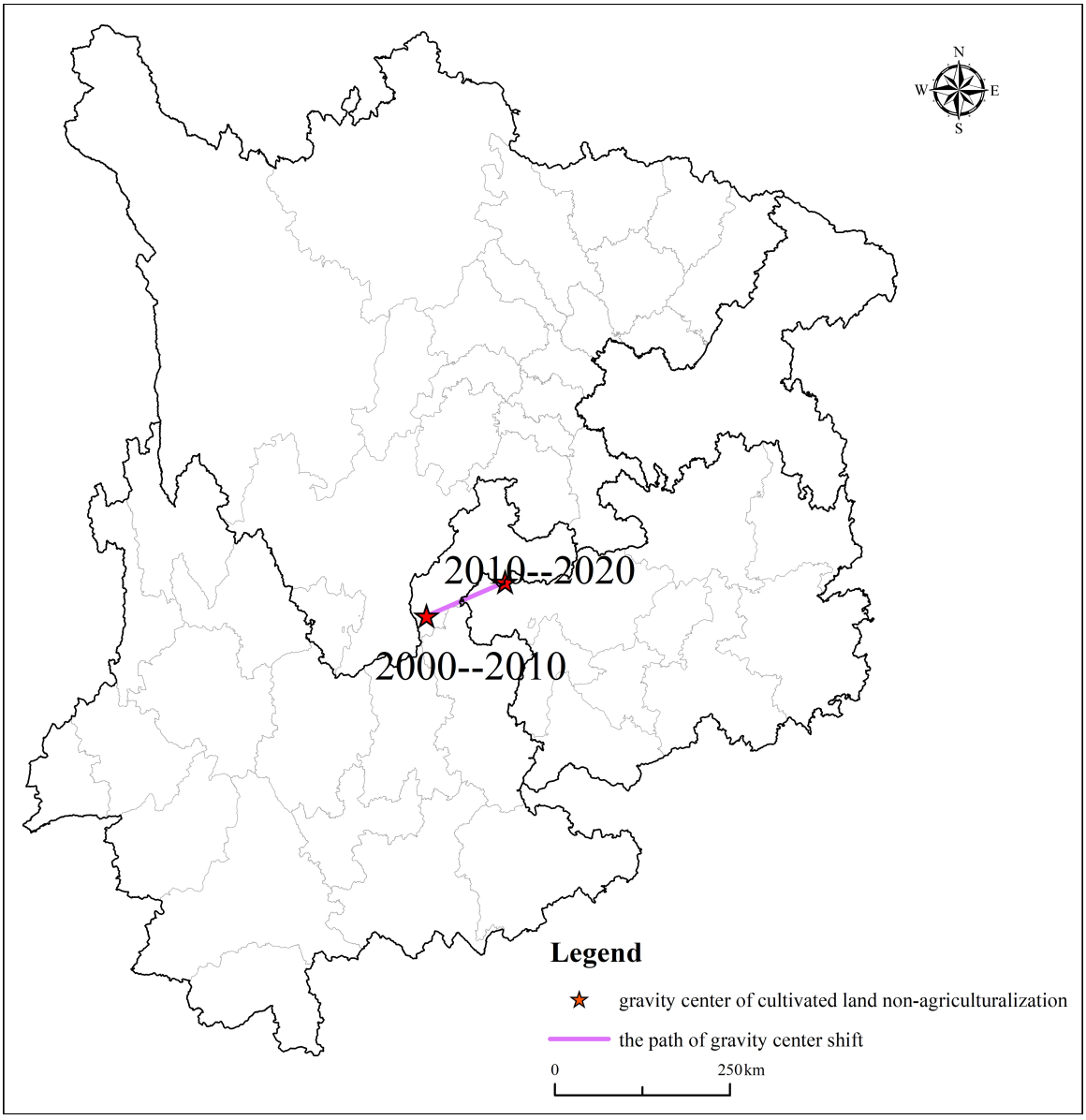



**Figure 6.** The pathway of non-agricultural gravity shift of cultivated land.

### *3.2. Drivers of Cultivated Land Non-Agriculturalization*

#### 3.2.1. Factor Detection Analysis

We used factor detection to explore the impact of drivers on the non-agriculturalization of cultivated land in this section, and the results of factor detection analysis are shown in Table 4. As can be seen from Table 4, the main driving factors of cultivated land non-agriculturalization between 2000 and 2010 were population density ($X1$) > the total retail sales of social consumer goods ($X8$) > GDP per capita ($X2$) > GDP per unit of land ($X7$) > total agricultural machinery power ($X9$) > the GDP share of primary industry($X3$).

The leading factors of cultivated land non-agrarianization in 2010–2020 were the total retail sales of social consumer goods (*X*8) > population density (*X*1) > GDP per capita (*X*2) > GDP per unit of land (*X*7) > cultivated land area (*X*5) > cultivated land area per capita (*X*6). The population density, total retail sales of consumer goods, GDP per capita, and GDP per unit of land were consistently the main driving factors of cultivated land non-agriculturalization throughout the study period. The results of the factor detection show a high degree of consistency in the spatial distribution of regional economic development, population density, land productivity and the non-agriculturalization of cultivated land. Industrial structure and real estate investment are the main factors of cultivated land non-agriculturalization for cities with high development level, while economic growth and urbanization are the main driving factors of cultivated land non-agriculturalization for small-sized or medium-sized cities, which are still at an early stage of development [39]. The prefecture-level cities in southwest China shared similar locational conditions and development situations. The development level of cities in southwest China was relatively low compared with cities in the east, consequently, economic development was still the core driving factor of cultivated land non-agriculturalization.

**Table 4.** Factor detection results of the cultivated land non-agriculturalization driving factors.

| Factor Sorting | *q* Values (2000–2010) | Factor Sorting | *q* Values (2010–2020) |
|---|---|---|---|
| *X*1 | 0.448 | *X*8 | 0.727 |
| *X*8 | 0.422 | *X*1 | 0.394 |
| *X*2 | 0.317 | *X*2 | 0.363 |
| *X*7 | 0.308 | *X*7 | 0.200 |
| *X*9 | 0.153 | *X*5 | 0.174 |
| *X*3 | 0.104 | *X*6 | 0.118 |
| *X*10 | 0.061 | *X*9 | 0.112 |
| *X*4 | 0.052 | *X*3 | 0.109 |
| *X*5 | 0.050 | *X*4 | 0.074 |
| *X*6 | 0.020 | *X*10 | 0.046 |
| *X*11 | 0.019 | *X*11 | 0.021 |

#### 3.2.2. Interaction Detection Analysis

The interaction detector is used to identify interactions between different explanatory variables which can detect whether multiple factors acting together increase or decrease the explanatory power of the dependent variable. Figure 7 presents the interaction detection results. The results manifest that each interaction detection showed a two-factor enhancement or non-linear enhancement for 2000–2010 and 2010–2020, suggesting that the non-agriculturalization of cultivated land in southwest China was the result of the combined effect of multiple factors. There were similar interaction detection results for both study periods. As an example, the effect of population density on cultivated land non-agriculturalization was strengthened after interacting with cultivated land area, GDP per unit of land and total agricultural machinery power in both study periods. The *q* value between GDP per capita and total agricultural machinery power was the strongest at 0.908, followed by GDP per unit of land and total agricultural machinery power with a *q* value of 0.849, and then by GDP per unit of land and population density with a *q* value of 0.847 during the period 2000–2010. The post-interaction *q*-values of total retail sales of social consumer goods and other factors all exceeded 0.7, especially the post-interaction *q*-value of total retail sales of social consumer goods and GDP per unit of land reached 0.893 from 2010 to 2020. In addition, population density had a q value above 0.6 after interacting with other factors, demonstrating that the non-agriculturalization of cultivated land was highly sensitive to the increase in total retail sales of social goods and population. The results of the interaction detection reveal that the influence of all factors increases when they were superimposed. This indicates that these factors did not act independently to affect the non-agriculturalization of cultivated land, but had an enhanced impact when combined with other factors.

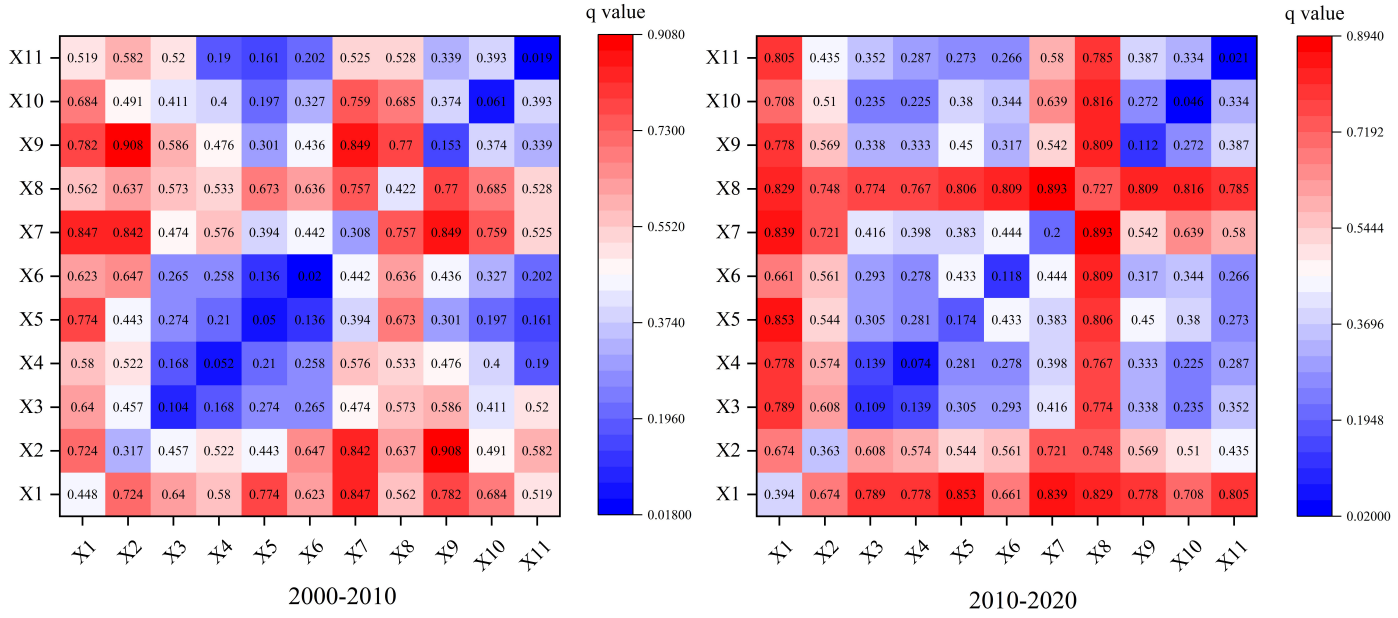



**Figure 7.** Interaction detection results in driving factors of cultivated land non-agriculturalization.

## 4. Discussion

### *4.1. Comparison with Other Studies*

The results reveal that the cultivated land area in the study region decreased from 31.866 million $hm^2$ to 31.183 million $hm^2$ from 2000 to 2020, with a 2.143% non-agriculturalization rate of cultivated land. The area of non-agricultural land went through a process of flat growth followed by a dramatic increase. The results of relevant research demonstrate that the area of cultivated land in the Wuhan urban area decreased from 141.924 million $hm^2$ to 131.926 million $hm^2$ from 1992 to 2007, and the rate of cultivated land non-agriculturalization reached 7.04% [40]. The area of cultivated land non-agriculturalization in the three northeastern provinces reached 165.99 million $hm^2$, and the rate of cultivated land non-agriculturalization reached 1.01% from 1993 to 2003 [41]. There was an obvious spatial variability in the occupation of cultivated land by construction land in the various regions of the country. The low economic efficiency of food cultivation and the increase in the amount of abandoned agricultural land and idle construction land had led to a 40% decrease in the cultivated land area of the Chengdu plain since 2010. Therefore, it is still widespread in the southwest that urbanization leads to the occupation of cultivated land for construction. Thus controlling the phenomenon of substantial occupation of cultivated land for construction and orderly reclamation are key measures for the protection of cultivated land in the southwest China.

### *4.2. Re-Conceptualization of the Cultivated Land Non-Agriculturalization*

In general, cultivated land protection is closely associated with food security. The Central Committee of the Communist Party of China and the State Council issued the Opinions on the Key Work of Comprehensively Promoting Rural Revitalization in 2022, proposing strict protection of cultivated land. We must resolutely prevent the non-agriculturalization of cultivated land. Furthermore, it is indispensable to ensure that cultivated land is used for grain production as a priority to guarantee national food security. Established studies have shown that the food self-sufficiency rate in China will decline from 95% to about 90% by 2035. However, consumer demand for staple foods tends to decline while the demand for livestock products, aquatic products, vegetables and fruits grows markedly [42,43]. Therefore, we should pour attention into the development of industries with high demand potential, such as animal husbandry, fruit and vegetable farming, to achieve the shift from ensuring grain security to ensuring food safety.

In addition, the proportion of cultivated land converted to forest land in the southwest expanded from 0.99% to 1.33%, due to the implementation of the Grain for Green policy and the rapid development of economic fruit forests between 2000 and 2020. The structure of the diet is changing to a more diverse one. Thus we should allow the production of "non-staple" crops that do not damage the cultivated layer and do not affect food production capacity to increase the flexibility of food cultivation and ensure food security.

### *4.3. Research Limitations*

This paper reclassified the global land cover data by using the CNLUCC classification system and categorized the artificial ground as construction land, which may be inaccurate. However, it can still reflect the spatial distribution and expansion process of construction land to a certain extent. We have selected only economic factors such as GDP per capita, but not enough natural factors such as soil and hydro-climatic characteristics were selected to explore the driving factors of cultivated land non-agriculturalization. In addition, the land systems and agricultural factors have not yet been addressed. However, the influence of natural factors on the non-agriculturalization of cultivated land often takes a prolonged period and is often expressed through socio-economic conditions. Thus selecting topography and some socio-economic indicators can still be a relatively good method to explore the driving factors of cultivated land non-agriculturalization.

## 5. Conclusions and Implications

### *5.1. Conclusions*

Firstly, we explored the spatiotemporal evolution of cultivated land non-agriculturalization in southwest China based on the global land cover data from 2000 to 2020. Secondly, we analyzed the shift of the gravity center for cultivated land non-agriculturalization in the study area. Finally, we discussed the driving factors of cultivated land non-agriculturalization and drew the following conclusions.

The non-agriculturalized area of cultivated land was $15.82 \times 10^4$ $hm^2$ from 2000 to 2010 and it rapidly grew to $87.03 \times 10^4$ $hm^2$ from 2010 to 2020. Spatially, the non-agriculturalization of cultivated land mainly occurred in regions with high urbanization levels, such as eastern Sichuan Province and western Chongqing Municipality, while the non-agriculturalization of cultivated land in other regions was small-scale and spatially dispersed. Chongqing and Chengdu had a much larger area of non-agricultural cultivated land than other prefecture-level cities, and the non-agriculturalization of cultivated land was consistently at a comparatively high level from 2000 to 2020. The speed index of cultivated land non-agriculturalization presents a spatially non-uniform. The three provincial capitals of Chengdu, Kunming, Guiyang, and Chongqing Municipality were all in a high rank of cultivated land non-agriculturalization. The gravity center of cultivated land non-agriculturalization moved from Zhaotong City in Yunnan Province to Bijie City in Guizhou Province, with the direction of movement roughly northeastward and a distance of 123.21 km. The non-agriculturalization of cultivated land was influenced by a multitude of factors. GDP per capita, total retail sales of consumer goods, GDP per unit of land, and population density had the most significant effects on the non-agriculturalization of cultivated land, indicating that economic development was the dominant driving factor of cultivated land non-agriculturalization in the study area.

The non-agriculturalization of cultivated land is related to the sustainable use of resources. In addition, the governance of the non-agriculturalization of cultivated land is a key area for relieving pressure on global food systems. This study explored the spatial and temporal evolution and gravity center shift of cultivated land non-agriculturalization in a typical region of southwest China, revealing the regional variability of cultivated land non-agriculturalization and providing a scientific reference for the conservation and management of cultivated land in other regions, and it is of great significance for ensuring food security as well as the sustainable use of resources. The non-agriculturalization of cultivated land is not only present in southwest China but is also widespread in other

parts of the globe, and the methodology and results of this study can be further applied to studies in China or other parts of the world.

### *5.2. Policy Implications*

Cultivated land is an essential foundation for food production. However, the phenomenon of cultivated land non-agriculturalization remains serious in southwest China due to urbanization. The economic circle in the Chengdu–Chongqing region is an influential economic center in the western region whose position in the national economic strategy pattern is increasingly elevated. It also assumes the crucial task of leading the development of the southwestern region. In the future, we should strictly control the massive occupation of cultivated land by urban and rural construction land. Ensuring that cultivated land is mainly used for agricultural products such as grain, cotton, oil, sugar, vegetables and fodder production to guarantee food security in Southwest China.

Southwest China has complex terrain and highly fragmented cultivated land. Accordingly, promoting small-scale machinery in mountainous areas and developing high-end intelligent machinery are powerful means to prevent the non-agriculturalization of cultivated land in southwest China. At the same time, we can develop the policy of subsidizing the purchase and application of agricultural machinery to improve the benefits of farming in southwest China.

We should lay out intensive livestock and fruit and forestry industries in the hilly areas appropriately. It can not only save the cultivated land in the main grain-producing areas, but also the manure and fertilizer produced by animal husbandry can be used for forestry and fruit cultivation in the vicinity. Appropriate development of livestock breeding and fruit industries in the mountainous areas of southwest China can alleviate the problem of low economic benefits of grain production due to fragmentation of cultivated land, and at the same time, it can meet the current consumer demand for livestock products, vegetables and fruits and increase the profitability of agriculture.

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