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Characteristics and Influencing Factors of Landscape Pattern Gradient Transformation of Small-Scale Agroforestry Patches in Mountain Cities

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Abstract: Small-scale agroforestry patches possess irreplaceable value compared to large-scale patches. In southwestern mountainous cities of China, the complex terrain and urbanization have led to the presence of numerous small, fragmented agroforestry patches around urban areas. These patches serve as crucial habitats for endemic species and provide essential space for wild food sources, thereby contributing to a range of ecosystem services. Consequently, their proper conservation and utilization planning are of paramount importance. This study investigates the transformation characteristics of landscape patterns of mountainous small-scale agroforestry patches and their constituent elements across urban–rural gradients, identifying the driving factors behind these transformations to support conservation and utilization planning. From an urban–rural gradient perspective, four directional transects were selected and divided into uniform sample grids. Using Fragstats 4.3, landscape indices of small-scale agroforestry patches were calculated, analyzing the transformation characteristics of these patches and their elements across different gradients. Spearman correlation coefficients in SPSS were employed to assess the influence of terrain and relevant anthropogenic factors on the transformation of agroforestry patches. The findings reveal the following: (1) Small-scale agroforestry patches and their elements exhibit similar patterns in terms of size, fragmentation, dispersion, and connectivity, showing an "increasing trend in size and connectivity, decreasing fragmentation, and fluctuating dispersion" from urban centers to natural areas, with slight variations in orchard patches. However, patch cohesion and shape complexity display nonlinear differentiated transformation characteristics. (2) Overall, small-scale agroforestry patches are significantly influenced by anthropogenic construction factors, with the landscape pattern of forest patches notably affected by terrain factors. (3) Across urban–rural gradient zones, the landscape patterns of small-scale agroforestry patches in urban centers, suburbs, and rural natural areas are more affected by terrain factors, whereas those in urban construction zones are significantly influenced by anthropogenic construction factors. The findings of this study provide a scientific basis for the conservation and planning of mountainous small-scale agroforestry patches.

Keywords: mountain cities; small-scale agroforestry patches; urban–rural gradient; landscape pattern; woodland patches; cultivated land patches; garden land patches; influencing factors

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1. Introduction

Small-scale agroforestry patches (SAPs) have been recognized as an important resource type in countries such as those in Europe since the early 21st century [1] and have been designated as key conservation targets [2]. These patches, also referred to as small-scale high nature value farmlands and home gardens, have seen a growing body of research since the 1980s. A search for the terms "High Value Farmland" and "home garden" in the Web of Science and Scopus databases reveals that the number of scientific papers published

annually on this topic did not exceed nine until 2006. By 2015, this number had increased to 19 papers per year. France published the first peer-reviewed article on SAPs in 2006, while Italy and Portugal began publishing in this field in 2010 and 2012, respectively. A total of 25 European countries have published peer-reviewed articles focusing on themes such as biodiversity, environmental science, and agricultural conservation policies related to SAPs [3]. Furthermore, research has demonstrated that SAPs possess significant species diversity value [4–6], habitat ecological maintenance value [7–9], wild food production value [10,11], diversified food supply value [12], medicinal plant supply [13–15], landscape recreation [16,17], preservation of traditional horticultural practices [18], and green infrastructure value [19]. In addition, the mountainous cities of southwestern China, due to their complex topography and climatic conditions, boast high forest coverage, creating environments rich in biodiversity [20,21]. The landscape resource value and species diversity value of SAPs in these mountainous areas are particularly notable [22,23]. In conclusion, SAPs in mountainous cities hold significant conservation value and present substantial research potential. However, rapid urbanization in China has significantly changed the spatial structure of urban and rural areas. Construction land has expanded uncontrollably, encroaching on surrounding natural resources such as farmland, forest land, grassland, and wetlands [24–26]. This has caused a series of environmental problems [27]. Rural settlements and SAPs, already fragmented by mountainous terrain and human activities [28], have become even more fragmented. Urban construction has further divided them with roads, public service facilities, and buildings, leading to their gradual erosion [29].

In China's land-use classification, SAPs refer to small, scattered agricultural and forestry lands not designated as protected areas. These patches are fragmented and dispersed due to complex mountainous terrain and human factors. According to national and local laws in China, farmland, orchards, and forest land under 3.3 hectares are not strictly regulated. Only forest land above 3.3 hectares and contiguous farmland and orchards are subject to clear regulatory requirements. In Chongqing, farmland and orchards above 3.3 hectares are designated as high-standard farmland, while smaller plots have no clear regulatory requirements and their occupation is not penalized. This makes them susceptible to encroachment by construction land in urban planning. Therefore, this study focuses on SAPs under 3.3 hectares that are not within protected areas. These patches are abundant in mountainous regions, and their total area is not less than that of protected agroforestry lands. Due to a lack of official recognition of their value, these patches lack protection and are gradually eroded and disappear. Research on these unique mountain agroforestry resources is crucial for urban development planning in mountainous cities.

To prevent further degradation due to urban expansion and effectively safeguard small agricultural and forest patches, understanding the transformation dynamics of small agricultural and forestry patches (SAPs) along the urban–rural gradient is crucial for devising scientifically sound protection and planning strategies. The concept of the urban-to-rural gradient, introduced by McDonnel in 2008, examines the ecological processes in complex urban–rural spatial environments and the impact of urbanization on such spaces. McDonnel extensively investigated urban–rural gradients from downtown New York to rural Litchfield County, Connecticut (along a 140 × 20 km research transect), unveiling the characteristics and causes of forest ecosystem structure, soil composition, climate, impermeability, land cover, and cultural composition along the gradient. This research aimed to develop a rational conservation strategy for natural resources along this trajectory [30]. Additionally, various studies have explored woodlands [31,32], cultivated land [33], insects [34], birds [35,36], changes in heat island intensity [37], water quality transformation [38], and landscape indices transformation [39] based on urban–rural gradients. Analyzing the changing characteristics of each factor along the urban–rural gradient provides a scientific foundation for planning and adaptive strategies.

Landscape pattern indices are metrics used to quantify and describe the spatial structure and distribution of landscapes. By analyzing the size, shape, number, and arrangement of various land use types, these indices reveal landscape complexity, heterogeneity, and

ecological processes [40]. They can be used to assess the health of landscape ecosystems. For example, the patch area, shape index, and connectivity index can evaluate habitat quality and biodiversity [41]. They also indirectly represent the ecosystem service capacity of landscape elements [42]. Calculating landscape indices helps to understand the spatial distribution and interactions of ecological processes within landscapes [43]. Connectivity is crucial for species migration and gene flow, while heterogeneity affects ecosystem stability and productivity. Additionally, landscape pattern indices provide scientific support for land-use planning and ecological management. Understanding the current landscape structure allows for the development of more effective conservation and management strategies [44]. Similarly, calculating landscape indices can reflect the current spatial pattern characteristics of SAPs in different gradient zones. This information is useful for formulating targeted planning strategies. Currently, there are many types of landscape indices [45]. For analyzing the transformation characteristics of SAPs in urban–rural gradient zones, indices such as the patch area, patch density, edge density (dispersion index, landscape division), aggregation index (landscape connectivity index), fractal dimension, and largest patch index (LPI) are commonly used [46]. By calculating these indices, we can comprehensively analyze the current structural characteristics of the landscape.

The transformation characteristics of landscape Indices for SAPs and their elements (farmland, orchards, forest land) can represent the current landscape structure along the urban–rural gradient. The spatial distribution of SAPs and each agricultural and forestry element along this gradient determines the direction of conservation strategies. For example, by calculating patch density in different zones, we can understand the fragmentation of farmland patches. Based on the current state of fragmentation, we can predict further fragmentation trends and develop control measures to prevent the further fragmentation of farmland in specific zones. For already fragmented areas, we need to increase farmland connectivity [47]. Furthermore, understanding the specific factors driving the transformation of SAPs can inform the development of targeted management measures for different zones. Scholars generally believe that both natural and human factors influence these transformations [48]. Natural factors include topography, hurricanes, and geological disturbances [49]. The current landscape pattern of SAPs in mountainous areas is greatly influenced by complex topography. Different elevations, slopes, and terrain undulations lead to significant differences in the distribution of these patches [50]. Human factors affecting these patches include construction intensity, road size, and density, as well as urbanization and economic activities [51]. Understanding the impact of these driving factors on SAPs helps in formulating more rational and differentiated management rules for SAPs in various zones.

To sum up, this paper includes three research objectives:

(1) What are the transformation characteristics of landscape patterns for SAPs and their elements (farmland, orchards, forest land) along the urban–rural gradient in mountainous city planning areas?

(2) What are the overall driving factors for SAPs and their elements (farmland, orchards, forest land) along the urban–rural gradient within the planning area of mountainous cities?

(3) What are the driving factors for SAPs and their elements (farmland, orchards, forest land) in different zones along the urban–rural gradient within the planning area of mountainous cities?

2. Materials and Methods

2.1. Study Area

For the present case study, we selected Yongchuan District in Chongqing City, located in Southwest China. Chongqing stands out as one of the most developed cities in China, serving as a core city within the Cheng-Yu economic circle. Characterized by diverse topography and challenging landforms, Chongqing is a representative mountainous city, posing difficulties in construction [52]. By visiting the districts of Chongqing, it is found that there are a lot of SAPs existing in the urban planning area, which form the special landscape

features of mountainous areas and are the potential resource elements of mountainous areas, as a part of urban and rural green infrastructure, these can play social, economic, ecological and other composite functions (Figure 1). These fragmented agricultural and forestry lands show different morphological characteristics along the urban–rural gradients, especially in the urban planning area/affected area, and these SAPs will gradually disappear as the city expands, planning areas are therefore considered as study areas. This led to the selection of the Chongqing Yongchuan Urban Planning Area as a case study (Figure 2), an area of 175 square kilometers.



Figure 1. Diagram of the current status of SAPs in the urban built-up area and urban fringe within the urban planning zone.

2.2. Research Framework

The study is divided into four steps: first, through the introduction part of the status of Agriculture and forestry in the Southwest Mountain region of policy analysis, we selected 3.3 hectares of unprotected agricultural and forestry land. Secondly, the samples were randomly selected from four different directions from rural to the urban center, and divided into an equal-distance grid of sample points. Thirdly, through the analysis of the data, the agricultural and forest patch and each element landscape indices were calculated by Fragstats 4.3. At the same time, the gradient change in the related factors was calculated; SPSS 19.0 Spearman correlation analysis was used to study the relationship between small-scale agroforestry patches and their influencing factors, and to determine which factors are the main driving forces to promote the segmentation, fragmentation, and even disappearance of agroforestry patches. Through the above research process, on the one hand, we can grasp the change characteristics of small-scale agricultural and forest patches and provide a scientific basis for the protection and utilization of small-scale agricultural and forest patches in urban planning areas; on the other hand, we know the factors that affect the characteristics of the patch pattern, which can provide the basis for the management and control of small-scale patches.

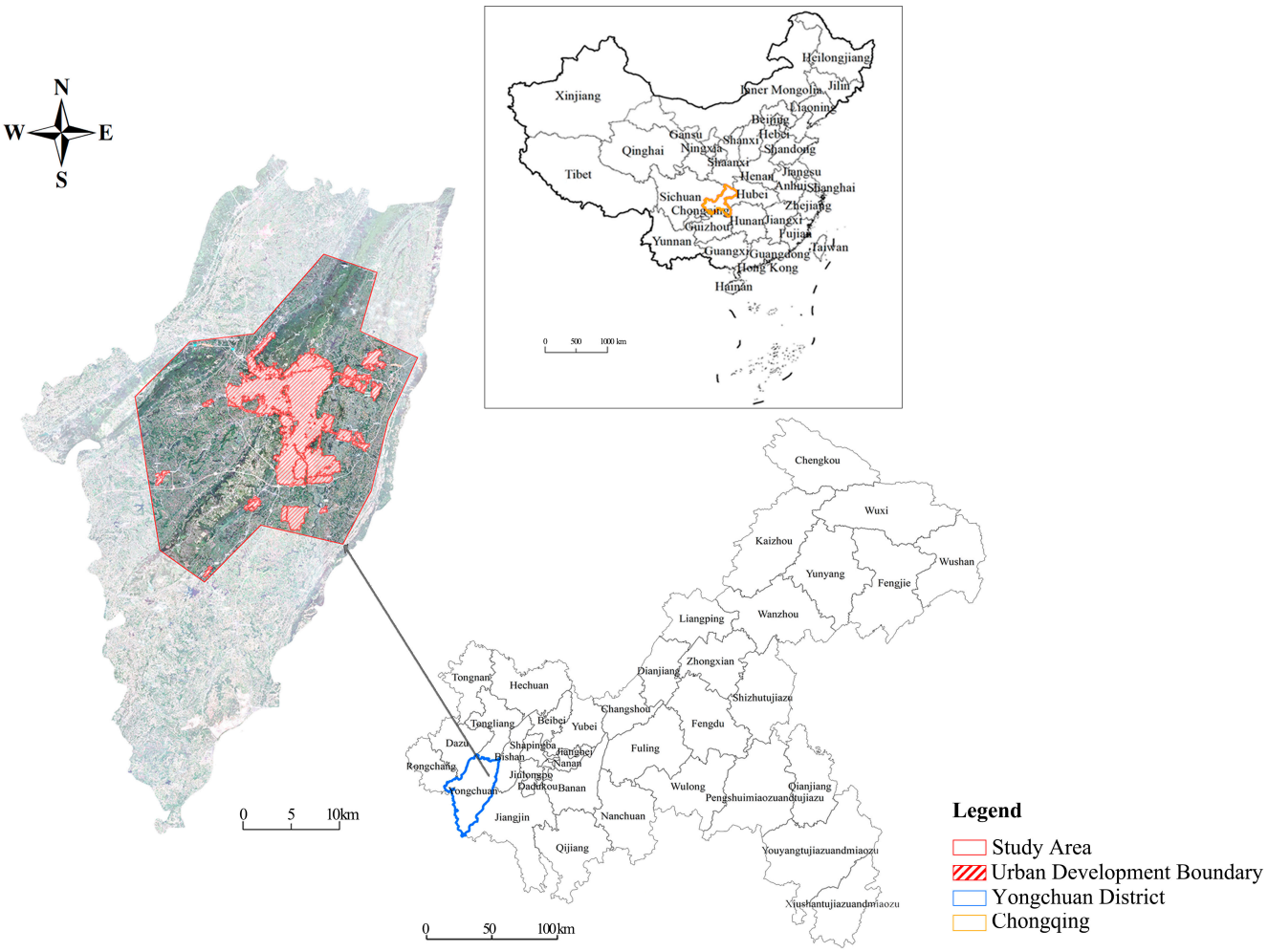


Figure 2. The location of the study area. The upper right figure illustrates the geographic location of Chongqing Municipality within China, while the lower right figure indicates the position of Yongchuan District within Chongqing Municipality. The left figure depicts the location of the research area within Yongchuan District, including the extent of urban built-up areas within the research area.

2.3. Study Object Selection

In the first chapter, the object of study has been clearly defined and determined in accordance with laws and regulations and the requirements for the protection of agricultural and forestry land, referring to small-scale agroforestry land with an area of less than 3.3 hectares. Therefore, this part of the land use should be statistically screened (Figure 3).

Through GIS, the space of agriculture and forestry under 3.3 ha is 8694.27 ha, accounting for 75.60% of the total area, and the space of agriculture and forestry over 3.3 ha is 2805.77 ha, accounting for 24.40% of the area. Overall, 5157.88 hectares (73.4%), 1268.29 hectares (91.1%), and 2268.13 hectares (73.5%) are under 3.3 hectares of arable land, garden land, and woodland, respectively (Table 1). And through the analysis of land-use characteristics, we attain an SAP spatial gradient of the transformation of the status analysis.

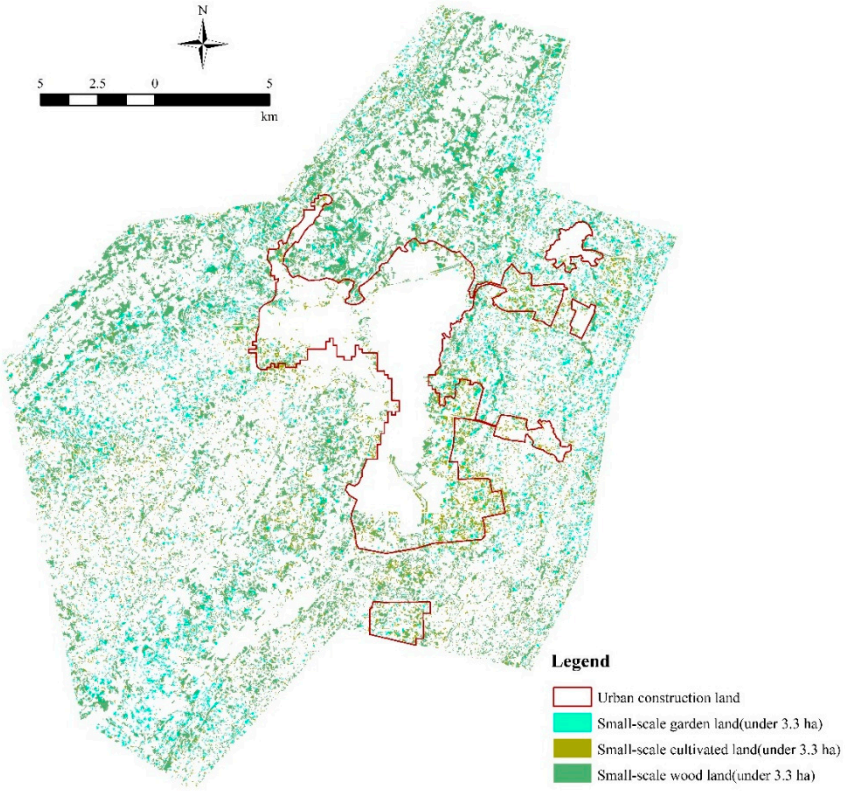


Figure 3. Identification of small-scale agricultural and forestry land. Using ArcGIS 10.2, small-scale agroforestry land patches of under 3.3 hectares were selected, which are intricately intertwined with agroforestry protection zones, spanning across both urban construction areas and the peripheries of cities.

Table 1. Yongchuan agricultural and forestry space statistics of various types of land area.

Type	Woodland		Cultivated Land		Garden Land	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Over 3.3 ha	815.8	26.45	1865.4	26.56	124.54	8.94
Under 3.3 ha	2268.13	73.55	5157.88	73.44	1268.29	91.06

2.4. Sample Selection

To accurately depict the landscape pattern characteristics of SAPs across diverse gradients, a spatially informed approach was adopted. Commencing from the city center area, defined as the starting point of the city's administrative office space, the investigation extended in four directions within the planning area. Samples were selected with dimensions of 22.4 km × 4 km along both horizontal and vertical axes. These samples were evenly divided into eight squares, each measuring 2.8 km × 4 km (Figure 4). According to the urban–rural transect zoning theory [53], the samples are divided into an Urban Center Zone, General Urban Zone (T2), Sub-urban Zone (T3), Rural Zone (T4), and Natural Zone (T5). The samples in the Urban Center Zone are 1-1, 2-1, 3-1, and 4-1. The samples in the Urban Zone are 1-2, 2-2, 3-2, and 4-2. The samples in the Sub-urban Zone are 1-3, 2-3, 3-3, and 4-3. The samples in the Rural Zone are 1-4, 2-4, and 4-4. The sample in the Natural Zone is 1–5.

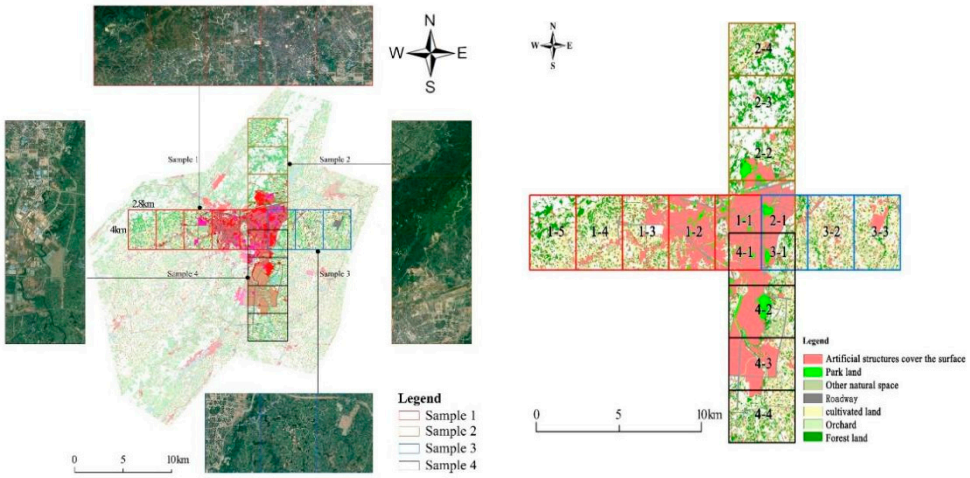


Figure 4. Sample partitioning. Spatial transects of urban–rural areas were delineated from the city center to the boundaries of natural conservation areas, partitioned evenly in 2.8 km × 4 km intervals along the cardinal directions of southeast, southwest, northeast, and northwest.

2.5. Data Analysis

2.5.1. Calculation of SAP and Agroforestry Elements Landscape Indices

SAPs are classified according to Chinese land-use standards; agricultural and forestry land can be divided into arable land (dryland, paddy field, irrigated land), garden land (orchard, tea garden land, oak garden land, other garden land), and woodland (arbor woodland, bamboo woodland, shrub woodland, other woodland)) (Table 2). The change in SAP landscape indices and the change in various factors were calculated to reflect their transformation characteristics.

Table 2. Classification of land uses for territorial space survey, planning, and use control.

Cultivated land	Paddy fields
	Irrigated land
	Drylands
Garden land	Orchards
	Tea garden land
	Oak park
	Other garden land plots
Woodland	Arbor woodland
	Bamboo woodland
	Shrub woodland
	Other woodland

Landscape indices can not only simplify the landscape information, but also reflect the structure and spatial configuration of landscape information. They represent a simple and applicable quantitative index. In this study, Fragstats 4.3 software was used to analyze the spatial landscape pattern of agriculture and forestry in the study area. The study divided the agroforestry space into 3 Mm × 3 m grids and calculated the landscape pattern index of cultivated land, garden land, and woodland within each 2.8 km × 4 km plot. Three levels of analysis were included: patch, class, and landscape. For the purposes of calculation, the parameters of landscape type, depth effect distance of landscape edge, difference weight of adjacent landscape type, and similarity of adjacent landscape type were set. Within this context, the term "landscape type" encompasses arable land, garden land, and woodland.

The "landscape edge depth effect distance" denotes the extent of the influence exerted by the edge effect of one patch on adjacent patches. The "difference weight of adjacent landscape type" signifies the extent of dissimilarity between two neighboring patches, while the "similarity of adjacent landscape type" quantifies the degree of resemblance between two adjacent patches.

Utilizing the tripartite data, Fragstats 4.3 was employed to compute landscape indices characteristics for agroforestry spaces, yielding the small agricultural and forestry patches (SAPs) landscape pattern indices for each segment. The indices encompass the patch area (PA), patch density (PD), edge density (ED), largest patch index (LPI), fractal dimension, and aggregation index (AI). These metrics collectively capture the scale, fragmentation, segmentation (spatial distribution), predominant types of agroforestry elements, shape complexity, and connectivity of agroforestry patches (Table 3).

Table 3. Description of various types of landscape indices.

Landscape Indices	Formula	Explain	Explain
Patch area (PA)	$PA = \sum_{j=1}^{n} a_{ij} * \frac{1}{10000}$	a_{ij} is the area of patch ij	PA can reflect the change in the agroforestry scale on the urban–rural gradient.
Plaque density (PD)	$PD = \frac{n_i}{A} * 10000/100$	n_i is the number of patches contained by patch type I, and A is the area of the whole landscape, including the background within the landscape. Units are 1/100 hm^2.	The patch density, defined as the number of patches per unit area, serves as an indicator of the fragmentation level in agricultural and forestry patches.
Edge density (ED)	Ed = E/A	E is the total perimeter of the plaque, and A is the total area of the patch.	The higher the boundary density, the more the land-use type is divided, and the more dispersed the layout.
Largest plaque index (LPI)	$LPI = \frac{\max(a_{ij})}{A}$	a_{ij} represents the area of patch ij; and A denotes the total landscape area, encompassing both the landscape interior and background.	Reflecting dominant land-use patch types and landscape dominance in different partitions.
Fractal dimension (FD)	$FD = \frac{2\ln(0.25p_{ij})}{\ln(a_{ij})}$	p_{ij} is the perimeter of patch ij; a_{ij} is the area of patch ij.	To quantify the complexity of patch shapes, values closer to 1 indicate simpler shapes, while values closer to 2 signify more intricate shapes, indicative of heightened artificial influence.
Aggregation index (AI)	$G_i = \left\{ \frac{g_{ii}}{(\sum_{k=1}^{m} g_{ik}) - mine_i} \right\}$ $AI = \begin{bmatrix} \frac{G_i - p_i}{p_i} \ (G_i < p_i \ and \ p_i < 0.5) \\ \frac{G_i - p_i}{1 - p_i} \end{bmatrix}$	G_i is the similar adjacency ratio, p_i is the area proportion of the patch type in the landscape.	Indicates the level of connectivity between patches; higher values denote increased connectivity.

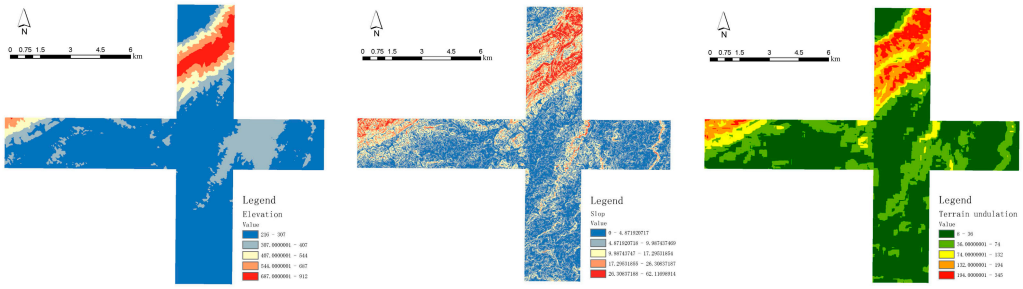
2.5.2. Statistical Analysis of Natural and Artificial Factors

Analysis of Topographic and Geomorphological Factors

Research shows that natural succession and disturbances have a relatively small impact on the overall changes in agroforestry patches and take a long time to manifest. In mountainous environments, key factors include complex topography such as elevation, slope, and terrain ruggedness. These topographic factors determine the layout of agroforestry spaces [50,54]. The underlying reason is that topography affects soil nutrients, climate, sunlight, and humidity [55,56], which indirectly determine the current distribution of agroforestry patches. Therefore, this paper chooses topography as a natural factor for analysis.

Based on the DEM data of 12.5 m, the elevation, slope, and undulation (Figure 5) were analyzed and calculated by Arcgis 10.2. The slope calculation was obtained by 3D Analyst, relief was calculated by the Spatial Analyst Tool neighborhood analysis focus

statistics. Then, the average values of elevation, slope, and fluctuation of each subarea were calculated by the Spatial Analyst Tool regional analysis regional statistics (Table 4).



(**a**) (**b**) (**c**)

Figure 5. Analysis of topographic and geomorphological. (**a**) represents the elevation within the spline space, (**b**) denotes the slope within the spline space, and (**c**) refers to the undulation within the spline space.

Table 4. Statistics of gradient transformation of surface terrain data.

Samples	Average Elevation	Average Slope	Average Rise and Fall
1-1	276.41	5.21	27.89
1-2	279.58	6.17	35.56
1-3	283.26	5.16	25.11
1-4	293.68	8.13	43.12
1-5	345.34	12.32	84.50
2-1	281.75	5.47	28.65
2-2	351.17	12.27	88.75
2-3	627.08	20.11	172.52
2-4	412.84	15.65	127.00
3-1	304.28	7.76	44.24
3-2	336.14	5.34	34.18
3-3	285.56	4.95	30.21
4-1	286.97	6.22	33.77
4-2	281.83	5.42	29.66
4-3	266.73	4.86	27.84
4-4	243.97	5.07	27.05

Artificial Factor Analysis

Artificial factors include the impervious area, road density, building coverage, and so on. The impervious area is actually the superposition of the building's surface coverage and the road area. In addition, other factors affecting SAP distribution are the construction of existing parks and the excavation of artificial ponds and lakes. First of all, the construction of the park will be combined with the existing distribution of agricultural and forestry resources, choosing to occupy these resources to build the park, so it will affect the transformation of the SAP status quo; at the same time, artificial pit pond lakes are usually used to irrigate cultivated land, garden land, and part of forestland, and their spatial distribution and scale are likely to affect the spatial pattern of SAPs [50]. Therefore, the selection of artificial factors includes building surface coverage, roads, parks, and the artificial excavation of the pit pond lake.

Based on the data of the third survey, the area scale of the road, park, building surface, and artificial pond and lake surface on the urban–rural gradient is calculated (Table 5).

Table 5. The gradient transformation of artificial elements.

Samples	Road Sites (ha)	Park Site (ha)	Building Surface (ha)	The Surface of Hang Tong Lake (ha)
1-1	148.76	63.02	750.4	24.10
1-2	148.71	72.86	662.5	44.55
1-3	67.6	5.85	307.07	46.91
1-4	42.68	0.62	109.44	52.50
1-5	25.39	0	67.62	25.28
2-1	226.68	84.76	651.96	16.62
2-2	54.06	70.1	183.27	32.86
2-3	19.09	0.07	27.42	7.48
2-4	23.35	0	59.2	29.82
3-1	129.8	64.78	408.98	35.41
3-2	33.23	0	132.55	111.58
3-3	0	0	167.03	92.53
4-1	110.44	59.44	566.69	34.74
4-2	109.79	110.6	402.18	95.40
4-3	120.11	4.33	536.53	48.72
4-4	56.35	0	95.19	97.29

2.5.3. Correlation Analysis

The paper uses Spearman correlation analysis to determine the relationship between SAPs and topographic and human factors. Spearman is a non-parametric test method that assesses the strength of the relationship between two random variables based on the size of the coefficient [57]. By calculating the rank correlation coefficient $r_s(Xi, Yi)$ and p-value between SAPs and various factors, we can determine the strength of their association. This helps to identify which factors drive the changes in the landscape indices of SAPs and elements across urban–rural gradient zones. The mathematical principle is as follows: Let $\{(X_i, Y_i)\}$, denote n pairs of data pairs with an independent and identical distribution whose parent body is a binary continuous distribution. To arrange Xi from small to large, we form a new set of data pairs X (1) < X (2) < X (3) . . . < X (N). Where), where the Y_i corresponding to the order statistic of X is called an adjoint of X_i. The formula is as follows:

$$r_s(X_i, Y_i) = 1 - \frac{6\sum_1^n (P_i - Q_i)^2}{n(n^2 - 1)}$$

In the formula, P_i means X_i is the K position in the sequence $\{(X_i)\}$; K is the rank of X_i; similarly, Q_i is the rank of Y_i. The positive (negative) correlation coefficient indicated that there was an influence relationship among the factors. Rs < 0.7 was a low correlation, 0.7–0.9 was a moderate correlation, and > 0.9 was a high correlation. If $p > 0.05$, the two functions were independent. The effect of each factor on patch transformation was estimated by the Spearman coefficient. The paper uses SPSS 19.0 to calculate the Spearman coefficients (r_s and p-value) between the landscape indices of SAPs and various topographic and human factors, which helps to identify which factors drive the transformation of the landscape patterns of SAPs.

3. Results and Discussion

3.1. The Transformation Characteristics of Agricultural and Forestry Landscape Pattern Gradients

3.1.1. Overall Transformation Characteristics of Agroforestry Patches

Through the calculation of four sample landscape indices, it was found that various landscape indices of agroforestry patches in different directions exhibit non-linear changes (Figure 6). Firstly, the area of SAPs, maximum patch index, and aggregation index all show an overall increasing trend from urban centers to natural areas, with the patch area being largest in rural areas and slightly decreasing thereafter, while patch density decreases linearly. These findings align with natural spatial distribution patterns, where patches tend to become larger, more aggregated, more connected, and less fragmented. The largest patch

areas in rural areas are attributed to the concentration of rural residents, who have the highest demand for SAPs.

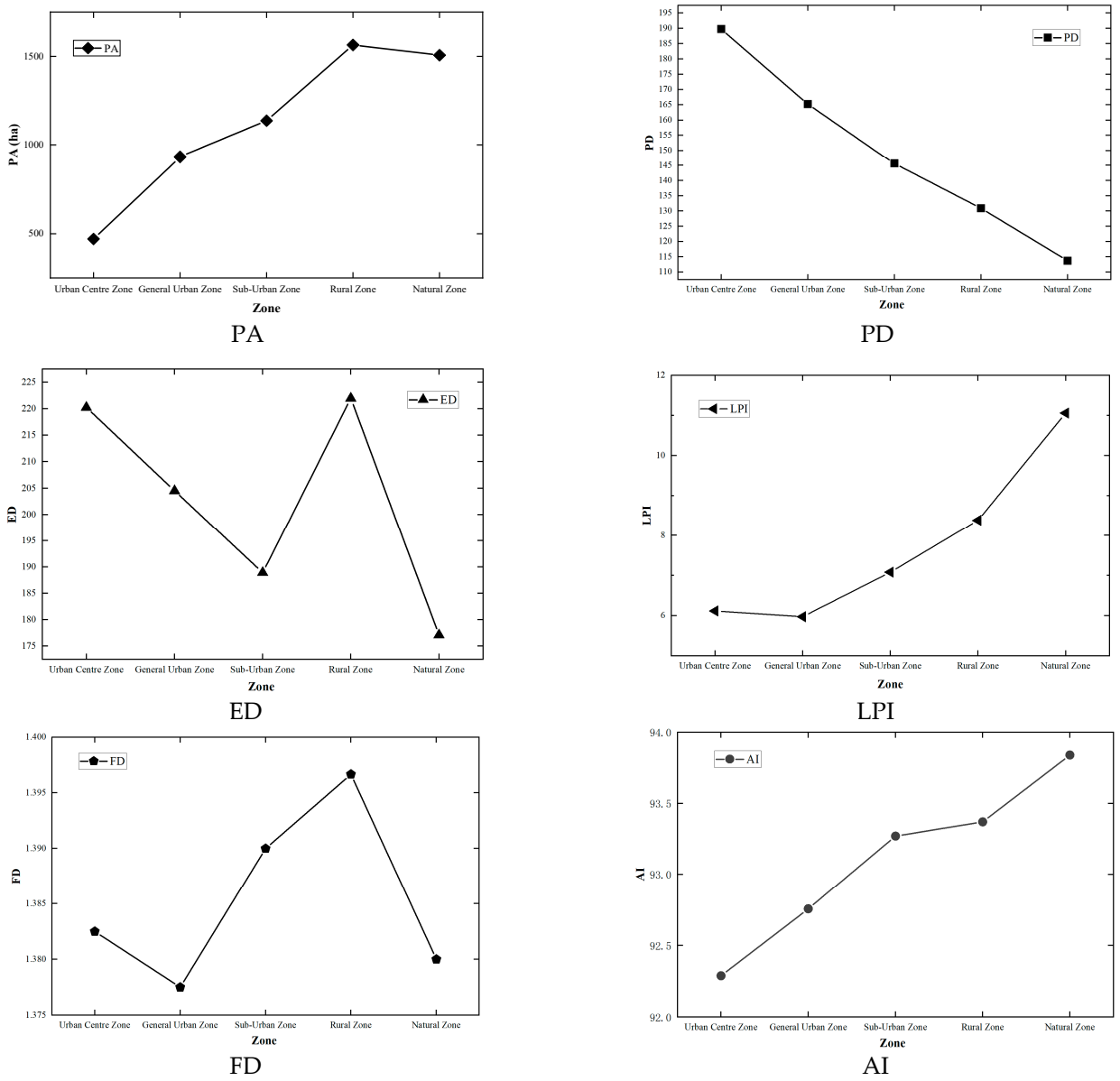


Figure 6. Landscape indices transformation of SAPs. The figure illustrates the trend of spline space landscape indices transformation for SAPs in different urban–rural zones.

Secondly, the boundary density of SAPs shows a stepwise change pattern, with similar boundary densities observed between urban centers and rural areas, indicating similar dispersion levels of these patches in these two zones.

Lastly, the fractal dimension of SAPs also displays a stepwise change pattern, reaching the highest values in suburban and rural areas, indicating the highest complexity of patch shapes in these regions. In contrast, the fractal dimension is smallest in urban development zones, indicating more regular shapes of agroforestry patches. Similar results are observed in the fractal dimension of SAPs between urban centers and natural areas.

3.1.2. Transformation Characteristics of Agricultural and Forestry Elements Transformation Characteristics of Landscape Indices of Woodland

The transformation characteristics of small-scale forest patches' landscape indices share similarities and differences with those of overall agroforestry patches. Firstly, based on the research findings (Figure 7), the area of forest patches shows a linear increase from urban centers to natural areas, while patch density exhibits the opposite trend. Compared to overall SAPs, the forest patch area reaches its maximum in natural areas, consistent with the pattern of natural ecological spatial changes. The density and edge density transformation characteristics of small-scale forest patches are similar to those of overall agroforestry patches.

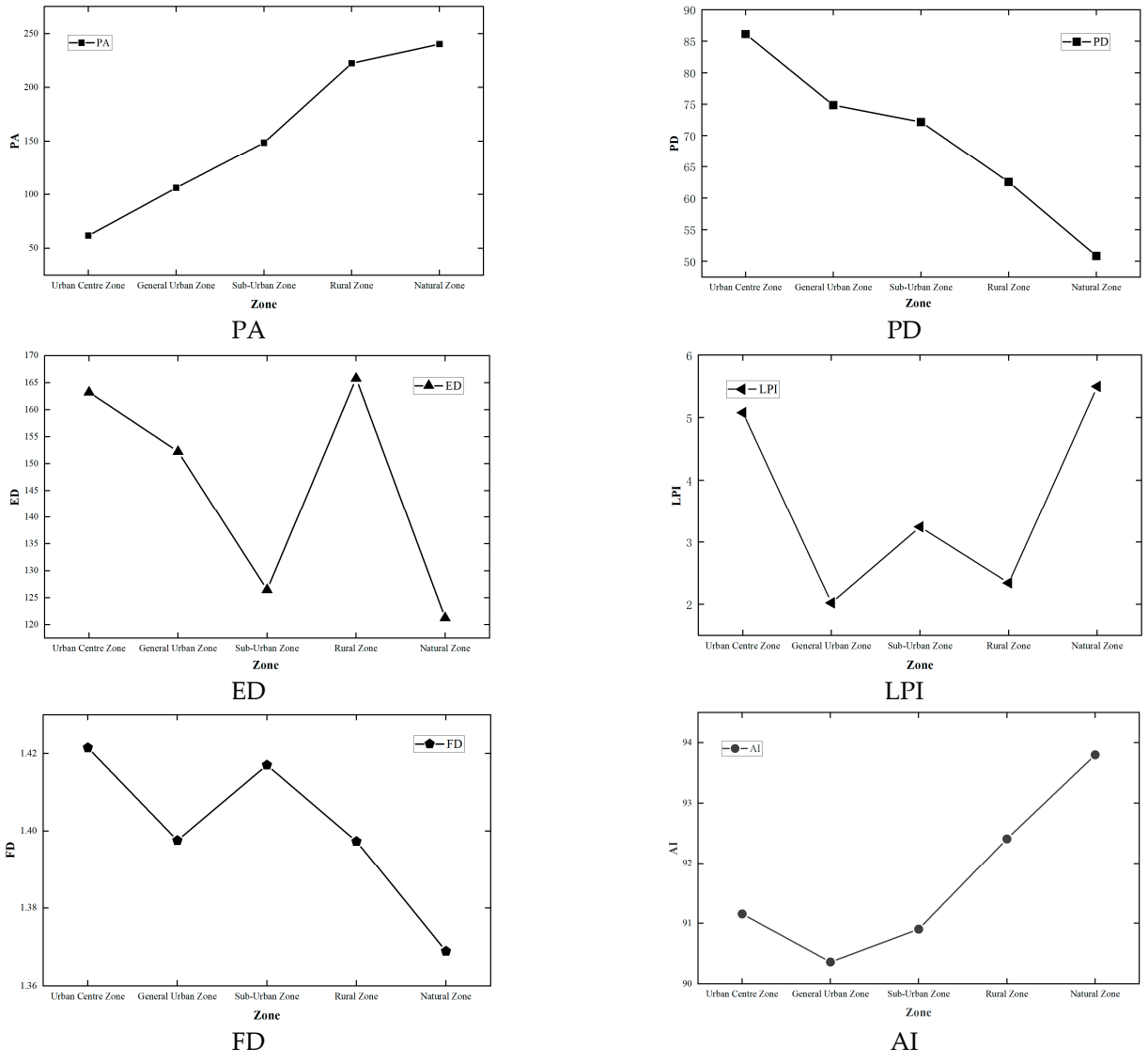


Figure 7. Representation of woodland landscape indices transformation. The figure illustrates the trend of spline space landscape indices transformation for small-scale woodland in different urban–rural zones.

Secondly, the maximum patch index, fractal dimension, and aggregation index of small-scale forest patches exhibit their own transformation characteristics. The maximum patch index is highest in urban centers and natural areas, and lowest in rural areas and urban development zones, indicating that small-scale forest patches have a high connectivity in areas with both high and low levels of urbanization. The fractal dimension is

largest in urban centers and suburbs, and smallest in natural areas, reflecting the varying complexity of small-scale forest patch shapes in these regions. The aggregation index is lowest in urban development zones and highest in natural areas, indicating the poorer connectivity of small-scale forest patches in urban development areas.

Transformation Characteristics of Patch Landscape Indices of Cultivated Land

The transformation characteristics of small-scale cropland patches share both similarities and differences with overall agroforestry patches (Figure 8). Firstly, the transformation pattern of small-scale cropland patch area is identical to that of overall agroforestry patches, adhering to normal conversion rules. Additionally, the edge density of small-scale cropland patches mirrors that of overall agroforestry and forest patches. The density of small-scale cropland patches also shows a general decline, with similar densities observed in suburban and rural areas. The maximum patch index exhibits an increasing trend, indicating the higher connectivity of cropland patches. In contrast, the fractal dimension of cropland patches displays entirely different transformation characteristics from agroforestry and forest patches, showing a consistent upward trend, reflecting increasingly complex shapes. Similarly, the aggregation index trends upward in alignment with agroforestry and forest patches.

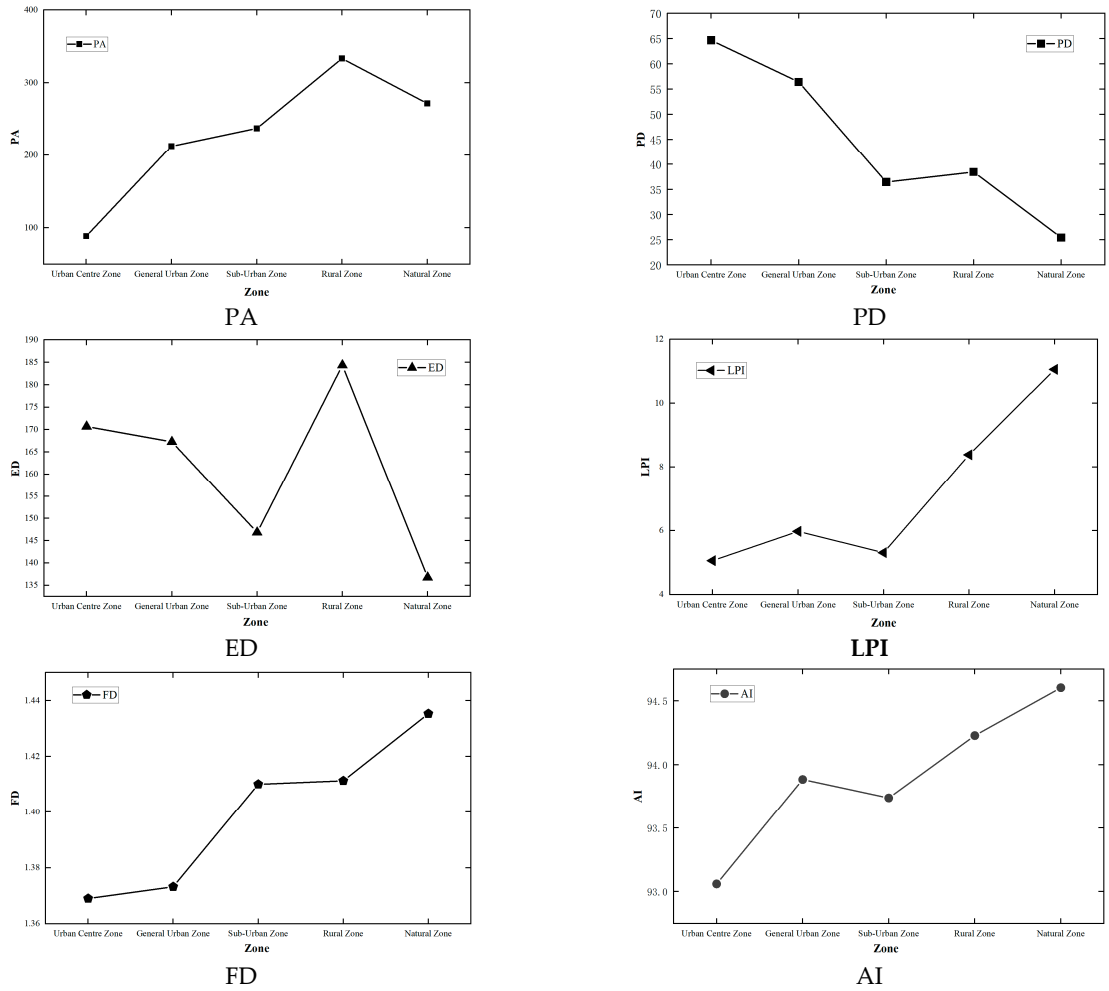


Figure 8. Representation of cultivated land landscape indices transformation. The figure illustrates the trend of spline space landscape indices transformation for small-scale cultivated land in different urban–rural zones.

Landscape Indices Transformation Characteristics of Garden Land

The garden land patches differ from other agroforestry elements and the overall agroforestry landscape indices in all aspects except patch area (Figure 9). Overall, the garden land patch area shows a continuous increase in size. The density, edge density, maximum patch index, and aggregation index of garden land patches exhibit a similar piecewise transformation pattern. Specifically, the fragmentation, dispersion, patch size, and connectivity are highest in urban center areas, sharply decrease in urban construction zones, show moderate growth in suburban areas, reach nearly their lowest in rural regions, and then gradually increase again in natural areas. This transformation aligns closely with urbanization patterns and natural features. Additionally, the fractal dimension of garden land patches shows a transformation pattern of initial increase followed by decrease, with the lowest fractal dimension observed in urban center areas and the highest in urban construction zones, gradually declining thereafter.

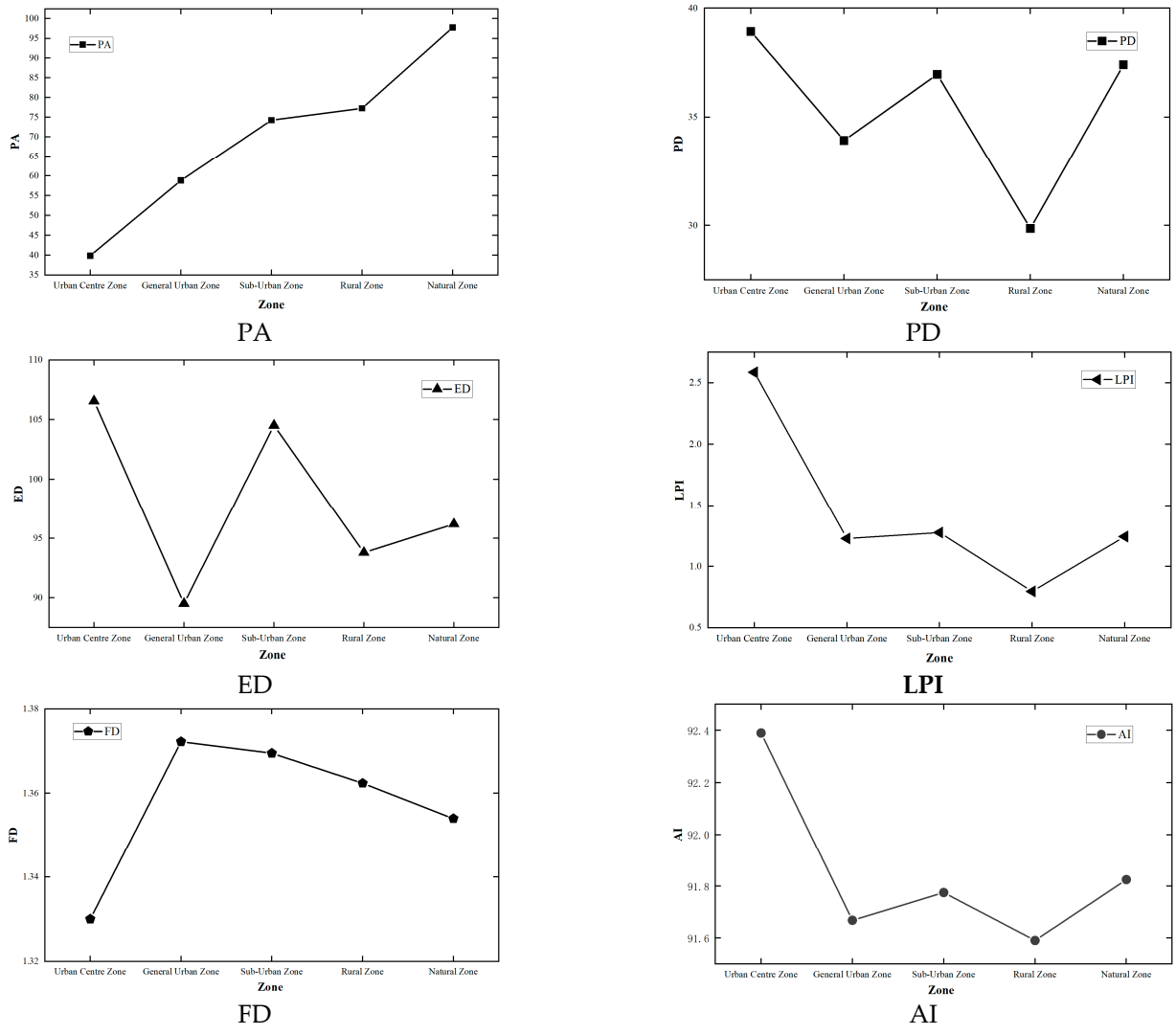


Figure 9. Representation of garden land landscape indices transformation. The figure illustrates the trend of spline space landscape indices transformation for small-scale garden land in different urban–rural zones.

3.2. Drivers of Gradient Transformation of Agroforestry Landscape Patterns

3.2.1. The Driving Factors of the Overall Transformation of Agroforestry Landscape Pattern

Based on the correlation analysis of landscape indices and natural or anthropogenic factors, it is evident that for SAPs across the urban–rural gradient, terrain factors have a relatively weak influence on agroforestry landscape indices (Figure 10). Firstly, the area of SAPs shows a strong negative correlation with road use, parkland, and building surfaces, indicating a predominant influence of anthropogenic factors on patch size. Patch density correlates negatively with terrain undulation but positively with road use and building surfaces, suggesting that flatter terrains are more susceptible to fragmentation due to construction activities. This is supported by the negative correlation between the aggregation index and the road and building land area. Other landscape indices (edge density, LPI, and fractal dimension) show no significant correlations with terrain or anthropogenic factors.

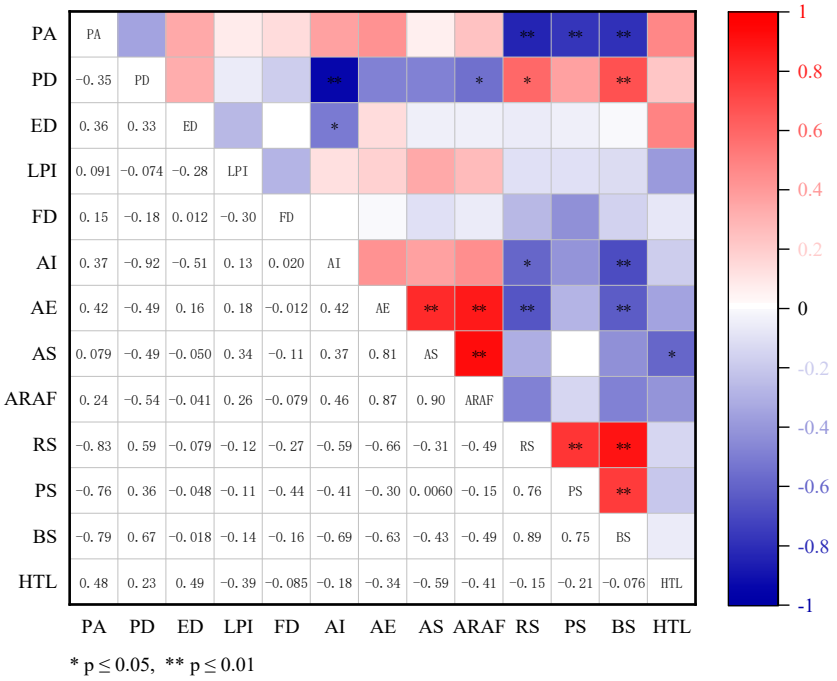


Figure 10. Spearman correlation analysis of landscape indices for SAPs. Note: ** indicates $p < 0.01$; * indicates $p < 0.05$; RS < 0.7 is a low correlation, 0.7–0.9 is a moderate correlation, and >0.9 is a high correlation.

On the other hand, in the urban center, there is a significant positive correlation between the patch area and the artificially excavated pond area. Additionally, the edge density of SAPs in the urban center is significantly influenced by terrain features, showing a positive correlation. This may be due to the fact that most SAPs in the center are located in terraced land difficult for construction, characterized by a high elevation, slope, and undulation. Moreover, the maximum patch index shows a positive correlation with the road area, indicating that roads may serve as corridors connecting SAPs in the urban center. Other landscape indices in this area show no correlations with influencing factors. In urban construction zones, patch area shows a negative correlation with road and building coverage, indicating the erosion of small agroforestry patches by construction activities. Other landscape indices show no significant correlations with influencing factors. In suburban areas, there is a significant positive correlation between the maximum patch index and slope, indicating that steeper areas tend to have more aggregated and larger SAPs. Outside urban areas, in rural and natural regions, patch density shows a significant negative correlation with terrain features and a significant positive correlation with road use area,

suggesting that flatter areas are more susceptible to fragmentation due to infrastructure such as roads (Figure 11).

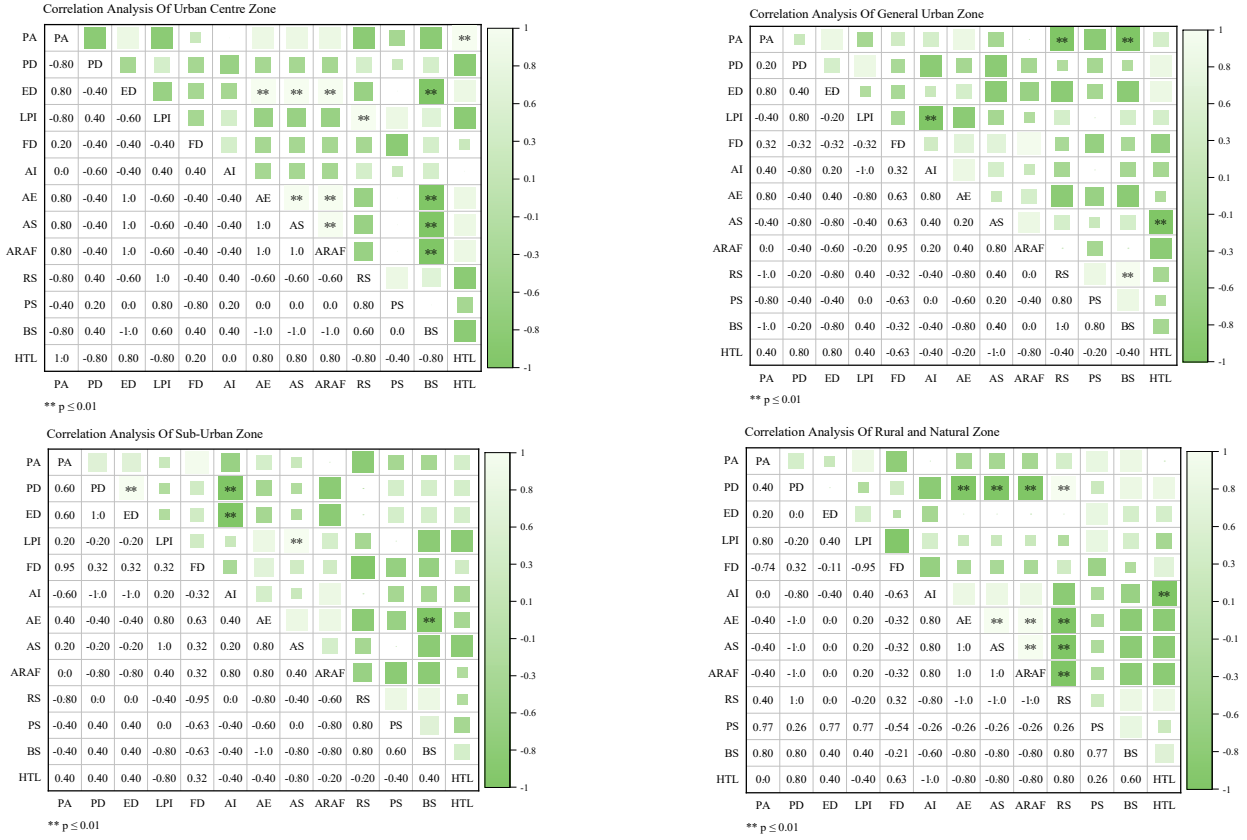


Figure 11. Spearman's correlation analysis of landscape indices of SAPs across the urban–rural gradient in each urban–rural zone.

Therefore, from the correlation analysis of landscape indices and natural and anthropogenic factors of SAPs, it is evident that anthropogenic construction activities predominantly drive the transformation of patch area. In flat areas, the transformation drivers for patch density (dispersion) and the aggregation index (connectivity) are primarily influenced by construction activities, whereas complex terrain environments are less affected. Additionally, there are significant differences in the driving factors of landscape indices across different urban–rural gradient zones. SAPs in urban centers exhibit a certain pattern stability, with less overall impact from anthropogenic construction activities. In contrast, patches in urban construction zones are dynamically changing due to ongoing construction activities. SAPs in steep areas of suburban zones are relatively well-preserved. In urban–rural and natural areas, SAPs in flat areas are fragmented due to road construction activities.

3.2.2. Drivers of Transformation of Each Element Landscape Pattern

Analysis of Driving Factors of Woodland Conversion

The results indicate that, overall, terrain features and anthropogenic factors similarly influence forest landscape indices (Figure 12). Forest patch area shows significant correlations with various factors, being positively correlated with terrain features such as elevation, slope, and undulation. This suggests that small-scale forest patches are predominantly located in areas with poorer construction conditions. Conversely, forest patch area shows a significant negative correlation with road, park, and building areas, indicating substantial anthropogenic erosion. Patch density correlates negatively with elevation and undulation but positively with the road and building land area, highlighting increased fragmentation driven by construction in flatter environments. The aggregation index of forest patches

shows a significant positive correlation with terrain features and a negative correlation with building surfaces and pond/lake areas, suggesting increased connectivity with more complex terrain while being hindered by construction activities.

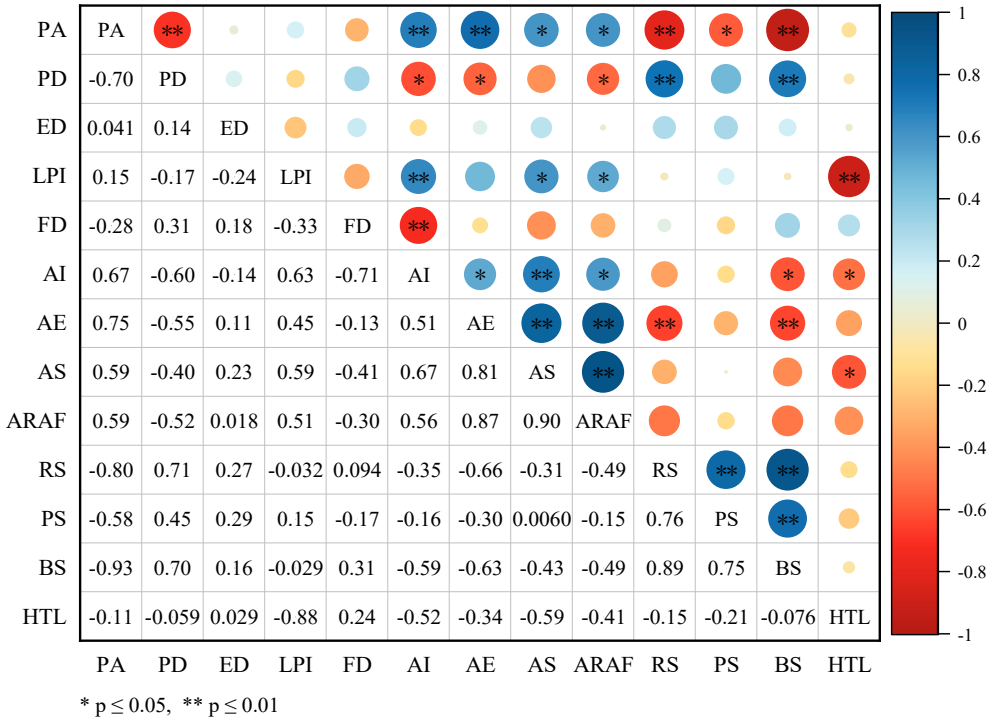


Figure 12. Spearman correlation coefficients for landscape indices of small-scale woodland patches. Note: ** indicates $p < 0.01$; * indicates $p < 0.05$; RS < 0.7 is a low correlation, 0.7–0.9 is a moderate correlation, and >0.9 is a high correlation.

Furthermore, the maximum patch index exhibits significant positive correlations with slope and undulation, and negative correlations with pond/lake areas, indicating a higher patch connectivity in steeper areas, yet it is inhibited by pond/lake construction. In urban centers, forest patch area shows a significant positive correlation with terrain features and a negative correlation with building area, implying larger forest patches in complex terrains where construction is less suitable, although still subject to erosion. Additionally, patch density and the maximum patch index show significant negative correlations with pond/lake areas, which are primarily artificial irrigation ponds, and positive correlations with arable land patch area (as mentioned below), suggesting space occupied by ponds or arable land contributes to forest fragmentation.

In urban construction zones, the forest patch area shows significant positive correlations with elevation, indicating more forest preservation in higher elevation areas. Edge density shows a significant positive correlation with slope and a negative correlation with pond/lake area, indicating natural dispersion driven by slopes hindered by pond/lake construction. In suburban areas, the forest patch area shows positive correlations with slope, edge density with undulation, and the maximum patch index with undulation, suggesting forest preservation in steep areas where the land is less flat; thus, forest patches are more dispersed due to human interference in flat land.

In rural and natural areas, the forest patch area shows significant positive correlations with terrain features and the aggregation index, and negative correlations with road-use area. Patch density shows negative correlations with the pond/lake area, and the maximum patch index shows positive correlations with the pond/lake area, indicating better forest preservation and higher connectivity in complex terrains while roads hinder connectivity. Additionally, pond/lake construction reduces forest fragmentation (Figure 13).

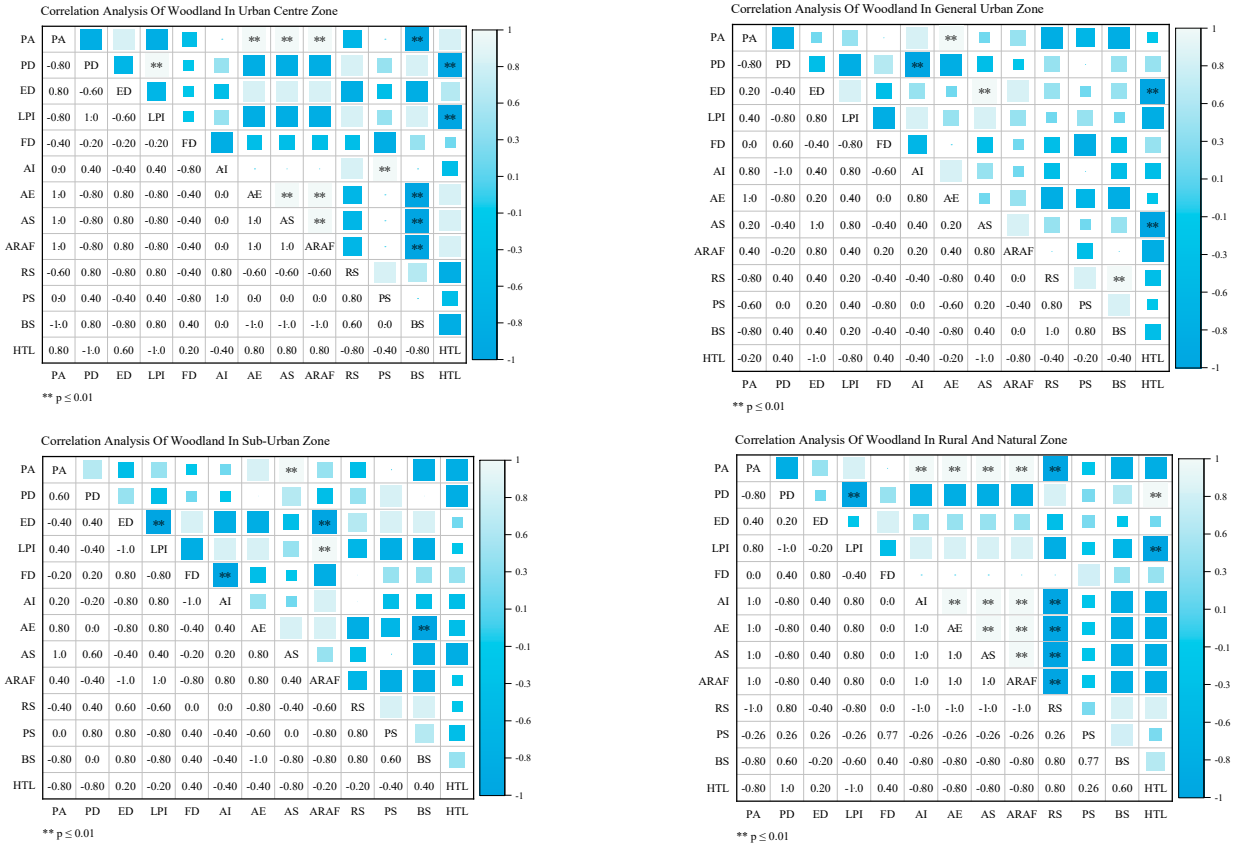


Figure 13. Spearman's correlation analysis of landscape indices of small-scale woodland patches across the urban–rural gradient in each sub-district.

Driver Factor Analysis of Cultivated Land Conversion

From the analysis results, it is evident that overall, arable patch area is significantly influenced by anthropogenic factors (Figure 14). It shows a significant negative correlation with road size, parkland, and built surfaces, while positively correlating with pond/lake areas. Arable patch density correlates negatively with slope and undulation, and positively with road and building land area, similar to forest patches. This indicates that areas with a greater slope and undulation have a lower patch density but a higher connectivity of arable patches, while larger construction areas result in a higher fragmentation of arable land. Additionally, the arable patch edge density and aggregation index show positive correlations with pond/lake areas, suggesting that larger ponds/lakes lead to a more dispersed distribution of arable land without affecting its connectivity.

In urban centers, the distribution of arable patch area and density is significantly influenced by ponds/lakes, with the former showing a positive correlation and the latter a negative correlation with pond/lake size, mirroring the overall influences on arable patch area and density. In urban construction zones, the shape complexity of arable patches correlates negatively with slope and positively with pond/lake area, indicating that higher slopes lead to less complex shapes of arable patches, suggesting more regular field patterns, while ponds/lakes promote greater shape complexity. In suburban areas, arable patch density correlates negatively with undulation, shape complexity positively correlates with undulation, and the aggregation index negatively correlates with slope. Flat areas in suburban regions exhibit a higher fragmentation and higher connectivity of arable patches but a lower complexity of shapes. In rural and natural areas, the arable patch area shows a positive correlation with building area, indicating that larger building areas correspond to larger arable patch areas, reflecting the development of residential land and subsequent expansion of surrounding small arable patches (Figure 15).

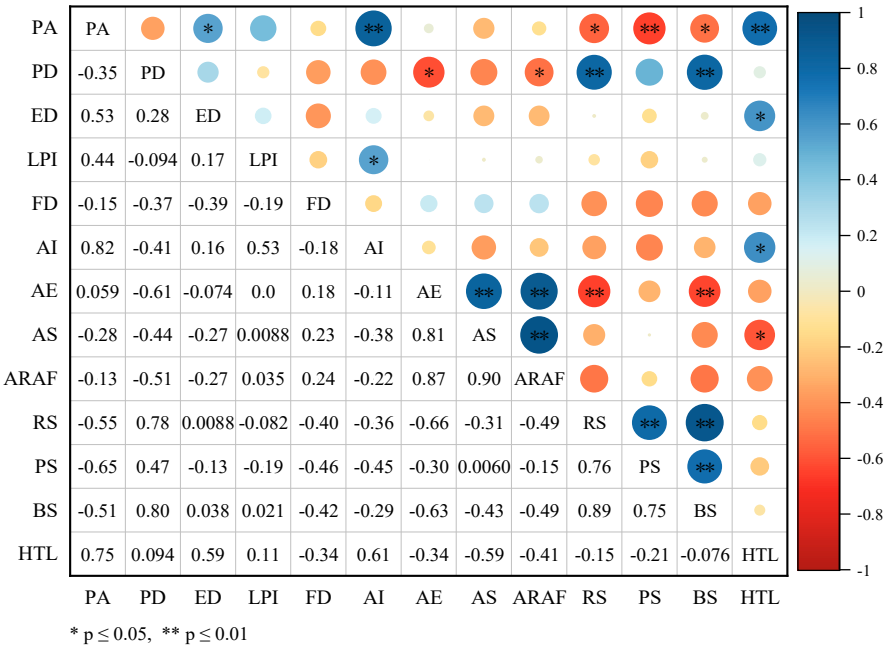


Figure 14. Spearman correlation coefficients for landscape indices of small-scale cultivated land patches. Note: ** indicates $p < 0.01$; * indicates $p < 0.05$; RS < 0.7 is a low correlation, 0.7–0.9 is a moderate correlation, and >0.9 is a high correlation.

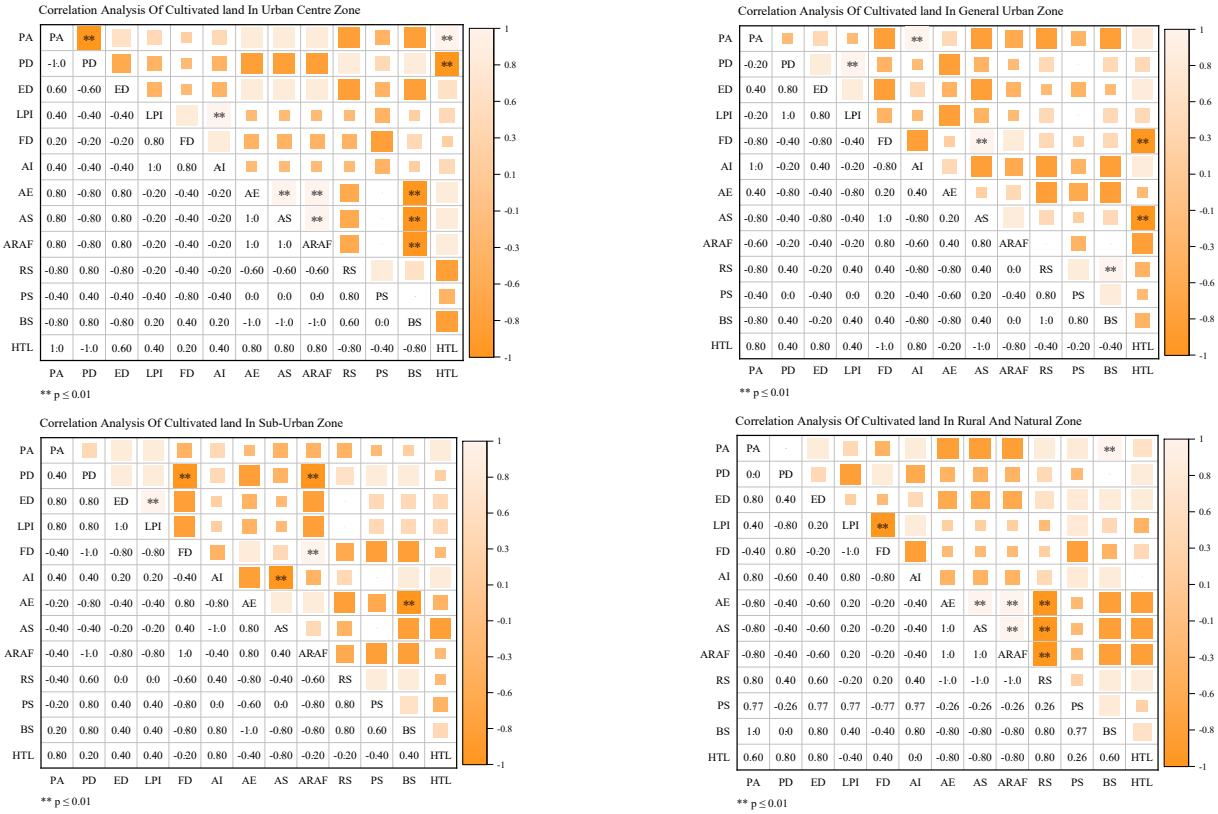


Figure 15. Spearman's correlation analysis of landscape indices of small-scale cultivated land patches across the urban–rural gradient in each urban–rural zone.

Analysis of Driving Factors of Garden Land Conversion

The overall area of garden patches is significantly influenced by human factors, showing a negative correlation with road and park areas, and a positive correlation with

pond/lake areas. This reflects that the construction of roads and parks typically occupies existing garden spaces, while agricultural land is not only taken up by roads and parks but also eroded by building construction. Both of these factors are closely associated with ponds/lakes, which require appropriate irrigation, thereby increasing the size of garden and agricultural areas. Additionally, garden patch density correlates negatively with slope and undulation, and positively with the road and building area, similar to patterns observed in forest patches. This suggests that areas with a flat terrain exhibit a higher fragmentation but a higher connectivity in complex terrains, where road and building construction are significant contributors to fragmentation, as evident from the maximum patch index. The fractal dimension also shows a moderate positive correlation with artificial pond/lake surfaces, indicating that these are excavated for irrigation purposes, influencing the complexity of garden patch shapes, with more pond/lake surfaces increasing the likelihood of garden cultivation (Figure 16).

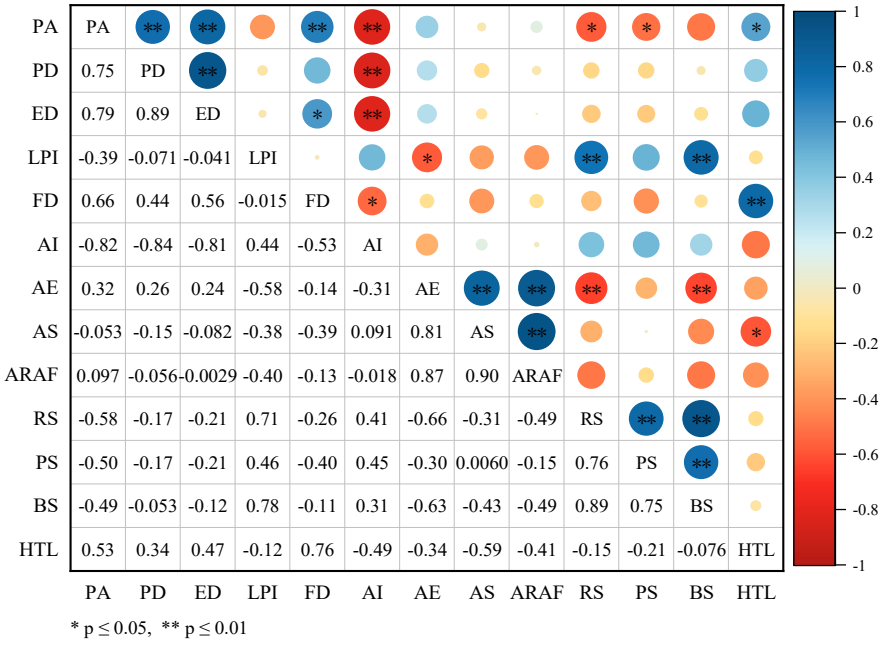


Figure 16. Spearman correlation coefficients for landscape indices of small-scale garden land patches. Note: ** indicates $p < 0.01$; * indicates $p < 0.05$; RS < 0.7 is a low correlation, 0.7–0.9 is a moderate correlation, and >0.9 is a high correlation.

In urban centers, the area, density, and edge density of garden patches correlate positively with the topographical environment but negatively with the building area, while the aggregation index shows a negative correlation with topography and a positive correlation with building area. This indicates that the size, fragmentation, and dispersion of garden patches in central areas are more significantly influenced by natural factors, with less disturbance in complex terrains. However, high fragmentation and dispersion in flat areas do not imply independence among patches but rather a higher connectivity. The results also show that larger fractal dimensions correspond to smaller road areas, highlighting roads as primary drivers of regular garden patch shapes. The situation in urban construction zones regarding arable patch area and density mirrors that of urban centers. In suburban areas, the garden patch fractal dimension correlates negatively with ponds/lakes, suggesting that the pond/lake layout determines the complexity of garden patch shapes. In rural and natural areas, the garden patch fractal dimension correlates positively with the building area, akin to agricultural land in rural natural areas (Figure 17).

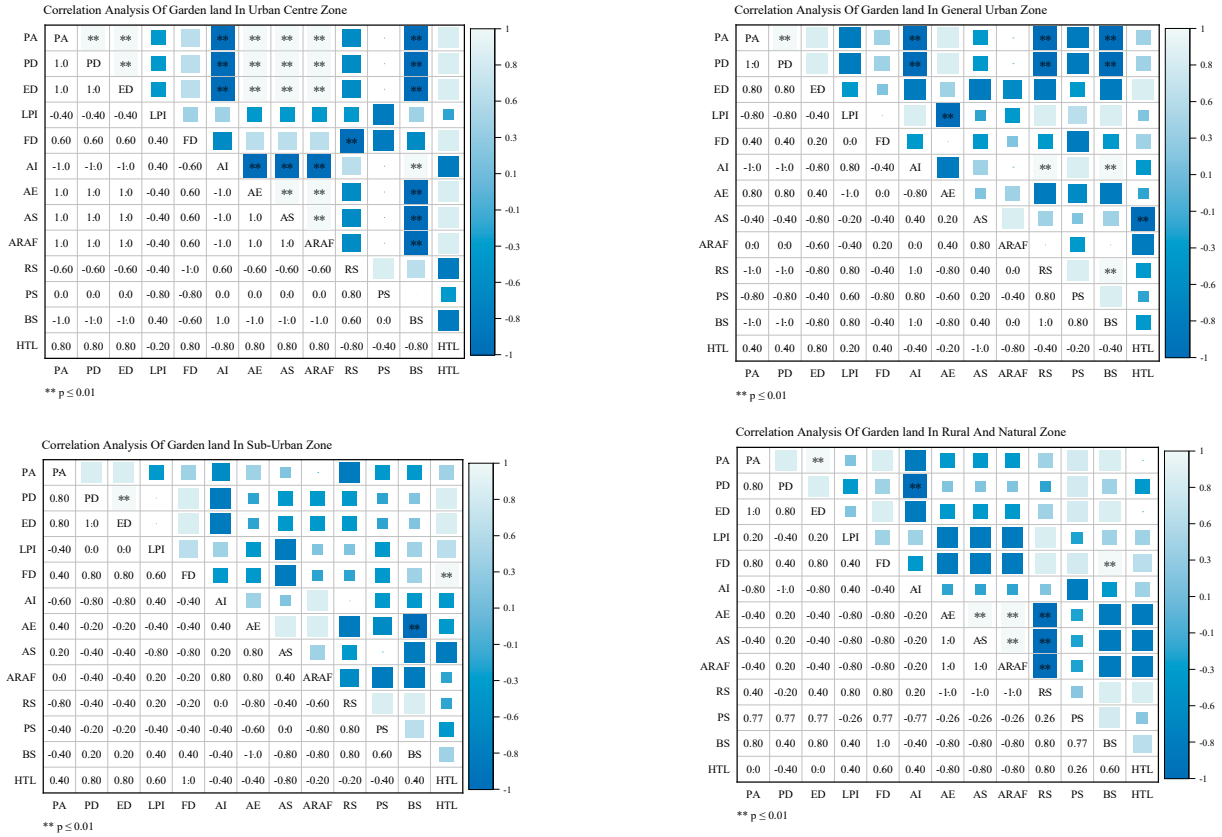


Figure 17. Spearman's correlation analysis of landscape indices of small-scale garden land patches across the urban–rural gradient in each urban–rural zone.

4. Discussion

4.1. Landscape Indices Transformation Characteristics and Driving Factors of Small-Scale Agroforestry Patches in Mountainous Urban Areas

Based on the research findings, the landscape indices' transformations of SAPs in mountainous urban areas exhibit significant differentiation. Overall, patch area shows an increasing trend across urban–rural gradients, while patch density demonstrates a decreasing trend. This transformation pattern reflects the conversion dynamics between agricultural and forestry land uses and natural ecological spaces [58]. However, small-scale garden patches exhibit variation, with the highest patch densities in central areas and the lowest in rural regions. Edge density shows an overall fluctuating trend, indicating varying degrees of patch dispersion or isolation, generally highest in central and rural areas and lowest in natural areas. Small-scale cropland and garden patches also exhibit slight differences. Additionally, the maximum patch index, fractal dimension, and aggregation index of SAPs and their elements demonstrate distinct transformation characteristics. These transformation patterns indicate that SAPs in mountainous urban areas differ from those in plain urban areas [59]. Mountainous SAPs consist of a semi-natural mix of various agroforestry elements, with different types exhibiting varied landscape patterns due to natural environments and urbanization processes. Furthermore, the area of SAPs is significantly influenced by human activities, leading to decreased patch sizes and increased fragmentation, consistent with existing research conclusions [29,60]. Notably, the landscape patterns of small-scale woodland patches are more significantly influenced by natural terrain factors. These findings underscore the need for tailored strategies in planning the conservation and utilization of SAPs in mountainous areas, based on their distinct typological differences.

Based on the analysis of driving factors across urban–rural gradients, it is evident that SAPs and their elements in different zones are significantly influenced by varying factors. In urban centers, suburban areas, and rural natural zones, these patches are primarily

influenced by natural terrain factors, which contrasts with general perceptions where urban centers and suburbs are typically more affected by construction processes. SAPs in urban development areas are notably disrupted by construction activities. Moreover, specific influencing factors vary across different zones. Therefore, differentiated zoning in planning and management may be crucial for guiding the conservation and utilization of SAPs in mountainous regions.

4.2. Planning and Management Methods for the Conservation and Utilization of Small-Scale Agroforestry Patches in Mountainous Urban Areas Based on Landscape Pattern Characteristics

4.2.1. Assessment of the Current Status of Small-Scale Agroforestry Patches in Mountainous Areas Should Employ a Differentiated Zoning Assessment Approach

The gradient changes in landscape indices reflect the diverse current structural characteristics of SAPs in mountainous areas across different zones. Moreover, the influencing factors on landscape patterns vary between these zones, suggesting the need for differentiated assessment systems. Research indicates significant variations in the current status, structure, and functions of agroforestry land along urban–rural gradients. This variation arises from differences in residents' demands and the current state of agroforestry land across different gradient zones, leading to distinct functional values [61]. Studies by Penghui et al [59] further highlight that socio-economic and ecological differences contribute to the spatial and functional differentiation of agroforestry areas along urban–rural gradients.

These findings collectively suggest that a uniform approach is not suitable for assessing small-scale agroforestry in environmentally distinct mountainous regions. For instance, applying criteria from basic farmland protection zones in plain areas to assess SAPs often fails to identify high-value agroforestry land accurately. This study's results also demonstrate that using indicators such as contiguity and slope criteria from basic farmland delineation standards [62] in assessing SAPs would likely exclude many valuable patches from protection zones. Given their fragmented nature and challenging geographic locations to meet regulatory requirements, many fragmented SAPs with unique species values near urban development areas and high slopes would struggle to qualify under minimum area standards, exacerbating their exclusion from protection zones.

4.2.2. The Conservation of Small-Scale Agroforestry Patches in Mountainous Areas Should Adopt a Zoning-Based Targeted Planning and Management Approach

Landscape indices of SAPs in mountainous areas are notably influenced by both human-made and natural factors, with significant differences observed among the constituent elements of these patches. Specifically, only forest patches are significantly affected by natural factors, whereas overall, human-made construction factors exert a more pronounced influence, consistent with drivers observed in agroforestry patches in Chinese plain cities [63]. However, SAPs and their elements across urban–rural gradients in mountainous cities do not universally share the same driving factors. For instance, in urban center areas, the area of SAPs correlates closely with the size of remaining ponds, while in construction zones, significant impacts are attributed to road and building construction.

Differences in characteristics among zoned agroforestry patches necessitate targeted planning and control strategies based on differential assessments. Specific planning interventions should be selected based on the specific driving factors of agroforestry patch landscape indices in each zone [64]. For example, based on current research, SAPs near urban areas should focus on artificial ecological restoration, utilizing landscape corridors to connect fragmented agroforestry patches into a green infrastructure network. Conversely, SAPs located further from urban centers should be enhanced through protective measures, delineating conservation boundaries and implementing specific control regulations [65].

Furthermore, within the same zone, driving factors influencing the landscape indices transformation of various small-scale agroforestry elements also differ. For example, in urban center areas, the area of forest and garden patches is closely related to terrain and environmental factors, while the area of arable land patches is strongly correlated with pond areas. In urban construction zones, forest patches are significantly influenced by elevation,

while garden patches are notably affected by road and building construction disturbances. Therefore, planning and control methods should not only be formulated based on zone differences but also classified according to the types of small-scale agroforestry elements.

4.3. Study Limitations

There are three limitations in this paper: First, although the characteristics of the landscape pattern transformation of SAPs and its elements have been described, there are still some problems in the study, such as the small number of samples and the short gradient distance between urban and rural areas; however,, larger samples and longer urban-rural gradient distances could yield more accurate study results.. Secondly, the selection of influencing factors of SAPs can be more diversified, and the changes in agroforestry landscape pattern may be influenced by other factors; examples include urban development policies and future directions [66], typhoons and earthquakes [49], and artificial and natural fires [67]. Therefore, all kinds of relevant factors should be considered in order to make SAP protection decisions more reasonable. Finally, this paper only explores the transformation characteristics of the SAPs landscape pattern from space. In fact, it is also affected by the time change, as the landscape indices of the same plot will be different at different times [68]. In order to understand the characteristics of SAP transformation, we must study it from the two dimensions of time and space, which is the content to be further improved in the future.

5. Conclusions

This study used Yongchuan, a mountainous urban area, as a case study to investigate the transformation characteristics and influencing factors of SAPs across urban–rural gradient zones. The research findings are as follows:

(1) The scale, fragmentation, dispersion, and connectivity of SAPs and their elements generally exhibit similar patterns. Specifically, from urban centers to natural areas, there is a trend of "fluctuating increases in scale and connectivity, decreasing fragmentation, and fluctuating changes in dispersion", with garden patches showing slight variations. However, patch cohesion and shape complexity display nonlinear differentiated transformation characteristics.

(2) In general, SAP are significantly influenced by human-made construction factors, with the landscape pattern of forest patches particularly affected by terrain and topographical factors.

(3) Within urban–rural gradient areas, the landscape configurations of SAPs in urban centers, suburbs, and rural natural settings are more significantly influenced by terrain factors, whereas those within urban development zones are distinctly affected by human-made construction factors.

The analysis of transformation characteristics and influencing factors of SAPs in mountainous areas suggests that while most landscape indices exhibit nearly identical transformation characteristics across urban–rural gradient zones, conservation and utilization strategies should be tailored to the differences in zone and element landscape patterns. It is essential to develop targeted strategies rather than applying uniform control methods like those used for basic farmland protection areas.

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