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Spatial Patterns, Drivers, and Sustainable Utilization of Terrace Abandonment in Mountainous Areas of Southwest China

Weiying Ren [1,2], Aoxi Yang [1,2] and Yahui Wang [1,2,3,*]

[1] School of Geographical Sciences, Southwest University, Chongqing 400715, China; y18463415135@email.swu.edu.cn (W.R.); xixi0201@email.swu.edu.cn (A.Y.)
[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; Tel.: +86-158-0119-2532

Abstract: Sloping farmland abandonment has become a typical land use pattern worldwide. Along with the aggravation of sloping farmland abandonment, terrace abandonment is also showing an increasing trend. Systematically clarifying the pattern and mechanism of terrace abandonment is a prerequisite for effective management. Based on the survey data of 145 villages, 697 rural households, and satellite remote sensing in Southwest China, this study uses spatial analysis and the Logit model to reveal the scale, pattern, and driving mechanism of terrace abandonment in the study area to provide scientific references for the sustainable utilization of terrace resources in mountainous areas. This study found that in the study area, 63% of the villages had experienced terrace abandonment, and nearly one-fifth of the rural households had abandoned terraces. The area of abandoned terraces accounted for 7.65% of the total area, and the scale of abandoned terraces reached 449,360 hectares, of which Chongqing has the highest proportion of terrace abandonment (11.5%), while Yunnan Province has the lowest (5.1%); the overall abandoned terraces show a pattern of higher in the east and lower in the west. Terrace abandonment is influenced by multiple factors. The rise in non-agricultural wages attracts rural labor migration as an external force, while the rising operating costs of mountain agriculture serve as internal drivers. Under the combined influence of internal and external factors, the abandonment of terraces in southwest mountainous areas is intensifying. The government should actively conduct assessments of terrace resources within the region and implement targeted measures to address terrace abandonment.

Keywords: terrace abandonment; spatial patterns; drivers; pull–push; mountainous areas; China

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Citation: Ren, W.; Yang, A.; Wang, Y. Spatial Patterns, Drivers, and Sustainable Utilization of Terrace Abandonment in Mountainous Areas of Southwest China. *Land* **2024**, *13*, 283. https://doi.org/10.3390/land13030283

Academic Editor: Marco Marchetti

Received: 12 January 2024
Revised: 15 February 2024
Accepted: 20 February 2024
Published: 25 February 2024

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1. Introduction

A terrace refers to a strip or wave-like section of fields built along the contour direction on hilly mountain slopes, condensing a large amount of labor, material, and capital inputs. This type of land use is formed by human beings to meet the needs of survival and adapt to the harsh environment of mountainous areas and is considered to be a high-quality arable land resource in hilly and mountainous regions. Terraces are further categorized into water terraces and dry terraces based on planting methods. As a form of the mountainous agricultural composite system, terraces not only enhance food production [1], improve farmers' livelihoods, and preserve water, soil, fertility [2–4], and microclimate regulation [5], but also carry multiple values of the local long farming culture and historical inheritance, aesthetics appreciation [6,7], and eco-tourism [8], making them a globally recognized agricultural cultural heritage [9]. At present, terraces are widely distributed all over the world, and East Asia, South Asia, Southeast Asia, the Mediterranean coast, Central America, and the coastal areas of Africa are all concentrated areas of terrace distribution [10]. However, due to natural changes, socio-economic development, and institutional changes, sloping farmland

in mountainous areas is facing serious marginalization or even abandonment [11], while high-quality terrace resources are also beginning to face the risk of abandonment.

Before the 21st century, terrace abandonment occurred mainly in the United States of America [12], Japan [13], China [14], and some developed countries in western Europe [15,16]. In the 21st century, terrace abandonment has been expanding globally and is showing an accelerating trend, with a notable increase in abandoned areas. Currently, terrace abandonment has been observed in over 60 countries and regions across six continents [12,13,16–18]. In particular, more than 90% of terraces on Lanzarote Island in Spain have been abandoned to the highest degree in history [15]. Large-scale terrace abandonment not only wastes a significant amount of human and material resources but also leads to reduced crop yields [19], hindering to some extent the achievement of the United Nations' sustainable development goal of "eliminating hunger and ensuring food security". Additionally, terrace abandonment exacerbates soil erosion and degradation in mountainous areas [20], leading to increased losses of soil and water [18], as well as changes in biodiversity [21] and other ecological issues, even damaging the cultural landscape of terrace agriculture, resulting in a series of adverse effects. Meanwhile, more scholars are participating in the research and governance of terrace abandonment. The research on terrace abandonment generally adopts methods such as farmer surveys [22], remote sensing interpretation [23], and meta-analysis [16] to explore the scale, spatiotemporal evolution, occurrence mechanisms, and risk prediction of terrace abandonment. As the problem of terrace abandonment shows a global trend of diffusion, the driving factors for abandonment also exhibit diverse and complex characteristics, with significant differences between different countries and regions. Generally, socio-economic factors are the key driving factors for the abandonment of farmland [24]. In addition, developed countries such as Spain [15] and Italy [25] are greatly influenced by natural environmental changes, agricultural intensification, and technological progress, leading to an expanding scale of abandonment. China [14], Peru [17], and other developing countries are greatly affected by urbanization and the outflow of the rural labor force, resulting in increasing abandonment risks. To address the challenge of terrace abandonment, scholars have proposed measures such as increasing agricultural planting subsidies [15], infrastructure construction and maintenance [26], and outsourcing of agricultural services [27]. Some countries and regions have also implemented policies to alleviate farmland abandonment, such as agricultural subsidy policies [13,15]. International organizations such as the Food and Agriculture Organization of the United Nations (FAO) and the International Terrace Landscape Alliance (ITLA) have also made significant contributions to the protection and management of terraces [18].

However, there are still some deficiencies in the academic research on terrace abandonment. On one hand, some scholars use remote sensing interpretation [23] or household surveys [22] to monitor the scale and pattern of terrace abandonment. However, due to the high cost of large-scale household surveys and high-resolution remote sensing images, they are mostly used for small-scale typical case studies [26,28], lacking the identification and mechanism exploration of large-scale abandoned terraces. On the other hand, as abandonment is the result of comprehensive multi-scale and multi-factor effects, there are significant differences in different regions. The current research mainly focuses on developed countries, especially in Europe where widespread agricultural land abandonment occurs [29]. Moreover, research on terraces in the European region often has a greater impact [30]. Many developing countries and regions, represented by China, are still in a rapid urbanization phase. The rapid transfer of rural labor remains a long-term trend and process [31], especially in hilly and mountainous agricultural areas where the labor force is rapidly and continuously decreasing, which is likely to exacerbate the extent of terrace abandonment. So, how extensive is the terrace abandonment in these countries and regions? What are the different mechanisms of abandonment? How can the reuse of abandoned terraces and risk prediction be achieved? These are the questions that need to be answered.

In the major terrace areas of the world, especially in underdeveloped countries and regions, conducting large-scale research on the scale and mechanism of terrace abandonment is an imperative prerequisite for the effective protection and management of terrace resources. China, as the largest developing country and socialist country in the world at present, was also one of the first countries to build terraces and has the most extensive distribution of terraces. Multiple news reports and studies indicate that China is facing a serious issue of terrace abandonment [14,26]. Therefore, researching the problem of terrace abandonment in China is of significant or special reference value for the protection of terraces worldwide and in other major regions and countries where terrace abandonment is prevalent. According to the Second National Land Survey in 2009 [32], China has a total terrace area of approximately 18,610 kha, accounting for 13.7% of the country's arable land area. The southwestern region of China, including Yunnan, Guizhou, Sichuan, Chongqing, and Tibet, has a total area of approximately 2.35 million square kilometers, accounting for about one-fourth of the total national land area. The mountainous area accounts for about one-third of the total national mountainous area and is a typical hilly and mountainous region. The terrace area of 5874 kha, approximately one-third of the total national terrace area, and is an important terrace farming area in China and even the world. At the same time, the southwest mountainous region is also a key area for the outflow of agricultural labor force [33] and the abandonment of cultivated land [22], serving as a natural experimental field and representative area for studying terrace abandonment in China. China's national situation of a large number of people and little land, and the situation of large-scale transfer of agricultural labor force, still exists and has existed for a long time; the management and sustainable use of terrace abandonment is of vital importance, and it is urgent to conduct research on the scale of terrace abandonment and its attribution.

Given this, this study is based on the research data of village surveys, rural household surveys, and satellite remote sensing images throughout the study area, and utilizes spatial analysis and the Logit model to firstly reveal the scale and pattern of terrace abandonment in the mountainous areas of Southwest China, then clarify the driving mechanism of terrace abandonment, and finally put forward countermeasures and suggestions on terrace abandonment management to provide scientific basis and policy suggestions for the sustainable utilization of terrace resources in hilly mountainous areas.

2. Materials and Methods

2.1. Study Area

The mountainous areas of Southwest China span Yunnan, Guizhou, Sichuan, Chongqing, and Tibet Autonomous Region. Among them, according to the Second National Land Survey in 2009, the terrace in the TAR only accounts for 0.21% of the total terrace area in the country, which is a very small proportion, so this study does not include the TAR in the scope of the study. The four southwestern provinces are generally located at 97°21′ E–110°11′ E, 21°08′ N–34°19′ N, with topographic units involving the Hengduan Mountainous Region, the Yunnan–Guizhou Plateau, and the Sichuan Basin. The region features rugged terrain, diverse climate types, complex natural agricultural conditions, and vertical land use as a prominent characteristic. With the migration of rural labor and the challenging farming conditions in the mountainous areas, several studies have shown significant terrace abandonment in the southwest mountainous areas [26,28,34] (Figure 1).

2.2. Data

(1) Research Data. To accurately assess the scale of terrace abandonment and precisely diagnose the reasons behind it, this study conducted an in-depth analysis of survey data from villages and rural households in a large area of southwest mountainous regions. Village surveys are used to take the whole village as an object and obtain relevant information about the whole village. Rural household surveys are conducted on households living in villages and involved in agricultural activities to obtain information on the entire household. The survey data were obtained from field investigations conducted by the

research team in Yunnan, Guizhou, Sichuan, and Chongqing from 2020 to 2021. To ensure a balance in samples, improve the sampling efficiency, and accurately estimate the scale of abandonment, a combination of stratified sampling and random sampling was used in the survey process. In the first stage, the sampling target was to select survey cities from 84 cities in the four southwest provinces. Considering the proportion of terraces in each province, cities with smaller terrace weights would not meet the requirements for sampling units. As a result, 47 survey cities were finally determined in the southwest mountainous areas. Then, the cities in each province were sorted according to the arable land area, and specific survey cities and counties were selected using systematic sampling. In the second stage, the sampling target was to select village-level sampling units from the surveyed counties. For operational feasibility, 1–2 villages were randomly selected in each designated county based on the location of the researchers and the distribution of terraces. The third stage of sampling aimed to randomly select 4–6 rural households from the village-level sampling units. The village surveys targeted informed village cadres, mainly village heads, information officers, etc., focusing on various types of cultivated land area and quality, labor conditions, land transfer, abandonment situation, crop planting, and so on. The rural household surveys targeted farmers managing cultivated land within the villages, focusing on various types of cultivated land area, land use, basic information about family members, and family income.

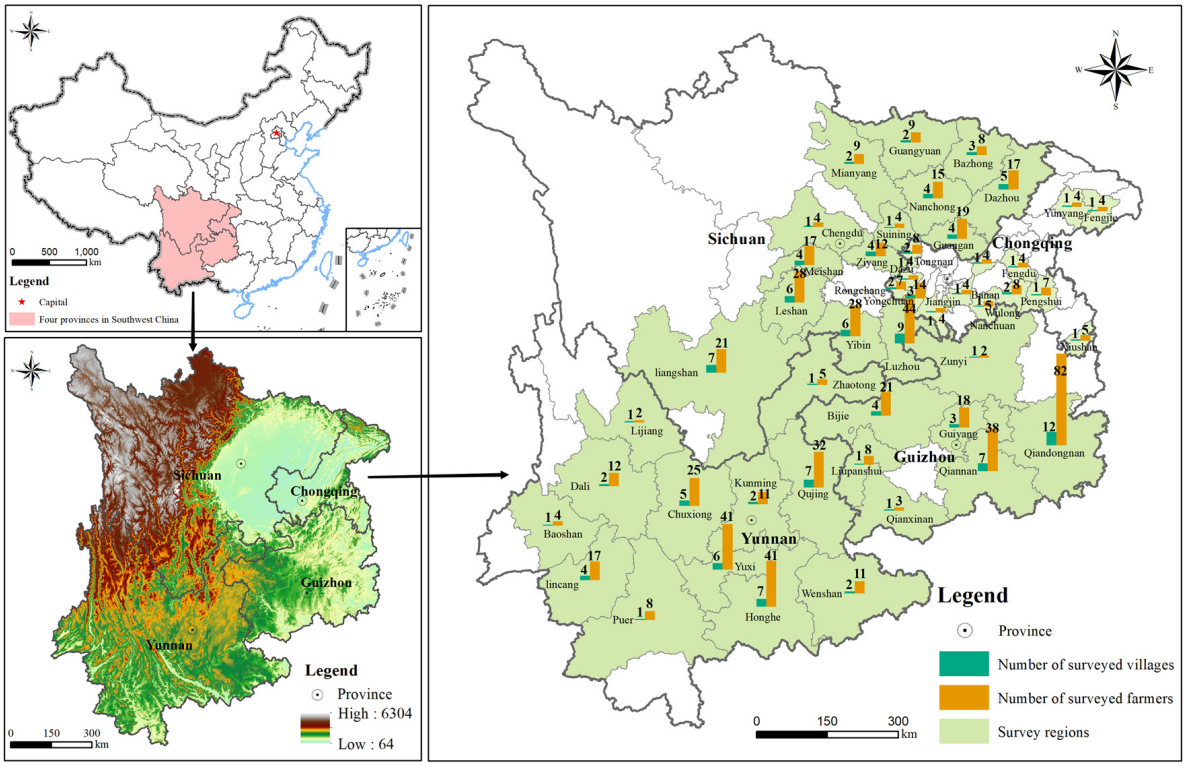

Figure 1. Research area schematic diagram.

The sampling survey had an extensive scope and was primarily conducted by college students returning home during holidays, balancing economic feasibility and result reliability. To improve the completeness and accuracy of the survey forms, priority was given to college students or graduate surveyors majoring in geography, land resources, and resource science, which are closely related to the survey content. During data collection, a set of effective logical criteria were established to verify the reliability of the survey forms, and follow-up phone calls were made to fill in any missing information to ensure the reliability of the results. A total of 150 village questionnaires and 755 rural household questionnaires were collected, totaling 905 questionnaires. For follow-up correction and cleaning of the

questionnaires, the process was as follows: ① Based on basic common sense and logic, data consistency checks, etc., to judge the error values and outliers that may appear in the questionnaire; ② Communicate with the investigator and the respondents, if there are errors or omissions in the questionnaire call back through the telephone to correct; ③ Do not meet the requirements of the survey, there are obvious errors that cannot be corrected and so these questionnaires to be eliminated. Ultimately, 145 village questionnaires and 697 rural household questionnaires, totaling 842 questionnaires, were confirmed. The distribution of the survey samples is shown in Figure 1.

(2) Remote Sensing Data. To verify the accuracy of the survey data in calculating the scale of abandoned terraces and to achieve spatial visualization of the abandoned terraces, this study further utilized remote sensing data to extract and validate information on abandoned terraces as a supplementary research effort. In this study, we utilize the first 30 m resolution Chinese terrace distribution dataset (https://essd.copernicus.org/articles/13/2437/2021/, accessed on 1 October 2023) released by Tsinghua University [35], from which we extracted the terrace distribution information of southwest mountainous areas in 2018 as the basic data. The overall accuracy of the mapping results reaches 94%, and the kappa coefficient reaches 0.72. In addition, this study acquired 2020 GlobeLand30 data (http://www.globeland30.org/, accessed on 1 October 2023) in the southwest mountainous areas as judgment data for identifying whether terraces are abandoned or not. The overall accuracy of the mapping was 85.72% with a kappa coefficient of 0.82.

2.3. Methods

2.3.1. Estimation of Terrace Abandonment Rate

The migration of rural households may cause bias in the rural household research samples, so the estimation of the terrace abandonment scale in this study primarily relied on the village questionnaires. As the number of village questionnaires in each city varies, the abandonment rate was weighted by the stratified sampling requirement. Furthermore, if a city exhibited a terrace abandonment rate of 0, the rural household research data within the village in that city was further used to measure and represent the terrace abandonment rate in that location. The specific calculation formula is as follows:

$$YBA_i = \sum_{j=1}^{n} XBA_{ij}/n \quad (1)$$

$$YA_i = \sum_{j=1}^{n} XA_{ij}/n \quad (2)$$

$$R = \sum_{i=1}^{m} YBA_i / \sum_{i=1}^{m} YA_i \quad (3)$$

In the formula, XBA_{ij} is the terrace abandonment area of village j in research county i; YBA_i is the average terrace abandonment area of research county i, i.e., the average value of terrace abandonment area of n villages in the area; XA_{ij} is the total terrace area of village j in research county i; YA_i is the average terrace area of research county i, i.e., the average value of terrace area of villages in the area; and R is the terrace abandonment rate, i.e., the ratio of the total of average terrace abandonment area in the m research county to the total of average terrace area in the m research county.

2.3.2. Extraction of Abandoned Terraces

In this paper, concerning the research of other scholars and combined with the practical needs of this study, the land use change in terraces into forests, grasslands, shrublands, wetlands, and bare lands that have been continuously deserted for two years or more is regarded as terrace abandonment. After obtaining remote sensing data, preprocessing, such as edge removal, mosaicking, masking, and reclassification, was conducted in ArcGIS. Specifically, the pixels belonging to terraces in 2018 were reclassified as 1, those belonging to

cultivated land in 2020 were reclassified as 2, those belonging to forests, grasslands, shrublands, wetlands, and bare land were reclassified as 3, and those belonging to other land use forms were reclassified as 4. Pixels that changed from being classified as 1 in 2018 to 3 in 2020 were identified as abandoned terraces. This identification was achieved through raster calculation using the Con function, with the formula "Con (("2018 Terrace dataset" == 1) & ("2020 Globeland30"== 3),1)". This allowed for the extraction of information on abandoned terraces. After that, high-definition Google historical images were utilized for sampling inspection of the abandoned terraces in each city, and the high-definition Google historical images were used as the basis to exclude part of the data information that was not abandoned but was incorrectly extracted as abandoned. Finally, we overlayed the administrative district data to carry out the partition statistics and visualization expression of the abandoned terraces information. The realization path is shown in Figure 2.

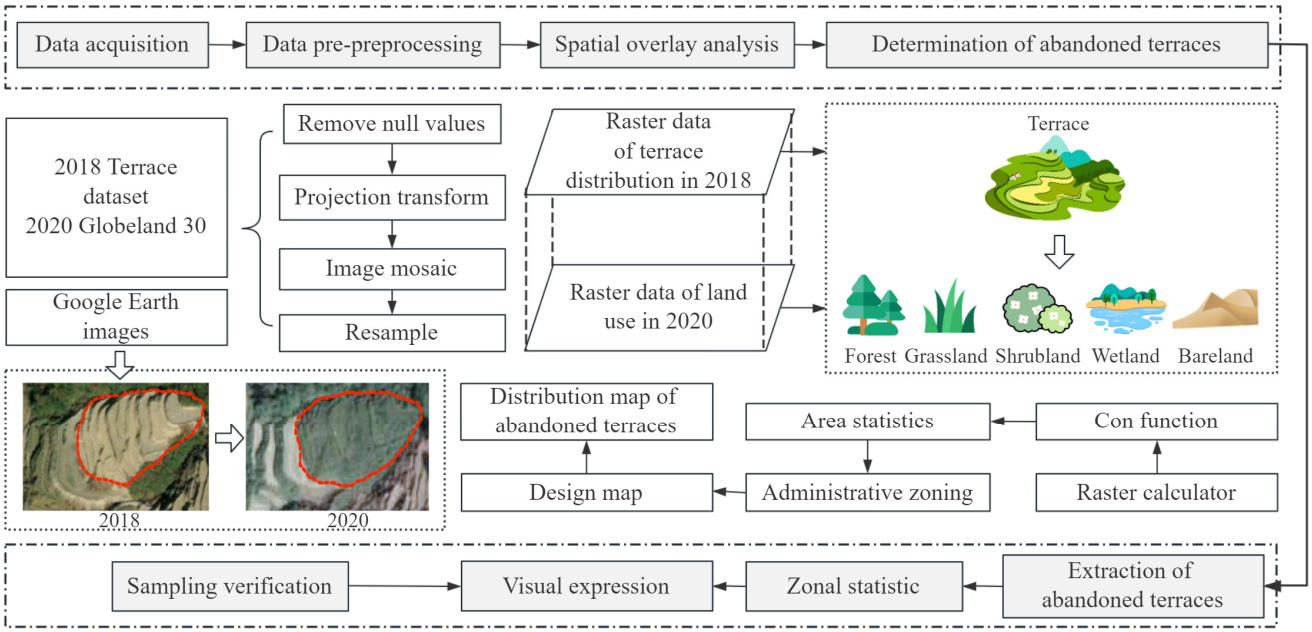

Figure 2. Technical route of the extraction of abandoned terraces.

2.3.3. Logit Regression Model

Based on 697 rural household research data sets, this study used the Binary Logit regression model and SPSS to quantitatively analyze the influencing factors of terrace abandonment. The explanatory variable was whether there is terrace abandonment in the rural household. According to the land use decision theory and previous research, the influencing factors of terrace abandonment are divided into two categories: the first category includes family and labor characteristics, such as the number of family agricultural laborers, the age of the head of the household, and the proportion of non-agricultural income in the family. These variables mainly involve household-level characteristics. The number of family agricultural laborers is an important production factor, reflecting the ability and labor cost input of rural households in terrace cultivation. The quantity of labor is closely related to whether terraces are effectively cultivated. The head of the household in Chinese families is often the main labor force, and their occupational choices at different ages are closely related to the agricultural management situation. The proportion of non-agricultural income in a family reflects the income structure of the farmers, indicating the degree of their dependence on agricultural management. To some extent, it can predict whether farmers will choose to abandon their fields. Additionally, the level of non-agricultural income is also a result of urbanization and industrialization.

The second category includes agricultural production conditions, such as total terrace area, number of plots, irrigation conditions of plots, soil fertility of plots, commuting time to

plots, relative elevation in plots, and whether the plots are located in scenic areas. The total terrace area can reflect the amount of labor performed by farmers in terrace management activities. The number of plots reflects the degree of fragmentation of the land and the difficulty of mechanization, which are related to the efficiency of agricultural management and are important factors affecting terrace abandonment. The irrigation conditions and soil fertility of the plots are measures of the cultivation conditions, reflecting the quality of terrace cultivation and affecting agricultural production efficiency. The longer the commute and the greater the difference in elevation from the dwelling, the more likely terraced plots are to be abandoned. Whether the terraces are located in scenic areas is related to whether agricultural production and management will receive additional subsidies and income, as well as whether the terraces can receive more comprehensive management and maintenance. Therefore, this factor is also closely related to whether terraces are abandoned. In addition, to explain the impact of regional differences, the region to which the terraces belong is Chongqing Municipality as a comparison variable, and Guizhou Province, Yunnan Province, and Sichuan Province as regional dummy variables to be considered in the model. The binary Logit regression model variables are shown in Table 1, and the regression model is as follows:

$$y_i = \ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \sum_{j=1}^{n} \beta_j X_{ij} + \varepsilon_i \quad (4)$$

Table 1. Selection and description of indicators affecting terrace abandonment.

Variables	Units or Interpretation of Variables	Mean	Standard Deviation	Sample Size
Explained variable				
Whether the terraces are abandoned	0 = No (81%), 1 = Yes (19%)	0.19	0.39	697
Explanatory variable				
Number of agricultural laborers	per	1.56	1.01	697
Age of rural household head	year	53.94	11.81	697
The ratio of non-agricultural income	%	67.04	33.16	697
Total area of terraces	hectare	0.37	0.79	697
Number of plots	plot	9.15	25.08	697
Irrigation condition of plots	1 = poor, 2 = fair, 3 = good	2.07	0.83	697
Soil fertility of plots	1 = poor, 2 = fair, 3 = good	2.15	0.71	697
Commuting time to the plots	minute	17.55	13.9	697
Relative height difference in plots	meter	76.54	104.98	697
Whether located in scenic areas	0 = No, 1 = Yes	0.09	0.28	697
Guizhou Province (dummy variable)	The terraced plots area in Guizhou	1	0	697
Yunnan Province (dummy variable)	The terraced plots area in Yunnan	1	0	697
Sichuan Province (dummy variable)	The terraced plots area in Sichuan	1	0	697

In the formula, y_i is an explanatory variable indicating whether the terraced plots of the ith rural household are abandoned; P_i is the probability of abandonment of the terraced plots of the ith rural household; X_{ij} denotes the value of the jth variable of the terraced plots of the ith rural household; n is the number of variables; β_0 and β_j denote the intercept term and the regression coefficient of the jth variable, respectively; and ε_i is the error term.

3. Results

3.1. Spatial Patterns of Terrace Abandonment

According to the terrace area data from the Second National Land Survey, the scale of abandoned terraces in the southwest mountainous areas has reached 449,360 hectares. When considering the degree of terrace abandonment in villages, it is observed that 63% of villages in the southwest mountainous areas have experienced terrace abandonment, with the highest rate of terrace abandonment in Chongqing Municipality, reaching 79%. From the perspective of rural household abandonment, 18.7% of rural households in the study

area have experienced terrace abandonment, of which Guizhou Province and Chongqing Municipality show relatively high levels, with the rate of rural household abandonment exceeding 20%. In terms of abandoned terrace areas, the overall terrace abandonment rate in the southwest mountainous areas was 7.65%, with the highest terrace abandonment rate of 11.5% found in Chongqing Municipality and the lowest rate of 5.1% in Yunnan Province (Figure 3).

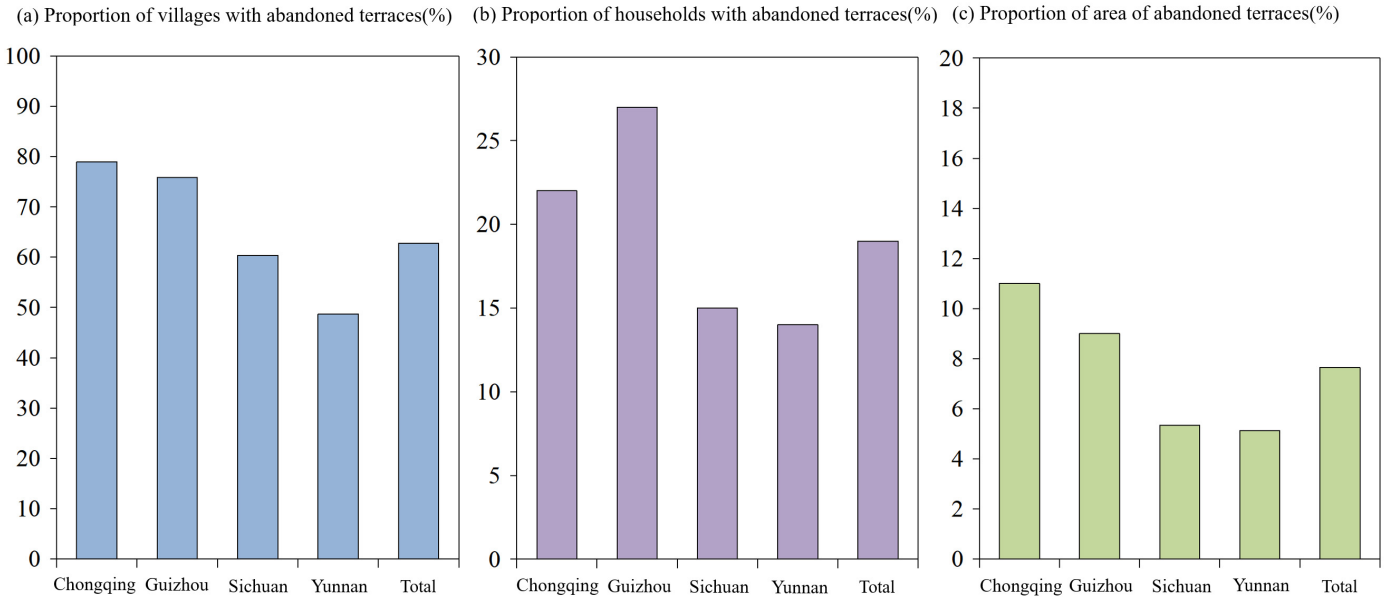

Figure 3. Extent of terrace abandonment at the provincial scale in the southwest mountainous areas.

From the perspectives of village abandonment rate, rural household abandonment rate, and area abandonment rate (Figure 4), Chongqing Municipality and Guizhou Province show higher abandonment rate indicators compared to Sichuan Province and Yunnan Province, demonstrating a spatial pattern of higher in the east and lower in the west for terrace abandonment in the study area.

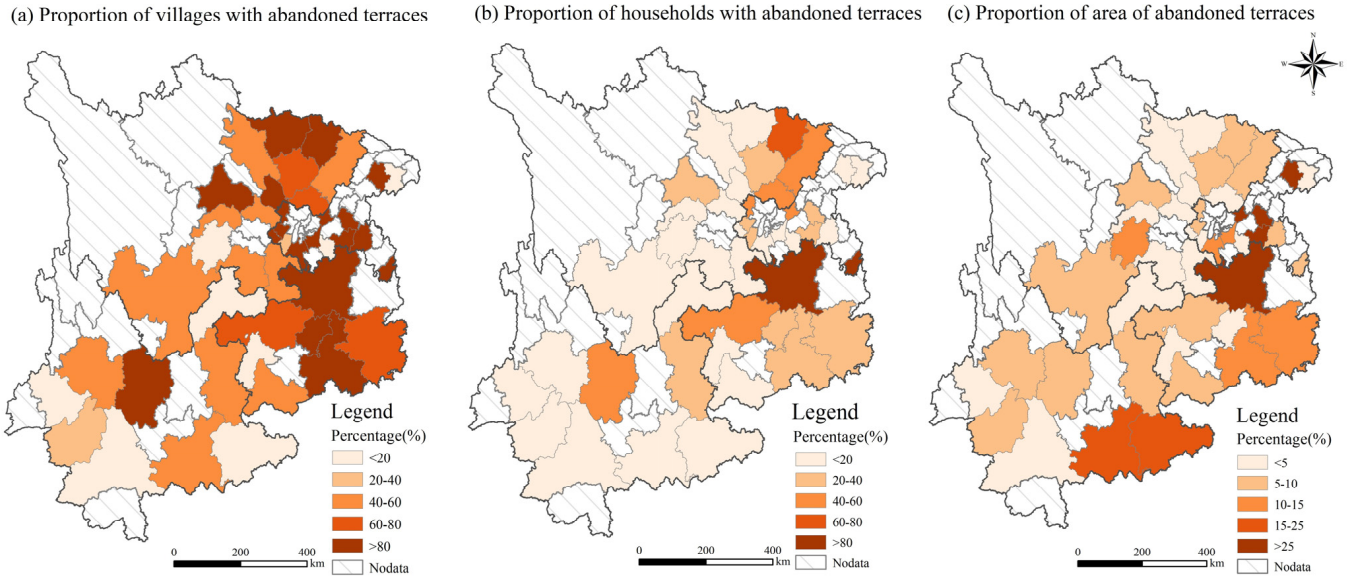

Figure 4. Extent of terrace abandonment at the city scale in the southwest mountainous areas.

3.2. Determinants of Terrace Abandonment

Before using the Logit model to simulate the determinants of terrace abandonment, this study conducted a test for multicollinearity among the variables. The results show that the variance inflation factors (VIF) for individual variables and overall variables passed the test, indicating that there is no multicollinearity issue among the variables. The significance of the Hosmer test for the Logit model is 0.454, which exceeds 0.05; thus, the result is accepted. The model's regression accuracy reaches 83.1%, and the Hosmer test suggests that the observed values are roughly similar to the expected values, indicating a good fit for the model. The regression results (Table 2) reveal the six explanatory variables: number of family agricultural laborers, the ratio of non-agricultural income, irrigation condition of plots, soil fertility of plots, commuting time to the plots, and whether the plot is located in a scenic area, which have passed the significance test ($p < 0.05$) and are significantly correlated with terrace abandonment.

Table 2. Binary Logit regression results of factors influencing terrace abandonment.

Variable	B	Standard Error	Significance	Exp(B)	95% Confidence Interval	
					Lower	Upper
Number of agricultural laborers	−0.532 ***	0.132	0.000	0.588	0.454	0.761
Age of rural household head	0.015	0.010	0.121	1.015	0.996	1.035
The ratio of non-agricultural income	1.019 ***	0.382	0.008	2.771	1.311	5.854
Total area of terraces	0.032	0.020	0.104	0.968	0.932	1.007
Number of plots	0.011	0.007	0.124	1.011	0.997	1.025
Irrigation condition of plots	−0.569 ***	0.154	0.001	0.566	0.418	0.767
Soil fertility of plots	−0.599 ***	0.161	0.005	0.549	0.401	0.753
Commuting time to the plots	0.046 ***	0.008	0.000	1.047	1.030	1.064
Relative height difference in plots	0.001	0.001	0.163	1.001	1.000	1.002
Whether located in scenic areas	−1.838 ***	0.634	0.004	0.159	0.046	0.551
Guizhou Province (dummy variable)	−0.200	0.418	0.632	0.819	0.361	1.857
Yunnan Province (dummy variable)	−0.213	0.388	0.583	0.808	0.377	1.730
Sichuan Province (dummy variable)	−0.261	0.370	0.482	0.771	0.373	1.592
Constant	−1.598	1.017	0.116	0.202		

Note: *** indicates significance at 5% level of significance.

In terms of family and labor characteristics, the number of family agricultural laborers is negatively correlated with whether terraces are abandoned. The fewer family agricultural laborers there are, the more difficult it is to effectively carry out agricultural activities and to achieve division of labor and cooperation, leading to a decrease in production efficiency and an increased likelihood of terrace abandonment. This reflects the constraint effect of the number of agricultural laborers, as the production decisions of farmers will change due to insufficient agricultural labor, such as by reducing the replanting index and abandoning part of the cultivated land to alleviate the shortage of agricultural labor input. Especially in hilly and mountainous areas with lower levels of mechanization, a large amount of labor is required for the cultivation and management of terraces, making the number of laborers particularly important. Additionally, for each additional family agricultural laborer, the likelihood of terrace abandonment is 0.6 times the original probability. The proportion of non-agricultural income is positively correlated with whether terraces are abandoned. When the proportion of non-agricultural income is high, it indicates that farmers have a lower dependence on agricultural production and that the income from agricultural activities is insufficient to meet the livelihood needs of the farmers. Consequently, farmers are more inclined to engage in non-agricultural activities, making terraces more likely to be abandoned. The increase in the proportion of non-agricultural income is essentially the result of socio-economic development, urbanization, and industrialization, and is also an important factor attracting a large-scale transfer of agricultural labor. It is also worth noting that there is a typical U-shaped relationship between the age of the household head and whether terraces are abandoned, with 50 years old being the main turning point of

the U shape. When the household head is younger than 50 years old, the tendency of the rural household to abandon terraces decreases as the age increases. However, when the household head is over 50 years old, the tendency to abandon terraces increases. In this survey, 31.8% of household heads were younger than 50 years old, and as the age increases, an increasing number of household heads will exceed 50 years old, thereby continuously increasing the risk of farmers abandoning terraces.

In terms of agricultural production conditions, the commuting time to the plots is positively correlated with whether the terraces are abandoned, while the irrigation conditions, soil fertility of the plots, and whether they are located in scenic areas are negatively correlated with whether the terraces are abandoned. The longer the commuting time to the plots, the higher the cost for farmers to manage the terraces. Farmers tend to retain plots with shorter commuting times, making terraces with longer commuting times more likely to be abandoned. Poor irrigation conditions in the terraces increase the likelihood of them being abandoned. High and stable yields in terraces depend on convenient irrigation facilities. In some terraces, the irrigation facilities are still inadequate, relying solely on rainwater. When the water supply is unstable, terraces are more likely to be abandoned. Additionally, the soil fertility of the plots is also a significant factor. The fertility of the soil directly affects agricultural production income. Plots with low fertility not only have low yields but also require more investment in fertilizers and pesticides, making it more likely that terraces are to be abandoned. Furthermore, the commuting time to the plots, irrigation conditions, and soil fertility are all agricultural production conditions that reflect the operating costs of agricultural production. The worse the production conditions, the higher the production costs, the lower the income for farmers, and the greater the likelihood of abandonment. Terraces have become valuable tourist resources due to their rich and flexible landscape features and related social and cultural systems. The likelihood of terraces located in scenic areas being abandoned is 0.16 times that of non-scenic areas. This is because terraces within scenic areas often receive subsidies for planting and better management due to the scenic benefits they bring. Moreover, the farmers can also profit from the local tourism industry, meeting their livelihood needs, and making it less likely for terraces to be abandoned. The number of plots and the relative height difference in the plots were not significant in the model calculations, possibly due to the large undulating terrain in the southwest mountains, where fragmented plots and large height differences are common and their impact is not as significant as other variables. In addition, in this survey, many farmers reported frequent crop damage by wild animals, with wild boar being the most significant culprit. Along with the ecological recovery of China's mountainous areas in recent years, wild animals, represented by wild boars, have emerged frequently, destroying field crops, reducing crop yields, while raising farmers' operating costs, and becoming another major risk to the abandonment of arable land in mountainous areas.

When looking at regional differences, the likelihood of terrace abandonment in Guizhou Province is 0.82 times that of Chongqing Municipality, while in Yunnan Province it is 0.81 times, and in Sichuan Province, it is 0.77 times. Therefore, in terms of the study on the likelihood of terrace abandonment, the likelihood in Chongqing Municipality is greater than in other provinces, which is consistent with the conclusion in the previous Section 3.1. Chongqing has the typical characteristics of a large city, large rural areas, and mountainous regions. According to the Chongqing Municipal Government Work Report, the urbanization rate of Chongqing was only 35.6% in 2000, and by 2020 this figure had soared to 69.5%, representing an increase of nearly 34 percentage points over 20 years. Behind this increase lies the decrease in over 7 million of the agricultural population, and the significant loss of agricultural population will undoubtedly exacerbate the risk of terrace abandonment.

3.3. Mechanisms of Terrace Abandonment

Whether or not rural households decide to abandon terraces is influenced by a combination of external force–internal thrust, and the driving mechanisms are complex and

varied. The rapid development of urbanization and industrialization is generally considered the fundamental cause of terrace abandonment in mountainous areas. Simultaneously, the rise in non-agricultural wages and the improvement in urban living standards attract rural laborers to migrate, serving as external forces causing terrace abandonment within the macro social context. Under the influence of external forces, the micro factors of the region and farmers are also direct causes of terrace abandonment. In the southwest mountainous areas, the terrain is undulating, the land is broken, the irrigation is not easy, the terraces have poor farming conditions, and natural disasters are frequent, coupled with the phenomenon of villages hollowing out and the shortage of laborers, which leads to an increase in terrace farming costs, becoming the internal driving force for the terrace abandonment by the rural households. Under the influence of external forces, with the support of internal thrust, the trend and degree of terrace abandonment in the southwest mountainous areas become more significant. Furthermore, the abandonment of terraces will further exacerbate the internal driving cycle: once terraces are abandoned, the cost for farmers to resume farming is higher, agricultural income is lower, and the willingness to continue planting is reduced. To seek new sources of livelihood, farmers are more inclined to leave the countryside. The continued outflow of agricultural labor further promotes the marginalization of rural farmland, exacerbating the abandonment of terraces and forming a vicious cycle of the driving mechanism for terrace abandonment (Figure 5).

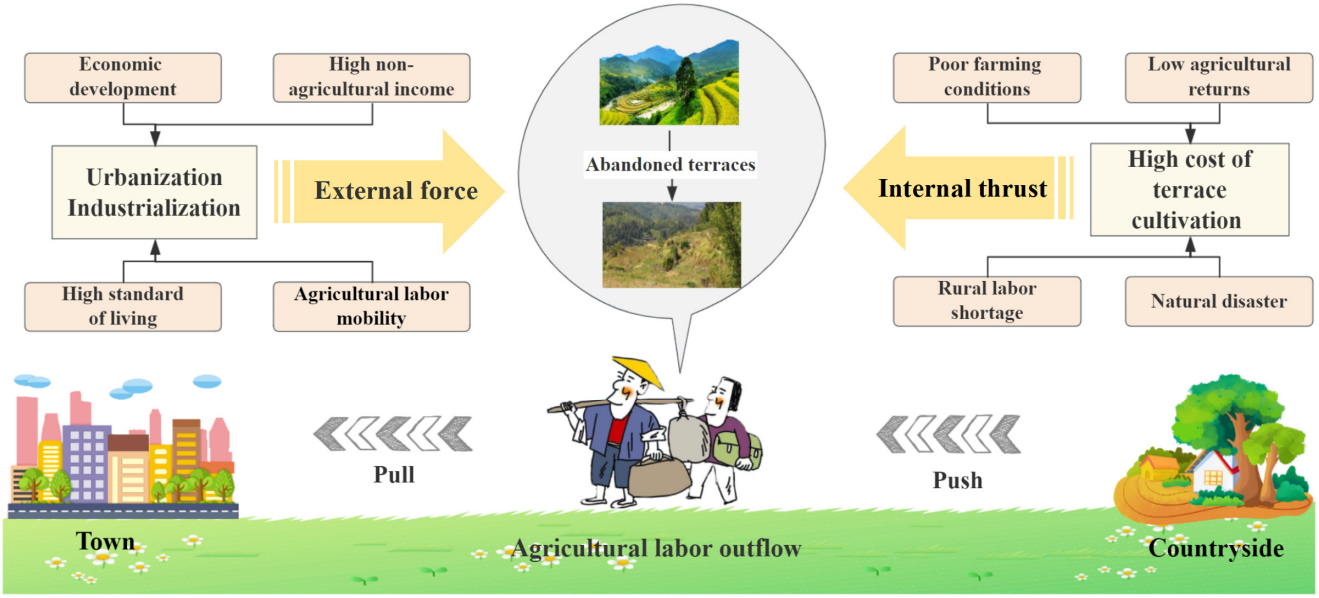

Figure 5. Driving mechanisms of terrace abandonment in mountainous areas.

4. Discussions

4.1. Remote Sensing Verification of Abandoned Terraces

In this study, we further utilized satellite remote sensing data from 2018 to 2020 to verify the measurement of terrace abandonment rates and to extract the distribution of abandoned terraces, as depicted in Figure 6. The remote sensing data calculation results indicate that the abandonment rate of terraces in the southwest mountainous areas is 6.49%, which is close to the research data result (7.65%), and the overall abandonment rate of terraces and the results for each province have errors within 4%, as detailed in Figure 7. The abandonment rates calculated from remote sensing data are mostly lower than the estimated results from the research. This difference may stem from the limitations in the accuracy of the remote sensing data and data processing, as well as the relatively short period (2018–2020) used for calculating the abandonment rate of terraces and the effectiveness of recent abandonment rectification policies.

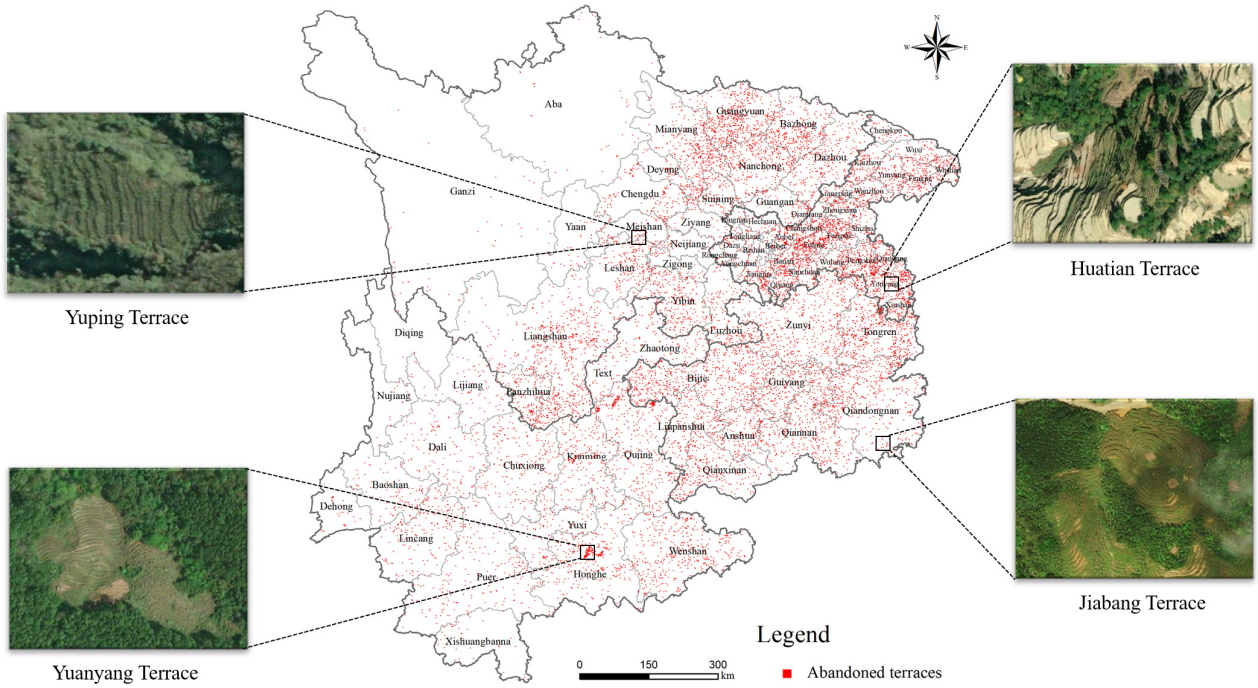

Figure 6. Distribution of abandoned terraces in mountainous areas of southwest China.

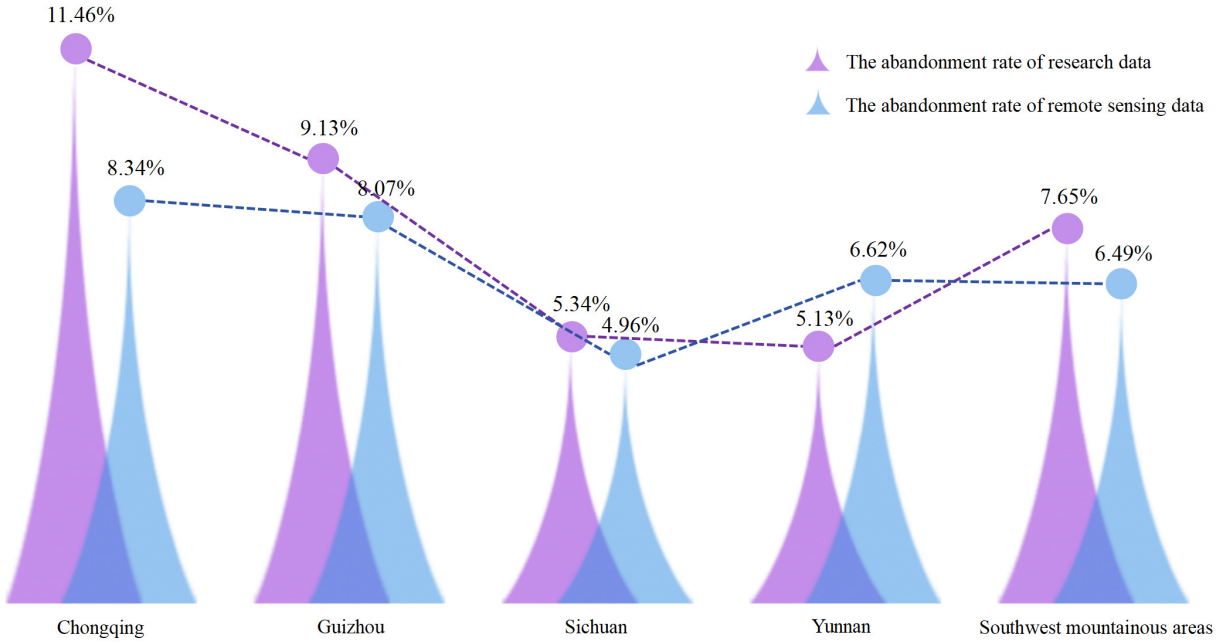

Figure 7. Comparative validation of terrace abandonment rate results in research area.

4.2. The Effect of Terrace Abandonment

The essence of terrace abandonment is the abandonment of arable land, with its primary impact being the challenge to food production, which has a significant negative impact on food production and threatens national food security to a certain extent [36]. The scale of abandoned terraces in the southwest mountainous areas has reached 449,360 ha, and according to the average yield of rice terraces in south China of 6510 kg/ha, the loss of grain production capacity due to terrace abandonment in this region amounts to approximately 2.96×10^9 kg (2.96 million tons) per year. According to the United Nations' food safety guideline of 400 kg per capita, the annual loss of food production in the mountainous areas of Southwest China due to terrace abandonment is close to the annual food consumption of

the population of Hong Kong Autonomous Region. In recent years, the increased frequency of global extreme weather events, national conflicts, high international food prices, and deterioration of the global food security situation have had a greater impact on China's food costs and planting structure [37]. China's modernization is characterized by a massive population, significant constraints on resource and environmental conditions, and a large population, which are prominent national conditions. Therefore, it is necessary to attach great importance to the study of terrace abandonment and to formulate effective strategies to alleviate this issue.

Terrace abandonment also has ecological impacts, affecting a range of complex ecological changes, including soil erosion [20], increased loss of soil and water [18], and changes in biodiversity [14]. Some studies have suggested that as abandoned land transitions into a natural ecosystem, the improved living environment for wildlife may increase their population, negatively impacting human production and life, leading to "ecosystem disservices" [38] and exacerbating conflicts in human–environment relationships. Additionally, abandoned terraces transitioning into natural environments also increase the risk and hazards of wildfires [39], and may even lead to geological disasters such as landslides [40].

Moreover, as one of the representatives of China's agricultural civilization, terraces hold significant agricultural cultural value and aesthetic landscape value [6,7], constituting important agricultural cultural heritage. Large-scale abandonment undoubtedly leads to the loss of these values carried by terraced fields, directly damaging the quality of core tourism resources, hindering the construction of rural ecological civilization, and impeding the effective implementation of rural revitalization strategies.

4.3. Strategies for Utilization and Conservation of Terrace Resources

Various measures can be taken at the local level to alleviate the current situation of terrace abandonment to protect and utilize terraced field resources.

First, local governments should identify the scale and distribution of abandoned terraces and take targeted measures to address the issue. For high-quality terraces with gentle slopes and large contiguous plots, terrace renovation and appropriate mechanization should be implemented. This includes leveling the plots, widening farming roads, improving farming conditions, and promoting the use of small- and medium-sized agricultural machinery to increase production efficiency. For steep slopes and small, scattered terraces, efforts should be made to encourage the cultivation of specialty crops suited for mountainous areas, thereby increasing planting income and utilization efficiency. As for fragmented and high-altitude low-quality terraces, a systematic implementation of returning farmland to forests and grasslands should be carried out to fully utilize the ecological service value of abandoned terraces [41].

The second is to encourage the circulation of terraces and actively attract useful social resources. Governments at all levels should establish specialized institutions for land transfer supply; strengthen supervision and guidance on the rural land transfer market; formulate preferential policies in conjunction with rural revitalization projects to attract talents, funds, models, technology, and management experience to develop characteristic agriculture in mountainous areas, including planting economic fruit forests according to local conditions, developing ecotourism, etc.; encourage individuals, social organizations, and enterprises to protect and manage mountainous land resources; and stimulate enthusiasm and initiative to participate in the protection and development of mountainous land resources.

5. Conclusions

The scale of abandoned terraces in the mountainous areas of Southwest China has reached 449,360 ha, with 63% of administrative villages experiencing terrace abandonment. Among these, villages in Chongqing Municipality have the highest abandonment rate at 79%. Additionally, 18.7% of rural households have abandoned terraces, with relatively high abandonment rates in Guizhou Province and Chongqing Municipality both exceeding 20%.

In terms of the area of abandoned terraces, the overall abandonment rate of terraces in the southwest mountainous areas is 7.65%, with Chongqing Municipality having the highest abandonment rate at 11.5% and Yunnan Province the lowest at 5.1%. The pattern of terrace abandonment in the study areas generally shows a higher in the east and lower in the west trend. Terrace abandonment is influenced by various factors such as external forces–internal thrust, among which the rapid development of urbanization and industrialization is the root cause of terrace abandonment in mountainous areas. The rise in non-agricultural wages has led to a large number of rural laborers moving to urban areas, which is an external force contributing to terrace abandonment. Under the action of external force, and due to the southwest mountainous areas with great terrain undulation, the fragmentation of land parcels, poor terrace-farming conditions, labor shortage, etc., have resulted in terrace farming cost increases and become the internal thrust driving rural households to abandon terraces. As a result of the combined impact of external force and internal thrust, the abandonment of terraces in the southwest mountainous areas is showing a rapid expansion trend.

To solve the problem of abandoned terraces in mountainous areas, we can start from the following aspects: First, local governments should conduct a comprehensive assessment to identify the scale and distribution of abandoned terraces. Based on the different characteristics and conditions of the terraces, targeted measures should be implemented to manage the abandonment problem. For high-quality terraces with gentle slopes and large contiguous plots, terrace renovation and appropriate mechanization should be implemented. For steep slopes and small, scattered terraces, efforts should be made to encourage the cultivation of specialty crops suited for mountainous areas, thereby increasing planting income and utilization efficiency. As for fragmented, high-altitude, and low-quality terraces, systematic implementation of returning farmland to forests and grasslands should be carried out to fully utilize the ecological service value of abandoned terraces [39]. Secondly, the government can formulate relevant preferential policies and favorable environments to encourage the circulation of terraces and the introduction of useful social resources, including talent, funds, models, technology, management experience, and so on. They can create favorable conditions for terrace management to stimulate the enthusiasm and initiative of land resource protection and personnel development in mountainous areas and achieve the redevelopment and utilization of abandoned terraces.

Undeniably, there are still deficiencies in this study. The accuracy of remote sensing identification of large-scale abandoned terraces is still not high enough, the identification methods and techniques are still to be improved, the mechanism of terrace abandonment is difficult to fully grasp, and there is a lack of prediction of the future development of abandonment. However, accurately grasping the overall situation and development trend of terrace abandonment is an important basis for revising relevant policies on land use and agricultural development in mountainous areas. It is still of great significance to determine the scale and mechanism of large-scale abandoned terraces. In the future, scholars can conduct in-depth research on improving the remote sensing accuracy of terrace identification, extraction technology of abandoned terraces, risk prediction models for abandonment, etc. and endeavor to carry out large-scale terrace abandonment assessment and mechanism research in major terrace distribution areas around the world. In addition, the effects of terrace abandonment, such as the loss of natural assets and livelihood capital for farmers, the impact of abandoned terraces in scenic areas on the quality of tourism resources, and the monitoring and response to geological disaster risks caused by terrace abandonment, are also worthy of discussion and research.

Author Contributions: Conceptualization, Y.W. and W.R.; methodology, W.R.; software, W.R. and A.Y.; validation, W.R., Y.W. and A.Y.; formal analysis, W.R.; investigation, Y.W.; resources, Y.W.; data curation, W.R.; writing—original draft preparation, W.R.; writing—review and editing, W.R. and A.Y.; visualization, W.R.; supervision, Y.W.; project administration, Y.W.; funding acquisition, Y.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Training Program of Innovation and Entrepreneurship for Undergraduates (202310635017), the National Natural Science Foundation of China (42271263, 41930757), Fundamental Research Funds for the Central Universities (SWU-KT22008), and we give thanks to the Chinese Academy of Sciences for providing the research data.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

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