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The Non-Agriculturalization of Cultivated Land in Karst Mountainous Areas in China

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Abstract: When used for agricultural production, karst mountainous areas are susceptible to soil degradation due to the effects of soluble rocks and the climate. To mitigate the risk, the Grain for Green Project, a sizable initiative, was commenced to transition cultivated land away from agricultural use. This conversion of cultivated land to non-agricultural land has been significant. The study area considered in this research included four small towns in southwest China in karst mountainous areas with various morphologies. The investigation of the non-agriculturalization of cultivated land in the four sample areas revealed that the non-agriculturalization rate of cultivated land as a result of the Grain for Green Project has reached between 21.36% and 51.43% each decade. Thus, the Grain for Green Project has been advantageous for lowering the landscape ecological risk. Furthermore, because an increasing number of agricultural production materials have been introduced to the cultivated land, the conversion from cultivated land to non-agricultural land has not caused a staple food crisis on the national scale. However, it is impossible to observe all the potential drawbacks of the non-agriculturalization of cultivated land from satellite photos alone, and further social data collection is required. The findings of this study can offer precise information for policymaking in relation to the protection of rural cultivated land and rural spatial optimization in karst mountainous areas.

Keywords: non-agriculturalization rate; ecological risk; cultivated land change; landform; land management

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1. Introduction

Cultivated land resources are the foundation of rural development and provide residents with important basic living materials such as grain, vegetables, and oilseeds [1,2]. However, with the occurrence of rapid urbanization and industrialization worldwide, an increasing amount of rural agricultural land is occupied by non-agricultural land (such as residential land, roads, industrial land, etc.) [3,4]. The serious non-agriculturalization of cultivated land has caused problems such as food crises and the intensification of social contradictions. This has been demonstrated in studies conducted in China, Iran, and Indonesia [5–7]. As a result, the issue of the non-agriculturalization of cultivated land has been the focus of study in the fields of land science and rural sustainable development [8,9].

Many scholars have conducted research on the quantitative evaluation of the non-agriculturalization of cultivated land, the influence of the non-agriculturalization of cultivated land on the social economy, and the driving mechanism and management measures of cultivated land conversion [10–12]. Questionnaire surveys, spatial autocorrelation, and gravity models are widely used in the quantitative evaluation of the non-agriculturalization of cultivated land [13,14]. Studies have shown that the non-agriculturalization of cultivated land provides a spatial condition for urbanization and industrialization, but also leads to a decline in the amount of cultivated land and food shortages, ultimately resulting in an increasingly intensifying contradiction between food security and economic development [15,16]. Urbanization, industrialization, economic benefits, and national management policy are the driving factors of the non-agriculturalization of cultivated land at the macro scale [17–19]. The livelihood changes and income levels of farmers due to cultivated land conversion play an important role in non-agriculturalization at the micro scale [20,21]. In addition, numerous studies have found that the reform of land administration systems and the promotion of "compact" urban development can effectively alleviate the conversion of cultivated land to non-agricultural land [9,22]. Current research focuses on suburbs or rural areas characterized by rapid economic development, whereas there is little concern for underdeveloped rural mountainous areas. Moreover, the conversion of cultivated land to non-agricultural land strongly changes the land-use structure, which changes the rural ecological environment. However, the impact of the non-agriculturalization of cultivated land on the ecological environment has not yet been reported. Due to the interference of various complex human activities, developing countries with rapid economic development face the serious non-agriculturalization of cultivated land, which has a profound impact on food security.

As the most populous country in the world, China's cultivated land resources are relatively scarce, and the protection of cultivated land is an important task for land resource management [23]. Under the influence of China's rapid economic development, the problem of the non-agriculturalization of cultivated land caused by its occupation by built-up land is very prominent [11]. Simultaneously, blind deforestation and cultivation on steep slopes have caused serious soil erosion and frequent natural disasters in China over the past few decades. The Grain for Green Project, which was initiated in 2000 and aims to improve the quality of the ecological environment, has been implemented against the backdrop of the continuous rise in the national yield for staple grains. It encourages the conversion of a significant portion of sloping cultivated land to ecological land (forestland, shrubland, and grassland), which exacerbates the non-agriculturalization of cultivated land [15,24]. The Grain for Green Project has been primarily implemented in the karst mountainous regions of southwestern China, which are typical ecologically sensitive areas [25]. Furthermore, the rural economy in karst mountainous areas has significantly improved as a result of the influence of western development policies [26]. However, the lack of land resources in karst mountainous areas has caused a significant proportion of rural labor to migrate to cities, thereby disrupting the stability of the cultivated land landscape (such as cultivated land abandonment) and altering the ability of karst mountainous areas to maintain their natural landscapes. Furthermore, cultivated land has been converted into other high-yield non-agricultural land as a result of the conversion of farmers' livelihoods and the decrease in economic income from cultivated land [27,28]. While the quantification of land-use changes would aid in the understanding of the general characteristics of the conversion between different land-use types, it would not explain the mechanism by which cultivated land is converted to non-agricultural land, especially on a small scale.

According to the dominant landform types, four townships in southwestern China's Guizhou Province with different landform types were selected as typical representatives. The objectives of this study include the following: (1) to quantify the rate of conversion of cultivated land to non-cultivated land in karst mountainous areas; (2) to explore the slope gradient and spatial heterogeneity of the non-agriculturalization of cultivated land in karst mountainous areas; and (3) to analyze the correlation between the non-agriculturalization of cultivated land and landscape ecological risk. This study provides a reference for the protection of cultivated land and may help to clarify tradeoffs between the societal targets of land and the impacts of land-use changes in karst mountainous areas.

2. Materials and Methods

2.1. Overview of the Study Area

Karst landforms are a variety of surface and underground forms created by the long-term dissolution of soluble rocks by water. Due to the rugged terrain, thin soil, and shortage of surface water resources in karst landform areas, ecological fragility is prominent, the response to the interference of outside factors is weak, ecological restoration is difficult, and the population carrying capacity is low. The types of small-scale landforms in the karst mountainous areas of China are diverse, and there are heterogeneities in human activities and the natural conditions of different landforms; this results in differences in the land-use structures and their spatial patterns in different landform types [29]. According to the main landform types of karst mountainous areas in southwestern China, four typical townships in Guizhou Province with different landform types (Longchang with a karst mid-mountain landform, Liuguan with a karst basin landform, Xianchang with a karst trough valley landform, and Minxiao with a karst low hilly landform) were selected as the research areas (Figure 1). The altitude of Longchang with a karst mid-mountain landform is between 1283 and 2581 m, and the terrain relief is large. The altitude of Liuguan with a karst basin landform is between 1226 and 1382 m, the terrain in the central and eastern parts of this town is relatively flat, and there are low mountains in the southern and northern parts of the town. The altitude of Xianchang with a karst trough valley landform is between 758 and 1283 m, the central part of the town is a flat valley, and the eastern and western parts are high-altitude mountains. The altitude of Minxiao with a karst low hilly landform is between 758 and 1283 m. The town is located near the Fanjingshan Nature Reserve. In addition, as typical ecologically fragile areas in western China, the four selected towns belong to China's important ecological restoration areas, and the Grain for Green Project has been continuously implemented in this area for more than 20 years. Moreover, under the influence of poverty alleviation and resource development, the economy of karst mountainous areas has developed rapidly, and the per capita income reached 1715 USD/year by the end of 2020. However, compared with eastern China, the karst mountainous areas are still economically underdeveloped and suffer serious population loss [30].

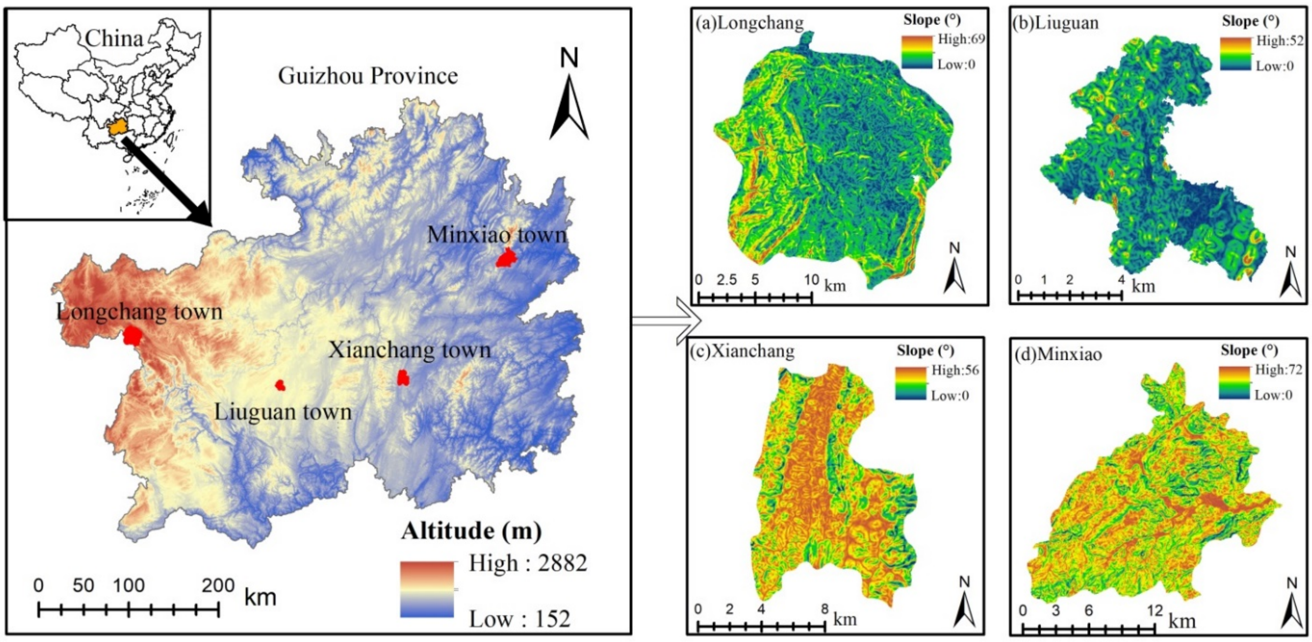

Figure 1. The locations of the four selected towns in karst mountainous areas. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

2.2. Data Sources and Processing

Two types of high-resolution remote sensing data from 2010 and 2020 were collected in this study, including SPOT remote sensing images (from March to November 2010) with a 5 m spatial resolution and Pleiades remote sensing images (from April to October 2020) with a 1 m spatial resolution. Image preprocessing was performed via geometric correction, image registration, image mosaic, and cutting. Due to the fuzzy boundaries between land-use types in the remote sensing images, it would be difficult for computer classification methods (such as supervised or unsupervised classification methods) to obtain good classification results. Therefore, the artificial visual interpretation of remote sensing images was adopted in this study. The detailed steps were as follows. First, the interpretation indicators of various land-use types were established via preliminary image interpretation and field investigation. Then, the images in 2010 and 2020 were visually interpreted, and the land use was divided into seven types: cultivated land, forestland, shrub-grassland, built-up land, roads, water bodies, and unused land (Figure 2). Finally, 400 field points were selected to evaluate the accuracy of the classification results. After the accuracy test, the mapping accuracy was found to exceed 89.16%, which indicates that the classification results were good and met the accuracy requirements of land data. Elevation data with a resolution of 30 m were downed from the platform of the Geospatial Data Cloud, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn, accessed on 18 August 2022). The slope analysis tool in ArcGIS software was used to generate slope data based on the elevation data, and the slope data were divided into five gradients via the quantile method (Table 1).

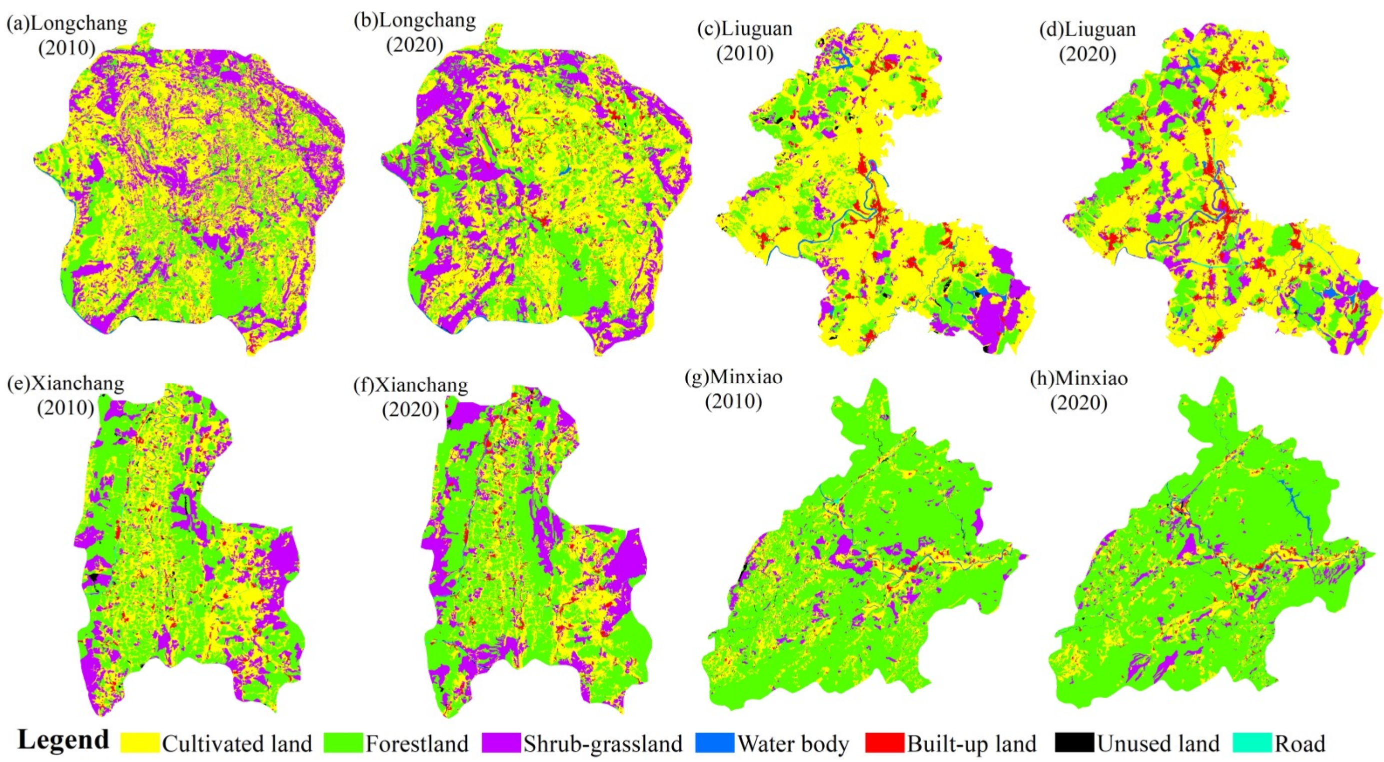

Figure 2. The distribution of land-use types. (**a**) Longchang in 2010,(**b**) Longchang in 2020, (**c**) Liuguan in 2010, (**d**) Liuguan in 2020, (**e**) Xianchang in 2010, (**f**) Xianchang in 2020, (**g**) Minxiao in 2010, (**h**) Minxiao in 2020.

Table 1. The slope classification of the karst mountainous areas.

Towns	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Longchang (karst mid-mountain)	0°–9.01°	9.02°–13.42°	13.43°–18.38°	18.39°–25.65°	25.66°–69.67°
Liuguan (karst basin)	0°–2.71°	2.72°–4.69°	4.70°–6.85°	6.86°–9.97°	9.98°–51.68°
Xianchang (karst trough valley)	0°–5.54°	5.55°–9.25°	9.26°–13.61°	13.62°–19.78°	19.79°–55.94°
Minxiao (karst low hilly)	0°–10.05°	10.06°–15.87°	15.88°–21.31°	21.32°–27.95°	27.96°–72.30°

2.3. Methods

2.3.1. Land-Use Change Matrix

In this study, the land-use change matrix is introduced to reflect the dynamic process of the reciprocal transformation between the areas of various land-use types at the beginning and end of a certain period. Its formula is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix} \tag{1}$$

where S_{ij} represents the area converted from land-use type i to land use type j, n is the number of land-use types, and i and j represent the land-use types before and after the conversion, respectively.

2.3.2. Calculation Method of the Non-Agriculturalization of Cultivated Land

In this study, land-use types other than cultivated land are defined as non-cultivated land-use types (namely, forestland, shrub-grassland, built-up land, roads, water bodies, and unused land). Because forestland, shrub-grassland, water bodies, and unused land are crucial to the ecological environment, these land-use types are collectively referred to as ecological land in this article. Similarly, built-up land and roads are land-use types formed by human activities and have become the main space of human life. Therefore, they are collectively referred to as living land. Based on the preceding analysis, in this study, the non-agriculturalization of cultivated land is defined as the conversion of cultivated land into non-cultivated land-use types. It is composed of two parts: (1) the conversion of cultivated land into ecological land (forestland, shrub-grassland, water bodies, and unused land), and (2) the conversion of cultivated land into living land (built-up land and roads). Based on the data, the rate of conversion of cultivated land to non-cultivated land is calculated as follows:

$$N_e = W_i / G_j \times 100\% \tag{2}$$

$$N_l = L_i / G_j \times 100\% \tag{3}$$

$$N = N_e + N_l \tag{4}$$

where N represents the rate of conversion from cultivated land to non-cultivated land, N_e is the rate of conversion from cultivated land to ecological land (forestland, shrub-grassland, water bodies, and unused land), N_l is the rate of conversion from cultivated land to living land (built-up land and roads), W_i is the area of cultivated land converted to ecological land from 2010 to 2020, L_i is the area of cultivated land converted to living land from 2010 to 2020, and G_j is the area of cultivated land in 2010.

The area of cultivated land converted to non-cultivated land is calculated by the spatial analysis tool in ArcGIS. In addition, to achieve the clear spatial expression of the non-agriculturalization of cultivated land, the spatial pattern of the non-agriculturalization of cultivated land from 2010 to 2020 was presented by using the grid tool in ArcGIS.

2.3.3. Calculation Method of Landscape Ecological Risk

The calculation model of landscape ecological risk is established by considering the landscape disturbance index and landscape loss index. The landscape disturbance index represents the degree of external disturbance to different landscapes, which is calculated by the landscape separation index, dominance index, and fragmentation index. The landscape loss index represents the loss degree of landscape types under the interference of various factors.

$$U_i = bC_i + cF_i + aD_i \tag{5}$$

$$C_i = n_i / A_i \tag{6}$$

$$F_i = 0.5\sqrt{\frac{n_i}{A}} / \frac{A_i}{A} \tag{7}$$

$$D_i = 0.25 \times (n_i / N + m_i / M) + 0.5 \times A_i / A \tag{8}$$

where C_i represents the landscape fragmentation degree, F_i is the landscape separation degree, D_i is the landscape dominance degree, and the values of a, b, and c are, respectively, assigned as 0.5, 0.3, and 0.2 according to the expert scoring method. Moreover, N_i and N are, respectively, the numbers of patches in landscape i, and all landscape types, A_i and A are, respectively, the patch areas in landscape i and all landscape types, and M_i and M are, respectively, the number of grids in landscape i and the total number of grids.

$$R_i = U_i \times Q_i \tag{9}$$

where U_i represents the landscape disturbance index, and Q_i is the landscape vulnerability index. According to experts' experience, water bodies and unused land are the most vulnerable to external disturbances and have a vulnerability index of 5. Built-up land and roads are stable and have a vulnerability index of 1. Finally, cultivated land, shrub-grassland, and forestland have vulnerability indexes of 4, 3, and 2, respectively.

Based on the area ratio of various landscape types in each grid, the calculation model of the landscape ecological risk index is established as follows:

$$ERI_i = \sum_{i=1}^{n} \frac{A_i}{A} \times R_i \tag{10}$$

where ERI_i represents the landscape ecological risk index, A_i is the area of landscape i, A is the area of all landscape types, and R_i is the landscape loss index of landscape i.

The grid tool in ArcGIS software was used to divide Longchang, Liuguan, Xianchang, and Minxiao into 167, 157, 148, and 160 grids, respectively. Then, the landscape ecological risk index of each grid was calculated to obtain the risk value of the sample center, and the spatial pattern map of landscape ecological risk was generated by using the spatial interpolation tool in ArcGIS software. The landscape indices (N_i, N, A_i, and A in Equation (10)) required for landscape ecological risk calculation were obtained by Fragstats 4.2 software.

2.3.4. Correlation between the Non-Agriculturalization of Cultivated Land and Landscape Ecological Risk

The global and local Moran's indices were introduced to analyze the spatial correlation between the non-agriculturalization of cultivated land and landscape ecological risk. The global Moran's index was used to determine the correlation between the non-agriculturalization of cultivated land and landscape ecological risk in the whole research area. The local Moran's index was used to identify the distribution of the types of spatial agglomeration between the non-agriculturalization of cultivated land and landscape ecological risk in local areas (i.e., within the demarcated grid).

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}(x_i - \overline{x})^2} \quad (11)$$

$$I_i = \frac{(x_i - \overline{x})}{S^2}\sum_{j=1}^{n} W_{ij}(x_j - \overline{x}) \quad (12)$$

where I and I_i are, respectively, the global and local Moran's indices, and X_i and X_j are, respectively, the values of the non-agriculturalization of cultivated land and landscape ecological risk in spatial units i and j. Moreover, $\overline{x}$ is the average value of the non-agriculturalization of cultivated land and landscape ecological risk of all spatial units, W_{ij} is the spatial weight, and S^2 is the variance of the non-agriculturalization of cultivated land and the landscape ecological risk value of each spatial unit.

A value of I greater than 0 indicates that there is a positive spatial correlation between the two variables. The larger the value, the more obvious the spatial agglomeration. A value of I less than 0 indicates a negative spatial correlation. If the value of I is equal to 0, there is no correlation between the two variables. According to the calculation results of I_i, the agglomeration types of the study area were divided into high-high, low-low, high-low, low-high, and not significant areas.

3. Results

3.1. Land-Use Change Matrix

From 2010 to 2020, the increased area of cultivated land in the four towns mainly resulted from shrub-grassland and forestland, while the decreased area of cultivated land was mainly converted to shrub-grassland, forestland, and built-up land. The transition area between cultivated land, forestland, and shrub-grassland in the four towns was large, whereas the transition area in water bodies and unused land was small. The increased area of built-up land and roads mainly resulted from cultivated land (Table 2).

3.2. Changes in the Non-Agriculturalization of Cultivated Land

Based on Equations (3)–(5), the rate of conversion from cultivated land to non-cultivated land was obtained, as reported in Table 3. The total rate of conversion from cultivated land to non-cultivated land in Xianchang with a karst trough valley landform was found to be higher than that in Minxiao with a karst low hilly landform. The total rates of conversion from cultivated land to non-cultivated land in Longchang with a karst mid-mountain landform and Liuguan with a karst basin landform were found to be lower than those in the other two towns. The rate of conversion from cultivated land to ecological land, in descending order, was found to be that of Xianchang, Minxiao, Longchang, and Liuguan. The rates of conversion of cultivated land to living land in Minxiao, Xianchang, and Liuguan were found to be higher than that in Longchang (Table 3).

Table 2. The land-use change matrix from 2010 to 2020 (hm^2).

Town	Land Use Types	Cultivated Land	Forestland	Shrub-Grassland	Water Bodies	Built-Up Land	Unused Land	Roads	Total Area in 2010
Longchang (karst mid-mountain)	Cultivated land	8674.70	951.97	2224.76	5.06	238.76	5.41	95.22	12,195.88
	Forestland	832.35	4422.79	746.47	3.29	142.01	1.87	35.61	6184.39
	Shrub-grassland	1718.58	1705.13	3130.53	14.76	121.64	10.35	51.82	6752.81
	Water bodies	7.47	6.57	9.82	60.02	0.08	0.80	0.53	85.29
	Built-up land	76.19	26.38	29.76	0.01	287.60	1.14	8.44	429.52
	Unused land	6.80	0.62	2.81	10.80	0.52	2.44	0.82	24.82
	Roads	97.01	39.61	33.77	0.88	17.73	0.71	132.96	322.67
	Total area in 2020	11,413.10	7153.07	6177.92	94.82	808.34	22.72	325.40	25,995.38
Liuguan (karst basin)	Cultivated land	1818.86	251.98	255.48	14.26	78.34	0.59	34.25	2453.75
	Forestland	119.61	542.28	105.39	2.18	10.86	0.79	3.23	784.34
	Shrub-grassland	204.60	95.36	143.36	1.91	4.72	0.00	3.89	453.83
	Water bodies	15.17	2.83	11.05	33.56	0.49	0.00	1.08	64.18
	Built-up land	20.47	10.22	11.39	0.71	104.61	0.04	1.15	148.58
	Unused land	6.77	6.52	13.93	0.30	0.17	0.03	0.16	27.88
	Roads	0.65	0.05	0.12	0.03	0.45	0.00	27.67	28.96
	Total area in 2020	2186.12	909.24	540.71	52.95	199.62	1.45	71.43	3961.52
Xianchang (karst trough valley)	Cultivated land	1520.95	1221.56	530.27	22.65	140.81	6.60	21.49	3464.34
	Forestland	655.70	2954.71	765.72	5.46	43.28	8.49	19.17	4452.53
	Shrub-grassland	234.41	808.00	992.40	0.77	16.96	3.62	4.51	2060.67
	Water bodies	25.27	8.56	2.82	2.87	3.55	0.21	0.19	43.46
	Built-up land	79.20	64.10	23.92	2.23	69.10	0.98	4.04	243.57
	Unused land	6.91	16.31	22.15	0.01	0.78	0.65	1.33	48.13
	Roads	5.40	9.13	6.33	0.25	5.65	0.16	48.35	75.27
	Total area in 2020	2527.83	5082.36	2343.61	34.24	280.12	20.71	99.08	10,387.96
Minxiao (karst low hilly)	Cultivated land	2532.27	1087.71	329.43	47.16	150.23	9.98	93.33	4250.11
	Forestland	443.17	17774.27	667.29	43.65	64.10	12.08	85.10	19,089.67
	Shrub-grassland	119.29	1129.55	343.23	8.08	5.31	0.23	7.62	1613.31
	Water bodies	21.11	13.65	12.93	95.73	3.31	0.85	4.51	152.09
	Built-up land	29.60	21.26	8.68	1.70	210.11	0.81	9.72	281.89
	Unused land	6.87	19.86	18.26	3.95	1.29	1.54	3.11	54.88
	Roads	19.97	27.37	12.81	4.23	5.92	0.33	62.42	133.06
	Total area in 2020	3172.28	20,073.68	1392.63	204.50	440.26	25.82	265.83	25,575.00

Table 3. The overall characteristics of the rate of conversion from cultivated land to non-cultivated land from 2010 to 2020 (%).

Town	Rate of Conversion from Cultivated Land to Ecological Land	Rate of Conversion from Cultivated Land to Living Land	Total Rate of Conversion from Cultivated Land to Non-Cultivated Land
Longchang (karst mid-mountain)	26.02	2.71	28.73
Liuguan (karst basin)	21.36	4.55	25.91
Xianchang (karst trough valley)	51.43	4.72	56.15
Minxiao (karst low hilly)	34.69	5.59	40.28

Note: Ecological land includes forestland, shrub-grassland, water bodies, and unused land. Living land includes built-up land and roads. Non-cultivated land includes ecological land and living land.

With the increase of the slope gradient (from gradient I to V), the rate of conversion of cultivated land to non-cultivated land was found to increase in Longchang with a karst mid-mountain landform and Liuguan with a karst basin landform but decreased in Xianchang with a karst trough valley landform and Minxiao with a karst low hilly landform. The rate of conversion of cultivated land to living land in the four towns with different landforms was found to decrease from slope gradient I to V. The change characteristics of the rate of conversion from cultivated land to ecological land in Longchang and Liuguan were found to be contrary to those in Xianchang and Minxiao from gradient I to V (Table 4).

Table 4. The slope gradient characteristics of the non-agriculturalization of cultivated land from 2010 to 2020 (%).

Town	Conversion Types	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Longchang (karst mid-mountain)	Rate of conversion from cultivated land to ecological land	3.25	3.77	4.67	6.33	8.00
	Rate of conversion from cultivated land to living land	0.79	0.69	0.54	0.44	0.25
	Total rate of conversion from cultivated land to non-cultivated land	4.04	4.45	5.20	6.77	8.25
Liuguan (karst basin)	Rate of conversion from cultivated land to ecological land	2.78	3.61	4.20	5.15	5.63
	Rate of conversion from cultivated land to living land	1.27	1.05	1.02	0.61	0.59
	Total rate of conversion from cultivated land to non-cultivated land	4.04	4.66	5.22	5.76	6.22
Xianchang (karst trough valley)	Rate of conversion from cultivated land to ecological land	12.44	12.43	10.81	8.77	6.98
	Rate of conversion from cultivated land to living land	2.16	1.38	0.75	0.28	0.14
	Total rate of conversion from cultivated land to non-cultivated land	14.60	13.81	11.56	9.05	7.12

Table 4. *Cont.*

Town	Conversion Types	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Minxiao (karst low hilly)	Rate of conversion from cultivated land to ecological land	10.81	9.49	7.24	5.10	2.04
	Rate of conversion from cultivated land to living land	3.38	1.15	0.63	0.33	0.10
	Total rate of conversion from cultivated land to non-cultivated land	14.19	10.64	7.87	5.43	2.14

Note: Ecological land includes forestland, shrub-grassland, water bodies, and unused land. Living land includes built-up land and roads. Non-cultivated land includes ecological land and living land. The slope is divided into five gradients (from gradient I to V) according to the slope value from lowest to highest.

The rate of conversion from cultivated land to forestland in Xianchang with a karst trough valley landform and Minxiao with a karst low hilly landform was found to be higher than those in Liuguan with a karst basin landform and Longchang with a karst mid-mountain landform. The rates of conversion from cultivated land to shrub-grassland in Minxiao and Liuguan were found to be lower than those in Longchang and Xianchang. The rates of conversion from cultivated land to water bodies and unused land in the four towns were found to be low. Moreover, the rates of conversion from cultivated land to built-up land and roads in Minxiao, Xianchang, and Liuguan were found to be higher than those in Longchang (Table 5).

Table 5. The rate of conversion from cultivated land to each non-cultivated land type from 2010 to 2020 (%).

Conversion Type	Longchang (Karst Mid-Mountain)	Liuguan (Karst Basin)	Xianchang (Karst Trough Valley)	Minxiao (Karst Low Hilly)
Conversion to forestland	7.81	10.27	35.26	25.59
Conversion to shrub-grassland	18.24	10.41	15.31	7.75
Conversion to water bodies	0.04	0.58	0.65	0.91
Conversion to unused land	0.04	0.02	0.19	0.23
Conversion to built-up land	1.96	3.19	4.06	3.53
Conversion to roads	0.78	1.40	1.62	2.20

The high-value area of the non-agriculturalization rate (>20%) in Longchang is concentrated in the western part, while the low-value area (<10%) is concentrated in the eastern and southern parts (Figure 3a). The high-value area of the non-agriculturalization rate (>20%) in Liuguan is widely distributed and mainly located in the western, northern, and central parts, while the areas with a non-agriculturalization rate of less than 20% are scattered (Figure 3b). The high-value area of the non-agriculturalization rate (>20%) in Xianchang is mainly distributed in the central part, and the non-agriculturalization rate in most of the eastern and western regions is less than 20% (Figure 3c). In most areas of Minxiao, the non-agriculturalization rate is less than 20%, and these regions are mainly located in the western, central, and southern areas (Figure 3d).

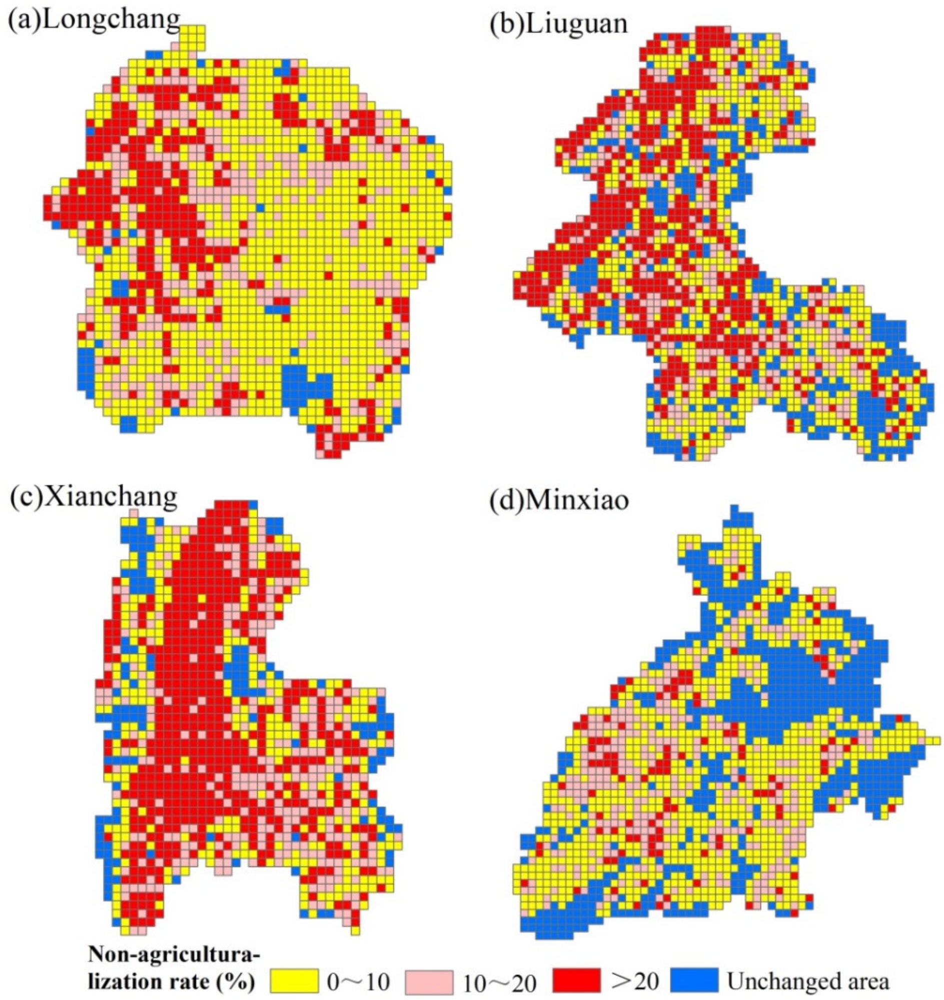

Figure 3. The spatial patterns of the non-agriculturalization of cultivated land from 2010 to 2020. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

3.3. Changes of Landscape Ecological Risk

Overall, the amounts of change of the landscape ecological risk in Longchang with a karst mid-mountain landform and Minxiao with a karst low hilly landform decreased from 2010 to 2020, while those in Liuguan with a karst basin landform and Xianchang with a karst trough valley landform increased. With the increase of the slope gradient, the amount of change of the landscape ecological risk index in the four towns was found to gradually decrease (Table 6).

Table 6. The changes of landscape ecological risk from 2010 to 2020.

Towns	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V	Total Area
Longchang (karst mid-mountain)	−1.4018	−1.2992	−1.1084	−0.8274	−0.4499	−1.0180
Liuguan (karst basin)	1.2768	1.0701	0.9876	0.9398	0.8968	1.0344
Xianchang (karst trough valley)	0.1763	0.133	0.0555	−0.0402	−0.0327	0.0606
Minxiao (karst low hilly)	−0.0626	−0.0549	−0.0447	−0.0322	−0.0247	−0.0373

Note: The slope is divided into five gradients (from gradient I to V) according to the slope value from lowest to highest.

Except for the southern part, most parts of Longchang experienced a decrease in landscape ecological risk, and the central part exhibited a significant decrease (Figure 4a). The landscape ecological risk increased in most parts of Liuguan, and the amount of increase of the landscape ecological risk in the southeastern part was higher than that in other parts (Figure 4b). The landscape ecological risk increased in the central part of Xianchang but decreased in the eastern and western parts (Figure 4c). The landscape ecological risk in Minxiao decreased in the western and eastern parts but increased in the southeastern and northern parts (Figure 4d).

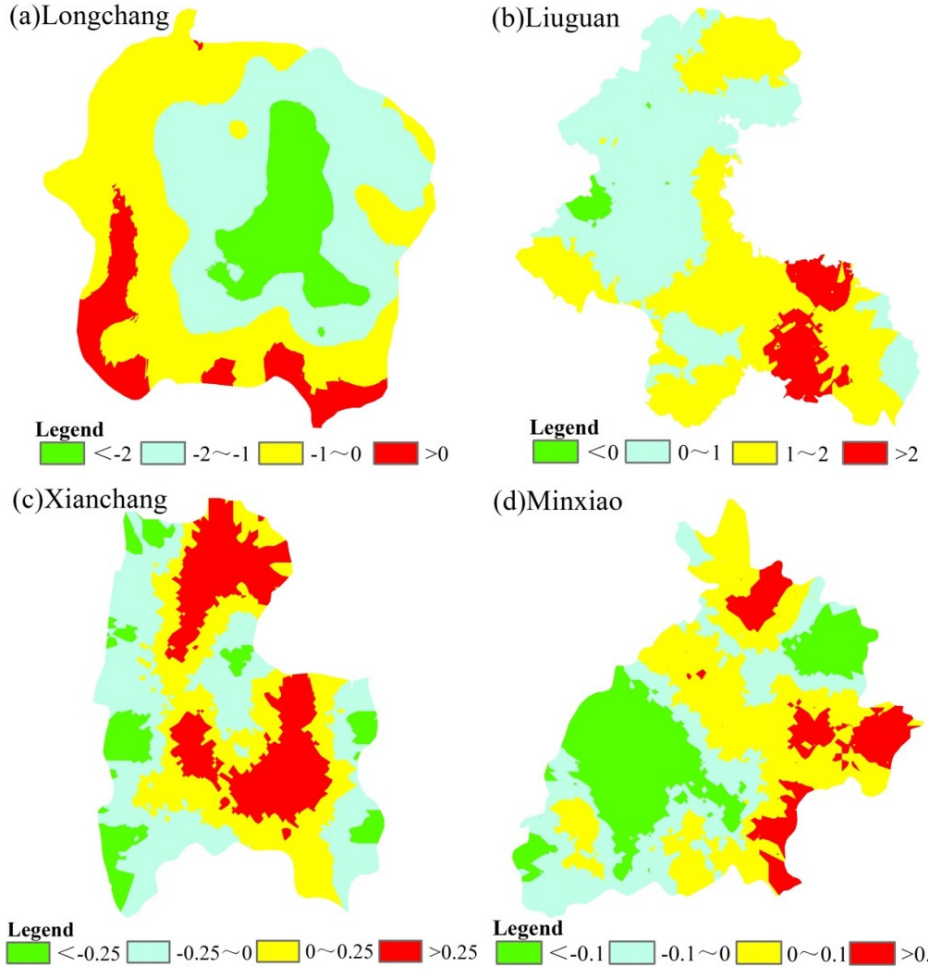

Figure 4. The spatial patterns of changes in landscape ecological risk from 2010 to 2020. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

3.4. Correlation between the Non-Agriculturalization of Cultivated Land and Landscape Ecological Risk

A negative correlation was found between the non-agriculturalization of cultivated land and landscape ecological risk in the four towns. The degrees of correlation between the non-agriculturalization of cultivated land and landscape ecological risk in Liuguan with a karst basin landform and Xianchang with a karst trough valley landform were higher than those in Longchang with a karst mid-mountain landform and Minxiao with a karst low hilly landform. Except for Liuguan, the degrees of correlation between the non-agriculturalization of cultivated land and landscape ecological risk in the other three towns were found to gradually decrease from slope gradient I to V (Table 7).

Table 7. The correlation coefficient (global Moran's index) between the non-agriculturalization of cultivated land and landscape ecological risk.

Town	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V	Total Area
Longchang (karst mid-mountain)	−0.197 **	−0.193 **	−0.186 **	−0.165 **	−0.086 **	−0.171 **
Liuguan (karst basin)	−0.280 **	−0.281 **	−0.290 **	−0.303 **	−0.322 **	−0.297 **
Xianchang (karst trough valley)	−0.325 **	−0.323 **	−0.315 **	−0.295 **	−0.291 **	−0.334 **
Minxiao (karst low hilly)	−0.151 **	−0.149 **	−0.143 **	−0.132 **	−0.127 **	−0.146 **

Note: ** indicates a significant correlation at the 0.01 level, * represents a significant correlation at the 0.05 level. The slope is divided into five gradients (from gradient I to V) according to the slope value from lowest to highest.

The high-high and low-high areas of Longchang are concentrated in the western and southern parts, while the low-low and high-low areas are concentrated in the central part (Figure 5a). The high-high and low-high areas in Liuguan are mainly distributed in the southern part, while the low-low and high-low areas are mainly distributed in the northwestern part (Figure 5b). The northern and southern parts of Xianchang are dominated by high-high and low-high areas, while the western and eastern parts are dominated by low-low and high-low areas (Figure 5c). The eastern and central parts of Minxiao are dominated by low-low and high-low areas, while the southeastern and northern parts are dominated by high-high and low-high areas (Figure 5d).

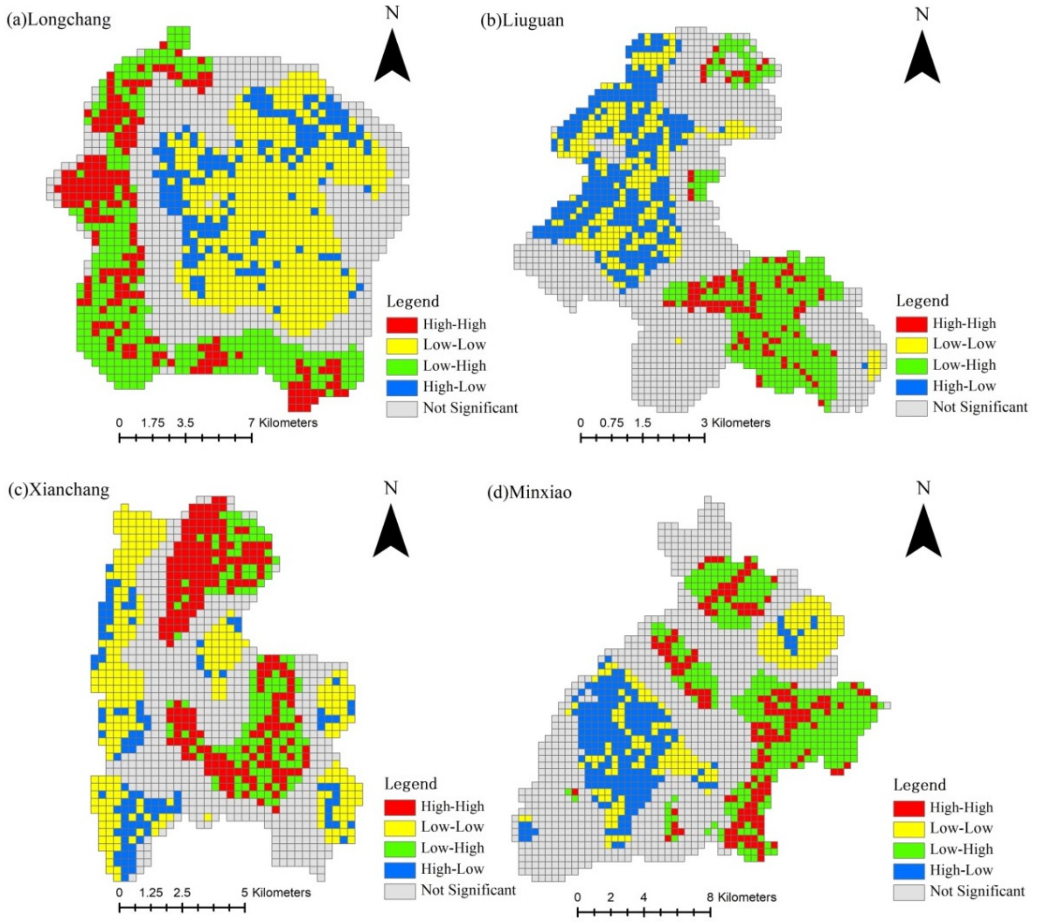

Figure 5. The spatial patterns of the types of agglomeration between the non-agriculturalization of cultivated land and landscape ecological risk. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

4. Discussion

4.1. Comparison with Previous Research Results

This study found that the karst mountainous areas in western China face the serious non-agriculturalization of cultivated land, which is consistent with the research results of scholars in Africa, Europe, and eastern China [4,9,10]. However, regarding the formation factors of the non-agriculturalization of cultivated land, the results of this study differ from those conducted in other regions around the world. Ecological management policy (namely, the Grain for Green Project) is the key factor causing the non-agriculturalization of cultivated land in the karst mountainous areas of western China, while non-agriculturalization in other regions of the world is mainly caused by urbanization and industrialization [31,32]. In addition, this study found a negative correlation between the non-agriculturalization of cultivated land and landscape ecological risk, i.e., the non-agriculturalization of cultivated land has a positive impact on the ecological environment, which is contrary to the research results of Yang [33] and Yang [34]. The reason for this is that the cultivated land in the karst mountainous areas considered in this study has been mainly converted to ecological land. In contrast, Yang [33] and Yang [34] found that cultivated land was mainly converted to built-up land.

4.2. Formation Mechanism of the Non-Agriculturalization of Cultivated Land in Karst Mountainous Areas

From the 1950s to the end of the century, a large amount of sloping land in karst mountainous areas in China was reclaimed to cope with the increased demand for food caused by the surging population. To deal with the serious ecological problems (such as rock desertification and soil erosion) caused by excessive land reclamation, the Grain for Green Project was implemented in the 21st century, which resulted in the conversion of a large amount of sloping cultivated land to ecological land [35]. Therefore, although the project is helpful for the restoration of the ecological environment, it causes the serious conversion of cultivated land to non-agriculturalization land-use types in karst mountainous areas. In addition, although economic development due to China's western development policy has led to the conversion of a portion of cultivated land in karst mountainous areas to built-up land and roads in the past ten years [36,37], the resulting rate of conversion of the non-agriculturalization of cultivated land has been far lower than the impact of the Grain for Green Project; this is related to the low demand for artificial land resulting from population losses and a low economic level. It should be noted that the cultivated land in karst mountainous areas is mainly converted into ecological land, and the increase of the natural landscape reduces the degree of landscape fragmentation and vulnerability. Therefore, there is a negative correlation between the non-agriculturalization of cultivated land and landscape ecological risk in karst mountainous areas.

Different landform regions have different natural conditions and human activities, which lead to differences in the distribution and utilization of cultivated land [38]. Under the interference of complex human activities, the changes of cultivated land in different karst landforms are bound to be different, which causes variations in the non-agriculturalization characteristics of cultivated land in different landforms. For example, Minxiao with a karst low hilly landform is located in the surrounding area of the Fanjing Mountain Nature Reserve. To protect and restore the ecological environment, a large amount of sloping cultivated land has been converted to forestland and shrub-grassland, which has caused a high non-agriculturalization rate in this town. However, the terrain of Liuguan is relatively flat, and there is little sloping farmland. The Grain for Green Project has had a relatively small influence on the conversion of cultivated land to non-agricultural land in this town, resulting in a lower non-agriculturalization rate in this town as compared to that in other towns with different landforms.

4.3. Land Management Policy

In view of the serious situation of the non-agriculturalization of cultivated land in karst mountainous areas, the following measures are suggested. (1) It is suggested that a balanced relationship between economic development, ecological restoration, and cultivated land protection be coordinated. First, the traditional mode of economic development in karst mountainous areas must be changed to reduce the amount of cultivated land occupied by built-up land. Second, it is necessary to reasonably arrange the implementation planning of the Grain for Green Project and prevent a large amount of cultivated land from being converted into ecological land. Finally, the red line of cultivated land protection should be delimited, and priority protection should be given to high-quality and concentrated contiguous cultivated land. The non-agriculturalization of high-quality cultivated land should be avoided. (2) It is necessary to improve the level of the intensive utilization of built-up land, and the government should establish an economic penalty mechanism to prevent the excessive conversion from cultivated land to built-up land. (3) It is necessary to improve the irrigation conditions of cultivated land, increase the usage degree of agricultural machinery, and improve the agricultural production efficiency. In addition, it is necessary to increase planting subsidies for cultivated land to prevent the abandonment of cultivated land, especially sloping cultivated land.

4.4. Limitations

The spatial resolution of the remote sensing images is one of the factors affecting the reliability of the research results. In view of the small spatial scale of the four selected towns, high-precision remote sensing images were selected for use in this study. However, due to the difficulty in obtaining long-term historical remote sensing images with high precision, only the past decade (between 2010 and 2020) was selected as the research period. Thus, the short research period was a limitation of this study.

5. Conclusions

The issue of the conversion of cultivated land into non-cultivated land in karst mountainous areas in China has been very serious. The conversion is mainly manifested as the conversion of cultivated land to forestland and shrub-grassland. The rate of conversion from cultivated land to ecological land is significantly higher than that from cultivated land to living land. There are differences in the non-agriculturalization of cultivated land in different slope gradients of different karst landforms. The Grain for Green Project has led to the conversion of a large amount of cultivated land into ecological land in karst mountainous areas in China and has played a key role in the non-agriculturalization of cultivated land in this area. The increase of ecological land and the decrease of cultivated land resulting from the non-agriculturalization of cultivated land have reduced the degree of landscape disturbance, which has led to a negative correlation between the non-agriculturalization of cultivated land and landscape ecological risk. It is worth noting that the conversion of cultivated land into non-cultivated land has not caused food risk, as revealed by the grain yield data on the national scale. This study is of great value to the formulation of protection strategies for cultivated land. Future research should predict the future conversion of cultivated land to non-agricultural land under different development scenarios based on a mathematical spatial model. In addition, in future research, questionnaires will be used to analyze the impacts of various economic factors on the non-agriculturalization of cultivated land at the scale of farmers.

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