Landscape Pattern-Based Ecological Risk Assessment of Cultivated Land in Hilly and Mountainous Areas: A Case Study of Tongnan District, Chongqing (Postprint)

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Abstract

[Purpose/Significance] The mechanization adaptation improvement of farmland in hilly and mountainous areas will alter the landscape pattern, elevation, slope, micro-topography, etc., of cultivated land, and evaluating its ecological risk is of great significance for providing data reference for subsequent improvement work. The objective of this study is to evaluate the changes in ecological risk of cultivated land caused by mechanization adaptation improvement in hilly and mountainous areas and to explore the relationship between ecological risk and cultivated land slope. [Method] Taking 20 counties in Tongnan District of Chongqing Municipality as evaluation units, based on land use data from 2010 and 2020, ArcGIS 10.8 and Excel software were used to calculate landscape pattern indices, the entropy weight method was employed to determine the weights of each index and construct an ecological risk assessment model to reveal the temporal and spatial variation characteristics of ecological risk; based on mathematical statistics principles, correlation analysis was conducted between ecological risk and slope to explore the relationship between ecological risk and slope. [Results and Discussion] During the two periods of 2010 and 2020, the disturbance index decreased from 0.97 to 0.94, indicating enhanced overall anti-interference capacity of cultivated land; the vulnerability index increased from 2.96 to 3.20, suggesting a more fragile structure of cultivated land; the ecological risk value decreased from 3.10 to 3.01, reflecting improved ecological security of cultivated land. In both periods, ecological risk areas were mainly low-risk and relatively low-risk zones, with low-risk area increasing by 6.44%, relatively low-risk area increasing by 6.17%, medium-risk area increasing by 24.4%, relatively high-risk area decreasing by 60.70%, and high-risk area increasing by 16.30%, resulting in a relative increase in ecologically secure areas of cultivated land. The slope of cultivated land was mainly within 2°~25°. When the slope of cultivated land was less than 15°, the proportion of slope area was negatively correlated with ecological risk value; when the slope of cultivated land was greater than 15°, the proportion of slope area was positively correlated with ecological risk value; when the slope was within 5°~8°, 15°~25°, and above 25°, the slope area was extremely significantly correlated with ecological risk value. Mechanization adaptation improvement of farmland should focus on the southern region of Tongnan District and concentrate on areas where cultivated land slope is within 5°~8° and 15°~25°. [Conclusion] By evaluating the ecological risk of cultivated land before and after mechanization adaptation improvement in Tongnan District and analyzing the correlation between ecological risk and cultivated land slope, it is demonstrated that mechanization adaptation improvement can reduce the ecological risk of cultivated land, the proportion of cultivated land slope area can serve as an important basis for precisely guiding mechanization adaptation improvement, and the mechanization adaptation improvement work in Tongnan District should focus on areas where cultivated land slope is within 5°~8° and 15°~25°.

Full Text

Ecological Risk Assessment of Cultivated Land Based on Landscape Pattern: A Case Study of Tongnan District, Chongqing

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Abstract

[Objective] Farmland consolidation for agricultural mechanization in hilly and mountainous areas alters the landscape pattern, elevation, slope, and microtopography of cultivated land. Assessing its ecological risk to provide data references for subsequent consolidation efforts is of great significance. This study aims to evaluate changes in cultivated land ecological risk before and after farmland consolidation for agricultural mechanization in hilly and mountainous areas, and to explore the relationship between ecological risk and cultivated land slope.

[**Methods**] Twenty towns in Tongnan District, Chongqing Municipality, were selected as evaluation units. Based on land use data from 2010 and 2020, landscape pattern indices were calculated using ArcGIS 10.8 and Excel software. Weights for each index were determined through the entropy weight method to construct an ecological risk assessment model, revealing temporal and spatial variation characteristics of ecological risk. Based on mathematical statistics principles, correlation analysis was performed between ecological risk and slope to investigate their relationship.

[**Results and Discussion**] From 2010 to 2020, the landscape disturbance index decreased from 0.97 to 0.94, indicating enhanced resistance to disturbance. The vulnerability index increased from 2.96 to 3.20, suggesting increased fragility of cultivated land structure. The ecological risk value decreased from 3.10 to 3.01, reflecting improved safety. During both periods, ecological risk areas were dominated by low-risk and relatively low-risk zones. Low-risk area increased by 6.44%, relatively low-risk area increased by 6.17%, moderate-risk area increased by 24.48%, relatively high-risk area decreased by 60.70%, and high-risk area increased by 16.30%, indicating a relative increase in cultivated land ecological safety zones. Cultivated land slope was primarily concentrated between 2° and 25°. When slope was less than 15°, the proportion of slope area was negatively correlated with ecological risk value; when slope exceeded 15%, the correlation became positive. Slope area proportion showed extremely significant correlation with ecological risk value when slope exceeded 25°. Farmland consolidation should focus on southern Tongnan District, particularly in areas with slopes between 5°–8° and 15°–25°.

[**Conclusion**] The assessment of ecological risk changes before and after farmland consolidation in Tongnan District and the analysis of correlations between ecological risk and slope demonstrate that farmland consolidation for agricultural mechanization can reduce ecological risk. The proportion of cultivated land slope area can serve as an important basis for precisely guiding farmland consolidation efforts. Future consolidation work in Tongnan District should prioritize areas with slopes between 5°–8° and 15°–25°.

Keywords: farmland consolidation for agricultural mechanization; cultivated land; ecological risk assessment; landscape pattern

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1. Introduction

Hilly and mountainous areas are important production bases for grain, oil, fruits, vegetables, and tea in China. However, natural conditions such as numerous slopes, steep gradients, small and scattered plots constrain agricultural mechanization development and limit agricultural economic growth. Since the mid-1990s, China has implemented land consolidation in hilly and mountainous areas to increase effective cultivated land area [**?**]. After years of exploration and practice, in 2014, Chongqing extended land consolidation content to promote farmland consolidation for agricultural mechanization, selecting accessible cultivated land with slopes not exceeding 25° and transforming scattered small plots into large plots such as sloping terraces, gentle slopes, and level terraces [?]. However, farmland consolidation for agricultural mechanization alters the original structure of cultivated land landscape, intensifying landscape fragmentation and segmentation, which affects farmland ecosystem stability to a certain extent [?]. In this context, studying cultivated land ecological risk can provide decision-making basis for risk prevention and control in farmland consolidation for agricultural mechanization, thereby promoting high-quality agricultural development in hilly and mountainous areas.

Currently, ecological risk assessment primarily focuses on land use change [?, ?], urban areas [?], watersheds [?, ?], and land consolidation [?, ?]. Main assessment methods include the Relative Risk Model (RRM) and Ecological Risk Index (ERI) [?, ?, ?]. RRM is used for regional composite pressure ecological risk assessment across multiple ecosystems such as terrestrial and aquatic systems, while ERI constructs evaluation models by selecting landscape pattern indices related to ecological risk values for landscape pattern studies. Existing landscape pattern-based ecological risk assessments for land consolidation mainly focus on evaluation index selection and model construction. Zhang et al. [?] selected landscape pattern indices such as plot size, plot fractal dimension, and plot separation degree to assess land consolidation impacts on hilly plot utilization. Sun et al. [?] selected indices related to cultivated land fragmentation such as patch number, mean patch area, edge density, and patch area coefficient of variation to analyze the applicability of landscape pattern indices in effectively representing cultivated land fragmentation changes. Pei et al. [?] constructed a vulnerability model through landscape pattern indices and built a cultivated land landscape ecological security evaluation model using landscape vulnerability, boundary fragmentation, and landscape type fragmentation. Wu et al. [?] used the RRM model to study interactions among risk sources, habitats, and risk receptors in land consolidation, classified risk levels, and quantitatively expressed ecological risk values. Additionally, some scholars have used mathematical statistics to analyze correlations between landscape pattern and cultivated land characteristics. Han et al. [?] analyzed correlations between landscape pattern indices and cultivated land quality to reflect cultivated land quality through landscape pattern indices. Zhang et al. [?] studied causes of cultivated land fragmentation based on global regression analysis, correlation analysis, and geographically weighted analysis, finding that cultivated land fragmentation had the highest negative correlation with average slope.

These studies provide approaches for cultivated land landscape pattern ecological risk assessment and correlation analysis based on landscape pattern. However, few scholars have explored the relationship between landscape pattern ecological risk and topographic factors. After farmland consolidation for agricultural mechanization transforms steep slopes into gentle slopes, cultivated land slope is affected, causing landscape pattern ecological risk to exhibit distribution differences across different slope characteristics [?]. Evaluating ecological risk changes before and after farmland consolidation for agricultural mechanization and exploring the relationship between ecological risk and cultivated land slope are of significant importance and application value. This study selected Tongnan District, Chongqing Municipality, as the research area, using land use data from 2010 and 2020. ArcGIS 10.8 and Excel software were used to calculate landscape pattern indices, and the entropy weight method was applied to determine index weights and construct an ecological risk assessment model. DEM data from 2010 and 2020 were processed to calculate slope and classify slope grades, analyzing the proportion of cultivated land area across different slope grades. From a landscape ecology perspective, this study reveals temporal and spatial variation characteristics of landscape pattern ecological risk and analyzes correlations between landscape pattern ecological risk and the proportion of cultivated land area across different slope grades to explore the relationship between ecological risk and slope, aiming to provide data references for farmland consolidation for agricultural mechanization in Tongnan District.

1.1 Study Area Overview

Tongnan District is located in northwestern Chongqing, central-eastern Sichuan Basin, along the middle and lower reaches of the Fu River, at the junction of Sichuan and Chongqing, between 105°31 44 E–106°00 20 E and 29°47 33 N–30°26 28 N. The landform belongs to the central Sichuan hilly area, with higher terrain in the northeast and south, and lower terrain in the central region. Most areas have elevations between 250–450 m, with a total elevation difference of 371 m. Cultivated land with slopes less than 25° accounts for approximately 90% of the total cultivated land area. Tongnan District belongs to the Jialing River system, with the Fu and Qiong Rivers running through the district from northwest to southeast. The district is narrow and elongated, 46.9 km wide from east to west and 72.1 km long from north to south, covering a total area of 1,584 km^2. It has 3 subdistricts and 20 towns under its jurisdiction. In 2015, Tongnan District took the lead in implementing farmland consolidation for agricultural mechanization, selecting contiguous areas with road access and slopes less than 25° for plot interconnection, elimination of operation dead angles, and optimization of plot layout [?]. By 2022, Tongnan District had completed 800 hm^2 of farmland consolidation for agricultural mechanization, covering 22 towns and subdistricts. Based on the amount of cultivated land and consolidation implementation in each town, this study selected 20 towns (excluding Guilin, Zitong, and Dafu subdistricts) as the research area. The elevation map is shown in Figure 1 [Figure 1: see original paper].

1.2 Data Sources and Preprocessing

Tongnan District has been implementing farmland consolidation for agricultural mechanization continuously from 2015 to 2022. To investigate temporal and spatial changes in cultivated land landscape pattern ecological risk caused by consolidation, 2015 was selected as the time node, with the 5-year period before consolidation (2010) and the 5-year period after consolidation (2020) as the study periods. All data processing was completed using ArcGIS 10.8 and Excel software. Land use data for both periods were obtained from the Geographic Monitoring Cloud Platform (http://www.dsac.cn/), from which raster data on cultivated land distribution were extracted for landscape pattern index analysis. The 2010 DEM data had a spatial resolution of 12.5 m from the ALOS PALSAR dataset, while the 2020 DEM data had a spatial resolution of 30 m from the SRTM1 V3.0 dataset (https://earthdata.nasa.gov/), used for calculating cultivated land slope. Chinese administrative division vector data were obtained from the Ministry of Natural Resources Standard Map Service (http://bzdt.ch.mnr.gov.cn/) for clipping land use raster data and DEM raster data.

1.3.1 Selection of Landscape Pattern Indices

Landscape pattern indices can quantitatively reflect landscape structural composition and spatial configuration characteristics, representing plot regularity, fragmentation scale, and spatial dispersion of cultivated land [?]. Considering the meanings of various indices and actual consolidation operations, and referencing commonly used indices in land consolidation and landscape pattern ecological risk assessment [?], six landscape pattern indices reflecting cultivated land shape, scale, and spatial distribution characteristics were selected.

Tongnan District's hilly landform results in scattered and fragmented cultivated land plots, causing difficulties for agricultural machinery access and operation, severely restricting agricultural mechanization development and hindering large-scale cultivated land development. Therefore, Patch Density (PD) and Division (D) were selected to characterize cultivated land distribution. PD reflects cultivated land fragmentation through relative patch size and density—higher PD indicates smaller patches, more difficult cultivation, and higher fragmentation [?]. D characterizes patch separation degree—higher values indicate more dispersed and complex landscape distribution [?].

Additionally, the complex shape of cultivated land in Tongnan's hilly terrain makes sloping land inaccessible and causes difficulties for machinery movement and turning, complicating land management. Therefore, Fractal Dimension (FD) and Edge Density (ED) were selected to characterize cultivated land scale. FD measures landscape patch complexity—higher values indicate more complex patch shapes. ED describes the degree of landscape segmentation by boundaries, directly reflecting landscape fragmentation [?].

Furthermore, Mean Shape Index (MSI) and Mean Patch Size (MPS) were selected to characterize cultivated land shape features. MSI, calculated from Landscape Shape Index (LSI), macroscopically describes cultivated land shape. LSI values approaching 1 indicate shapes closer to squares, which are easier to manage; values further from 1 indicate more irregular shapes that are more difficult to manage [?]. MPS macroscopically describes patch area size—smaller patches indicate poorer cultivability. The ecological significance and calculation methods of relevant landscape pattern indices are shown in Table 1 .

1.3.2 Construction of Ecological Risk Assessment Indices

To quantitatively express the relationship between cultivated land landscape pattern changes and landscape ecological risk, landscape disturbance index and landscape vulnerability index were constructed based on landscape ecology theory [?] and the six selected landscape pattern indices [?, ?]. The ecological risk assessment index was then built from these two indices to quantitatively transform cultivated land landscape shape, scale, and spatial characteristics into landscape ecological risk values.

1) Landscape Disturbance Index (U). During farmland consolidation for agricultural mechanization in Tongnan District, cultivated land changes from a discontinuous, complex pattern to an interconnected, relatively simple pattern. For example, consolidation can reduce slope gradients, eliminate operation dead angles, extend machinery movement routes, and increase plot scale. These modifications directly affect cultivated land landscape pattern, reducing boundaries and transition zones between plots, thereby improving overall farmland scale and continuity and making landscape patterns more unified and orderly. Therefore, PD, D, and FD, which significantly impact landscape pattern, were selected to construct the landscape disturbance index [?], as shown in Equation (8):

$$U = a \times PD + b \times D + c \times FD$$

where U is the landscape disturbance index; PD is patch density (patches/km^2); D is division; FD is fractal dimension; and a, b, c are the weights of PD, D, and FD, respectively.

Drawing on existing research and considering actual consolidation conditions in the study area, PD was considered to have the greatest impact on landscape pattern, followed by D and FD. Therefore, weights a, b, and c were assigned values of 0.5, 0.3, and 0.2, respectively, with $a + b + c = 1$ [?, ?].

2) Landscape Vulnerability Index (V). The landscape vulnerability index characterizes the fragility of cultivated land structure—higher values indicate less stable ecosystems. Based on ecological meanings of indices, ED, MSI, and MPS, which are closely related to landscape vulnerability, were selected to construct the landscape vulnerability index, as shown in Equation (9):

$$V = W_1 \times ED + W_2 \times MSI + W_3 \times MPS$$

where V is the landscape vulnerability index; ED is edge density (km); MSI is mean shape index; MPS is mean patch size (km^2/patch); and W_1, W_2, W_3 are the weights of ED, MSI, and MPS, respectively.

3) Weight Calculation for Landscape Vulnerability Index. Compared with subjective methods such as the Analytic Hierarchy Process, the entropy weight method is an objective approach for weight determination [**?**, **?**]. Therefore, this method was used to calculate weights for ED, MSI, and MPS to improve scientific rigor. Before weight calculation, the range standardization method [**?**] was applied to normalize indices for comparability. Based on impacts on landscape pattern, ED and MSI were classified as negative indicators, while MPS was classified as positive. Negative indicators are negatively correlated with V, while positive indicators are positively correlated. Normalization calculations are shown in Equations (10) and (11):

$$\text{Positive indicator: } U_i = \frac{X_i - X_{i\min}}{X_{i\max} - X_{i\min}} \quad (10)$$

$$\text{Negative indicator: } U_i = \frac{X_{i\max} - X_i}{X_{i\max} - X_{i\min}} \quad (11)$$

where U_i is the normalized value; X_i is the original value of the ith county's landscape pattern index; $X_{i\min}$ is the minimum value; and $X_{i\max}$ is the maximum value.

The entropy value (e_i) of landscape pattern indices was calculated using Equation (12):

$$e_i = -\frac{1}{\ln(n)} \sum_{i=1}^{n} P_{ij} \ln(P_{ij})$$

where n is the number of evaluation units.

The weight (W_i) was calculated using Equation (13):

$$W_i = \frac{1 - e_i}{\sum_{i=1}^{m} (1 - e_i)}$$

where m is the number of landscape pattern indices. The calculated weights were $W_1 = 0.31$ for ED, $W_2 = 0.45$ for MSI, and $W_3 = 0.24$ for MPS.

4) Ecological Risk Index (ERI). Based on the landscape disturbance index and vulnerability index, the ecological risk assessment index was constructed to characterize ecological risk degree in evaluation units. Higher values indicate greater ecological risk, calculated using Equation (14):

$$ERI = U \times V$$

where ERI is the ecological risk assessment index; U is the landscape disturbance index; and V is the landscape vulnerability index.

1.3.3 Correlation Analysis Between Ecological Risk Value and Slope

According to the slope classification standards in the Third National Land Survey [?], farmland consolidation for agricultural mechanization should preferably select areas with slopes below 25°, with areas below 15° prioritized. Considering actual terrain characteristics in the study area—where cultivated land with slopes of 0°–2° and >25° is limited, and most cultivated land has slopes of 2°–25°—the 2°–25° range was subdivided into four grades to determine optimal consolidation slopes. Cultivated land slopes were classified into six grades: 0°–2°, 2°–5°, 5°–8°, 8°–15°, 15°–25°, and >25°, designated as Grade I, II, III, IV, V, and VI, respectively. The proportion of area for each slope grade in each evaluation unit was calculated. Using SPSS 26 software, correlation analysis was performed between slope grade area proportions and cultivated land landscape ecological risk values to reveal relationships between slope and landscape ecological risk, thereby determining consolidation direction.

2.1.1 Temporal Characteristics of Cultivated Land Landscape Ecological Risk

Based on landscape pattern index calculation formulas, cultivated land PD, D, FD, landscape disturbance index, ED, MSI, MPS, landscape vulnerability index, ecological risk assessment index, and their mean values were calculated for each evaluation unit in 2010 and 2020. Results are shown in Table 2 . From 2010 to 2020, mean values of PD, D, and FD decreased from 0.75, 1.76, and 0.35 to 0.71, 1.72, and 0.34, respectively, indicating reduced fragmentation and increased plot contiguity. The mean disturbance index decreased from 0.97 to 0.94, showing enhanced overall resistance to disturbance. Mean ED decreased from 2.74 to 2.56, mean MPS increased from 4.40 to 5.55, indicating reduced segmentation. Mean MSI increased from 1.36 to 1.53, showing more irregular plot shapes. Mean vulnerability index increased from 2.96 to 3.20, indicating increased landscape fragility. The ecological risk assessment index decreased from 3.10 to 3.01, indicating reduced ecological risk. Notably, Huayan Town's MSI increased dramatically from 5.10 in 2010 to 27.25 in 2020. Examination of original data revealed that while cultivated land patches in Huayan Town decreased and connectivity increased, the irregularity of plot shapes also increased substantially, explaining this large difference.

Tongnan District has continuously implemented farmland consolidation for agricultural mechanization since 2015. From a macro perspective, the decreased mean values of PD, D, FD, and ecological risk indicate that national consolidation policies have achieved significant results in reducing fragmentation, improving plot connectivity, and enhancing ecological safety.

2.1.2 Spatial Distribution and Transformation Characteristics of Ecological Risk

Based on cultivated land landscape ecological risk values calculated from the ecological risk assessment index, each evaluation unit was assigned a value using ArcGIS 10.8 software. To clearly distinguish different risk grades, the subjective classification method [**?**] was used to divide risk into five levels: low risk (ERI < 1.75), relatively low risk ($1.75 \leq$ ERI < 2.00), moderate risk ($2.00 \leq$ ERI < 2.25), relatively high risk ($2.25 \leq$ ERI < 2.50), and high risk (ERI ≥ 2.50). Spatial distribution maps for 2010 and 2020 were generated (Figure 2 [Figure 2: see original paper]), and area, proportion, and change rate for each risk grade were calculated (Table 3).

As shown in Figure 2 and Table 3, high-risk areas accounted for a small proportion in both 2010 and 2020, with area increasing by 26.24 km^2 (16.30% change rate). Xinsheng, Wofu, and Wugui towns maintained the same risk level. Relatively high-risk area decreased by 130.30 km^2 (60.70% change rate), with Yuxi, Guxi, and Baolong towns decreasing to moderate, relatively low, and low risk, respectively. Moderate-risk area increased by 53.31 km^2 (24.48% change rate), with Chongkan Town unchanged, Tai'an and Biekou towns decreasing to low and relatively low risk, respectively, and Huayan Town converting to high risk. Relatively low-risk area had the largest proportion, accounting for 34.62% in 2010 and 36.76% in 2020, with area increasing by 29.74 km^2 (6.17% change rate). Shouqiao, Shuangjiang, and Shanghe towns remained unchanged, while Mixing Town converted to moderate and relatively high risk. Low-risk area proportion was second only to relatively low-risk area, increasing by 20.11 km^2 (6.44% change rate). Tangba and Tianjia towns remained unchanged, while Xiaodu and Qunli towns converted to relatively low risk.

During the entire study period, different risk grades showed significant differences in area change. Low, relatively low, moderate, and high-risk areas expanded, while relatively high-risk areas contracted, indicating that low-risk areas gradually dominated the overall layout. Farmland consolidation for agricultural mechanization increased plot operation connectivity and achieved success in merging small plots into larger ones. However, Huayan Town emerged as a new high-risk area, likely due to accelerated urbanization and industrialization in recent years, as indicated by statistical yearbooks.

Low and relatively low-risk areas spread northward, moderate-risk areas spread westward, relatively high-risk areas remained in the north with new additions spreading northeastward, and high-risk areas remained mainly in the south with new additions spreading northwestward. These patterns indicate that farmland consolidation for agricultural mechanization was more effective in northern Tongnan District, facilitating agricultural resource development. The southern region showed less effective results, requiring continued optimization of cultivated land landscape pattern in future consolidation efforts, such as increasing plot connectivity and eliminating transitional boundaries between plots to ensure sustainable agricultural development.

2.2.1 Analysis of Cultivated Land Slope Grade Area Proportion

Using Excel software, the proportion of cultivated land area for each slope grade in each evaluation unit was calculated, and bar charts for 2010 and 2020 were generated (Figure 3 [Figure 3: see original paper]).

Figure 3 shows that slope grade area proportions within the same evaluation unit changed little between the two periods, but significant differences existed among different slope grades. Both periods were dominated by Grade IV slopes, with proportions ranging from 23% to 43%. Grade II and III slope proportions ranged from 7% to 35%, with similar trends within the same evaluation unit. Grade V slope proportions ranged from 2% to 38%, showing the largest variation among evaluation units. Grade I and II slope proportions ranged from 0.03% to 13%, with smaller variations. These results indicate that most cultivated land in the study area has slopes of 2°–25°, with large topographic variations among evaluation units in this range. Areas with slopes less than 2° or greater than 25° account for small proportions with minimal topographic variation among evaluation units.

2.2.2 Correlation Between Ecological Risk and Cultivated Land Slope

Using the proportion of slope area at each grade as independent variables and corresponding ecological risk values as dependent variables, correlation analysis was performed between slope grade area proportions and ecological risk values using SPSS 26 software. Correlation coefficients are shown in Table 4 .

Table 4 shows varying degrees of correlation between different slope grade area proportions and ecological risk values. In both 2010 and 2020, Grade I, II, III, and IV slope area proportions were negatively correlated with ecological risk values, while Grade V and VI proportions were positively correlated. In 2010, correlation coefficients ranked as: Grade VI (0.849) > Grade V (0.609) > Grade III (0.592) > Grade II (0.438) > Grade I (0.374) > Grade IV (0.320). Grade III, V, and VI showed highly significant correlations; Grade II showed significant correlation; Grades I and IV showed non-significant correlations. Therefore, within the 0°–15° range, ecological risk values decreased with increasing slope area proportion, while above 15°, risk values increased with slope area proportion.

In 2020, correlation coefficients ranked as: Grade VI (0.839) > Grade V (0.729) > Grade III (0.677) > Grade II (0.534) > Grade I (0.471) > Grade IV (0.049). Grades II, III, V, and VI showed highly significant correlations; Grade I showed significant correlation; Grade IV showed non-significant correlation. Within the 0°–8° range, ecological risk values decreased with increasing slope area proportion, while above 15°, risk values increased with slope area proportion. Overall, correlation coefficients increased with slope grade, with strict increasing trends for Grades I, II, III, V, and VI. Grade IV showed the smallest correlation coefficient. The correlation coefficient for Grade VI exceeded 0.8 in both periods, indicating that slopes above 25° had the greatest impact on ecological risk values, far exceeding the impact of slopes between 8°–15°. Additionally, correlation coefficients for Grade III and V increased from 2010 to 2020, indicating strengthened correlations in these slope ranges.

Based on these results, within the 0°–15° slope range, appropriate crops suitable for local conditions should be planted during consolidation to improve yield and quality while balancing ecological risk. Above 15°, appropriate irrigation methods and integrated water-fertilization management strategies should be implemented to prevent soil erosion and water waste.

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3. Discussion

Farmland consolidation for agricultural mechanization is primarily based on cultivated land landscape pattern. Changes in landscape pattern indices such as fragmentation and separation degree affect cultivated land quality and utilization efficiency. Therefore, using landscape pattern indices to construct an ecological risk model can effectively assess cultivated land ecological risk values. Additionally, consolidation affects micro-topography, slope, and elevation, with slope being a major factor influencing soil erosion. Analyzing correlations between slope area proportion and ecological risk values can identify priority slope ranges for efficient consolidation implementation.

This study evaluated cultivated land ecological risk in Tongnan District from landscape pattern and topographic perspectives, yielding the following findings:

1) Based on landscape pattern index calculations, mean values of PD, D, FD, and ED decreased from 2010 to 2020, while mean MPS increased, indicating reduced fragmentation and segmentation after consolidation. Scattered cultivated land was merged into larger plots, increasing contiguity and facilitating centralized machinery management and large-scale

operation. Increased MSI indicated more complex plot shapes, potentially requiring consideration of machinery access convenience. The disturbance index decreased from 0.97 to 0.94, enhancing overall resistance to disturbance. The vulnerability index increased from 2.96 to 3.20, indicating increased structural fragility, possibly related to accelerated urbanization and destruction of original landscape structures. The ecological risk assessment index decreased from 3.10 to 3.01, reducing ecological risk. Farmland consolidation for agricultural mechanization effectively improved cultivated land landscape pattern, compensating for human activity disturbances and enhancing farmland ecosystem security.

2) Spatial distribution and transformation characteristics showed that low-risk and relatively low-risk areas dominated in both 2010 and 2020. Low-risk area increased by 6.44%, spreading northward; relatively low-risk area increased by 6.17%, spreading central-east and southeast; moderate-risk area increased by 24.48%, spreading west and northwest; relatively high-risk area decreased by 60.70%, with new additions spreading northeast; high-risk area increased by 16.30%, with new additions spreading northwest. Overall, ecological risk decreased and safety zones increased.

Cultivated land slope was primarily concentrated between 2°–25° in both periods, with large topographic variations among evaluation units. Slope area proportion was negatively correlated with ecological risk value below 15° and positively correlated above 15°. In 2010, highly significant correlations occurred at 5°–8°, 15°–25°, and >25°, with coefficients of 0.592, 0.609, and 0.849, respectively. In 2020, highly significant correlations occurred at 2°–5°, 5°–8°, 15°–25°, and >25°, with coefficients of 0.534, 0.667, 0.729, and 0.839, respectively. Correlation coefficients for 5°–8° and 15°–25° increased, strengthening their relationships with risk values. According to relevant data, moderate sheet erosion begins at 5° slopes, with intense erosion occurring at 10°–15°. Considering ecological risk reduction and actual terrain conditions, farmland consolidation for agricultural mechanization should focus on southern Tongnan District, particularly in the 5°–8° and 15°–25° ranges. Although slopes above 25° are considered unsuitable for agricultural production, their high correlation with ecological risk suggests that small-scale slope consolidation above 25° could be beneficial.

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4. Conclusion

This study constructed an ecological risk assessment model to reveal temporal and spatial variation characteristics of ecological risk before and after farmland consolidation for agricultural mechanization in Tongnan District, Chongqing. Based on mathematical statistics principles, correlation analysis between ecological risk and slope explored their relationship. Comparing ecological risk values between 2010 and 2020, farmland consolidation for agricultural mechanization reduced cultivated land ecological risk and improved safety. The proportion of cultivated land slope area correlates with ecological risk values. Considering Tongnan District's actual terrain and ecological risk reduction, future consolidation should prioritize southern areas with slopes between 5°–8° and 15°–25°.

This study did not consider internal cultivated land factors such as soil organic matter content and soil compaction degree. Future research could incorporate soil quality factors for more comprehensive analysis of ecological risk changes caused by farmland consolidation for agricultural mechanization.

Conflict of Interest Statement: The authors declare no conflicts of interest related to this research.

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