RESPONSE OF THE LANDSCAPE TO FRAGMENTATION DUE TO HUMAN DISTURBANCE IN A MOUNTAIN CITY: EVIDENCE FROM GUIYANG IN SOUTHWEST CHINA

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Abstract. Under the interference of a series of strong human activities, such as the rapid expansion of built-up land and massive infrastructure construction, the issue of landscape fragmentation in mountain cities has become highlighted. Therefore, the city of Guiyang in southwestern China is selected as a representative of a typical mountain city in this study. Multiple landscape fragmentation indices and the human disturbance index (HDI) are used to analyze the response of the landscape to human disturbances in a mountain city. The results reveal that the gradient zone with a relatively flat topography is a significant region for the substantial changes of the HDI and landscape fragmentation indices. The changes of the HDI and landscape fragmentation indices are found to be similar in the gradient zone of the slope, topographic relief, and topographic position index, but different in each gradient zone of the elevation. Positive correlations are found between the HDI and the landscape fragmentation indices except largest patch index (LPI) in most terrain gradient zones. The research results can be used as important indicators of ecosystem monitoring in mountain cities and provide a scientific basis for the landscape planning of mountain cities.
Keywords: *landscape indices, human activity, topographic gradient, spatial pattern, geographic information system*

Introduction

With the rapid advancement of urbanization, human activities have strongly changed urban landscape patterns, which has gradually changed original continuous landscapes into discontinuous mosaic patches and increased landscape fragmentation (Kowe et al., 2020; Jiang et al., 2021). This has resulted in the fragmentation of natural habitats and the loss of biological habitats, and thus seriously threatens the supply levels of urban ecosystem services (Zambrano et al., 2019; Amburgey et al., 2021). Therefore, it is necessary to investigate urban landscape fragmentation under strong human disturbance, which is of great significance to sustainable urban development and landscape management (Aubrechtova et al., 2020; Luo et al., 2020).

Current research on landscape fragmentation mainly focuses on economically developed or rapidly developing cities. Europe, the United States, and eastern China are the key regions of global landscape fragmentation studies (Kowe et al., 2021). From the perspective of the research content, the assessment and evolution of urban landscape fragmentation are important aspects of contemporary research (De Montis et al., 2017; Gbanie et al., 2018; Kowe et al., 2020). Multiple landscape pattern indices have been extensively used as assessment methods in the quantitative analysis of landscape

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fragmentation (Flowers et al., 2020; Nasehi and Namin, 2020). In addition, with the increasing interference of human activities on the urban landscape, numerous studies have shown that land-use changes (such as built-up land expansion) under the influence of human activities are important factors that can induce urban landscape deterioration due to fragmentation (Canedoli et al., 2018; Ninh and Waisurasingha, 2018). Topography is an important factor in the formation and evolution of landscape patterns in mountainous areas, and has a profound impact on landscape fragmentation (Munroe et al., 2007; Muhammed and Elias, 2021). Under the influence of complex human activities and topographies, mountain cities have become typical regions of landscape fragmentation (Jaeger et al., 2008; Tian et al., 2019). Although many achievements have been made in the global research on urban landscape fragmentation, there have been few studies on the changes of landscape fragmentation in mountain cities. Moreover, there has been no report on the terrain gradient of landscape fragmentation evolution in mountain cities.

In the process of rapid economic development, mountain cities in China are suffering from a series of strong human disturbance activities, such as rapid urban expansion, industrial and mining development, and massive infrastructure construction, which have deeply changed their landscape patterns. The issues of landscape fragmentation have attracted the attention of many scholars (Wu et al., 2019; Jia et al., 2020; Xing et al., 2021). Therefore, in this study, Guiyang, a typical mountain city in southwestern China, is selected as an example to analyze the response of urban landscape fragmentation to human disturbances in mountain cities.

The following hypotheses are proposed. (1) There is obvious spatial heterogeneity in both landscape fragmentation and the human disturbance intensity in mountain cities. (2) The landscape fragmentation and human disturbance intensity in different terrain gradients are different. (3) The correlation between the degree of human disturbance and landscape fragmentation is different in different terrain gradients.

Materials and methods

Overview of the study area

Guiyang is an important city in southwestern China (106°07′-107°17′E, 26°11′-26°55′N) and covers an area of 8034 km^2. The city is located in the eastern part of the Yunnan-Guizhou Plateau. Mountains are the dominant geomorphic type, and account for 87.5% of the total land area. The altitude ranges from 511 to 1738 m. (*Fig. 1*). The climate is a subtropical humid monsoon climate; the annual average temperature is 15.3°C, and the average annual precipitation is 1100 mm. The city has diverse ecosystem types and rich biodiversity, with a forest coverage rate of 55% (Yang et al., 2020). The major rivers in the study area include the Wujiang River, Nanming River, and Maotiao River. Several large lakes (Hongfeng Lake, Baihua Lake, Aha Lake) are primarily distributed in the southwestern area of the city. The urbanization process of Guiyang has accelerated in the past two decades, with an increase in population from 3.7 million in 2000 to 5.99 million in 2020. The gross domestic product (GDP) of the city increased from 26.481 billion RMB in 2000 to 431.145 billion RMB in 2020. As a typical karst ecological fragile area, Guiyang is characterized by low environmental carrying capacity (Ren and Zhao, 2020). Under the effect of rapid economic development and population growth, the pressure of human activities on the ecological environment of the city has increased sharply (Wang and Dai, 2021).

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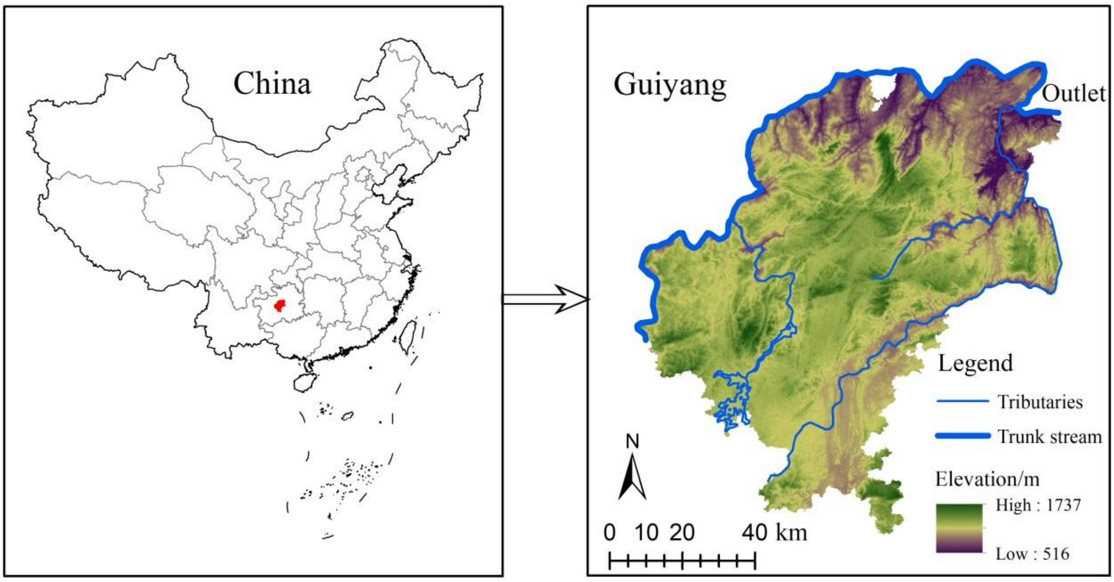

Figure 1. *The location of Guiyang*

Data sources and processing

The study data included TM/ETM$^+$ remote sensing images and Digital Elevation Model (DEM) data from 2000 and 2020. The remote sensing images and DEM data were downloaded from the geospatial data cloud platform (http://www.gscloud.cn/). The cloud cover of the images was less than 10%, and the resolution was 30 m. The processing steps of the remote sensing images using ArcGIS 10.5 and ENVI 5.0 software included image fusion, image mosaic, image registration, geometric precision correction, radiation correction, and color enhancement. Then, the initial landscape type was determined by the man-machine interactive interpretation method.

The interpretation process was executed using the following key steps: (1) based on the actual situation of the study area, the landscape type classification system was divided into paddy fields, non-irrigated farmland, forests, shrubbery, grassland, water bodies, urban land, rural residential areas, and industrial and mining areas; (2) the image features and field survey results were employed to establish interpretation markers for each landscape type; (3) classification templates were established using the maximum likelihood method; (4) image interpretation was performed based on the classification template and topography to determine the landscape type data; and (5) it was determined via field verification that the accuracy of remote sensing interpretation was over 85%. The grid size of the landscape type data and DEM data at 30 m was unified with the assistance of ArcGIS 10.5 software.

According to the topographic characteristics of the study area and the research results of Zang et al. (2019), four topographic indices (the elevation, slope, topographic relief, and topographic position index) were selected to demonstrate the topographic characteristics. Based on the elevation data, the slope was obtained via the 3D analyst tool of ArcGIS 10.5 software. Topographic relief was determined by calculating the difference between the maximum and minimum elevation under the spatial resolution of 30 m via the spatial analyst tool of ArcGIS 10.5 software. The topographic position index reflects the spatial differentiation of topographic conditions by considering both

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the elevation and slope, and this index can be obtained by calculating the elevation and slope information at any point. The four topographic indices were divided into five gradient zones (I, II, III, IV, and V) via the quantile method of ArcGIS 10.5 software.

$$T_{tr} = C_{max} - C_{min} \quad \text{(Eq.1)}$$

$$T_{tpi} = \log[(E/\bar{E}+1)\times(S/\bar{S}+1)] \quad \text{(Eq.2)}$$

where T_{tr} is the topographic relief, T_{tpi} is the topographic position index, C_{max} and C_{min} are respectively the maximum and minimum elevation within a spatial window, E and $\bar{E}$ are respectively the elevation at any location and the average elevation in the study area, and S and $\bar{S}$ are respectively the slope at any location and the average slope in the study area.

Methods

Selection and calculation of the landscape fragmentation index

A single landscape index cannot fully reflect the characteristics of landscape fragmentation. Therefore, the patch density (PD), largest patch index (LPI), landscape division index (DIVISION), and Shannon's diversity index (SHDI) were selected to represent the degree of landscape fragmentation based on previous studies (Qiu et al., 2012; Flowers et al., 2020; Nasehi and Namin, 2020). The landscape fragmentation indices were calculated using Fragstats v4.2.

Each landscape fragmentation index was calculated by Fragstats 4.2 software. In total, 324 fishnets (4×4 km) were created by ArcGIS 10.5 software to demonstrate the spatial pattern of the landscape fragmentation index. With the fishnet as the basic analysis unit, the landscape fragmentation index of each fishnet was calculated and kriging spatial interpolation was carried out to obtain the spatial distribution of the landscape fragmentation index. Based on the data of each topographic gradient zone, the spatial analyst tool of ArcGIS 10.5 software was used to clip the spatial distribution map of the landscape fragmentation index, and the landscape fragmentation index of each terrain gradient zone was then statistically determined.

Calculation of the HDI

The human disturbance index (HDI) was developed to reflect the degree of disturbance of the landscape pattern caused by human activities. The index is calculated based on the human disturbance coefficient of different landscape types and the area of each landscape type (Liu et al., 2018). The calculation formula is as follows.

$$HDI = \sum_{i=1}^{m}\left(\frac{A_i}{A_j}\right)\times P_i \quad \text{(Eq.3)}$$

where m is the number of landscape types, A_i is the area of landscape type i in the fishnets, A_j is the area of the fishnets, and P_i is the human disturbance coefficient of each landscape type. The coefficients of the human disturbance intensity in nine landscape types were determined according to the expert scoring results (*Table 1*).

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Table 1. *Coefficients of the human disturbance intensity in nine landscape types*

Landscape types	Coefficients
Paddy fields	0.65
Non-irrigated farmland	0.70
Forests	0.20
Shrubbery	0.45
Grassland	0.50
Water bodies	0.40
Urban land	0.95
Rural residential areas	0.85
Industrial and mining areas	0.90

Correlation analysis of the landscape fragmentation indices and HDI

The spatial correlations between the landscape fragmentation indices and the HDI were quantitatively analyzed by the band collection statistics of ArcGIS 10.5 software. The correlations between these two layers were determined by computing covariance and correlation matrices.

Results

Overall changes of the landscape fragmentation indices and the HDI

The PD and SHDI values were observed to increase between 2000 and 2020, while the LPI values decreased, and the DIVISION did not exhibit any significant changes. The change rate of the PD was found to be significantly higher than those of the other three landscape fragmentation indices. The HDI was found to have increased over the last 20 years (*Table 2*).

Table 2. *The overall changes of the landscape fragmentation indices and the HDI from 2000 to 2020*

Time	PD	LPI	DIVISION	SHDI	HDI
2000	1.4925	39.2197	0.7683	0.7418	0.4921
2020	1.6876	38.0524	0.7734	0.7821	0.5415
2000-2020	13.07%	-2.98%	0.66%	5.43%	10.04%

PD, patch density; LPI, largest patch index; DIVISION, landscape division index; SHDI, Shannon's diversity index; and HDI, Human disturbance index

Spatial patterns of the landscape fragmentation indices and the HDI

Except for scattered areas in the northwestern and northeastern regions of the study area, the PD increased in most parts of the study area, and the change rate of the PD from 2000 to 2020 was high in the southern region (*Fig. 2a*). On the contrary, the LPI decreased in most parts of the study area except for small areas in the southeastern, western, and northwestern regions (*Fig. 2b*). The values of DIVISION and SHDI

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increased in most parts of the study area. The regions with high increase rates of these two indices (DIVISION > 6% and SHDI > 8%) were both mainly distributed in the western and southern regions of the study area, while the regions with declining values were mainly distributed in the northwestern, southeastern, and southwestern regions (*Fig. 2c* and *d*). The HDI was found to have increased in most regions of the study area, and the southern region was the highlight of the increase in the index from 2000 to 2020 (*Fig. 2e*).

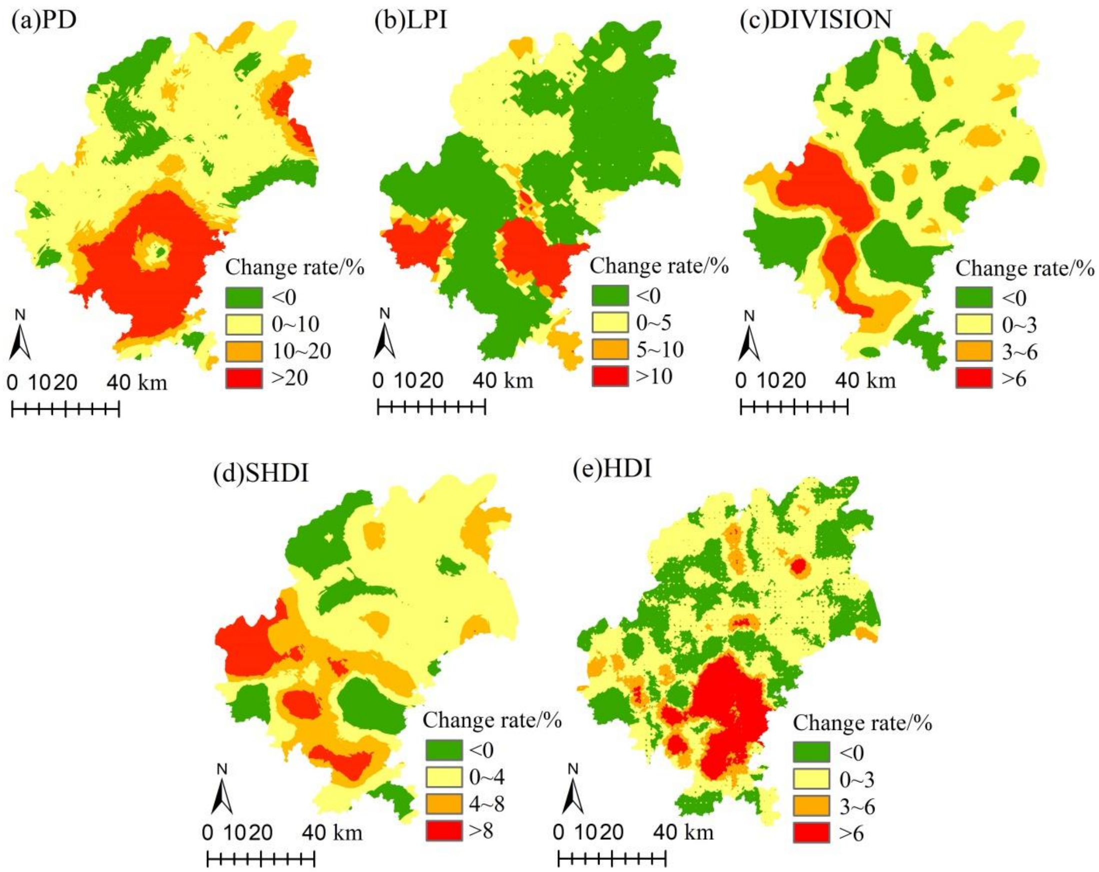

Figure 2. *The changes of the spatial patterns of the landscape fragmentation indices and the HDI from 2000 to 2020 (PD, patch density; LPI, largest patch index; DIVISION, landscape division index; SHDI, Shannon's diversity index; and HDI, Human disturbance index)*

Topographic gradients of the landscape fragmentation indices and the HDI

From 2000 to 2020, the change rate of the PD was found to decrease with the increase of the gradients (from gradient I to V) of the slope, topographic relief, and topographic position index. Moreover, the change rate of the PD also decreased from elevation gradients II to V. The change rates of the LPI, DIVISION, and SHDI experienced fluctuating changes from elevation gradients I to V, whereas they first decreased and then increased from gradients I to V of the slope, topographic relief, and topographic position index (*Fig. 3a-d*). From gradients I to V of the slope, topographic relief, and topographic position index, the change rate of the HDI gradually decreased from 2000 to 2020, whereas the change rate of the HDI in elevation gradients II, III, and IV was significantly higher than that in gradients I and V (*Fig. 3e*).

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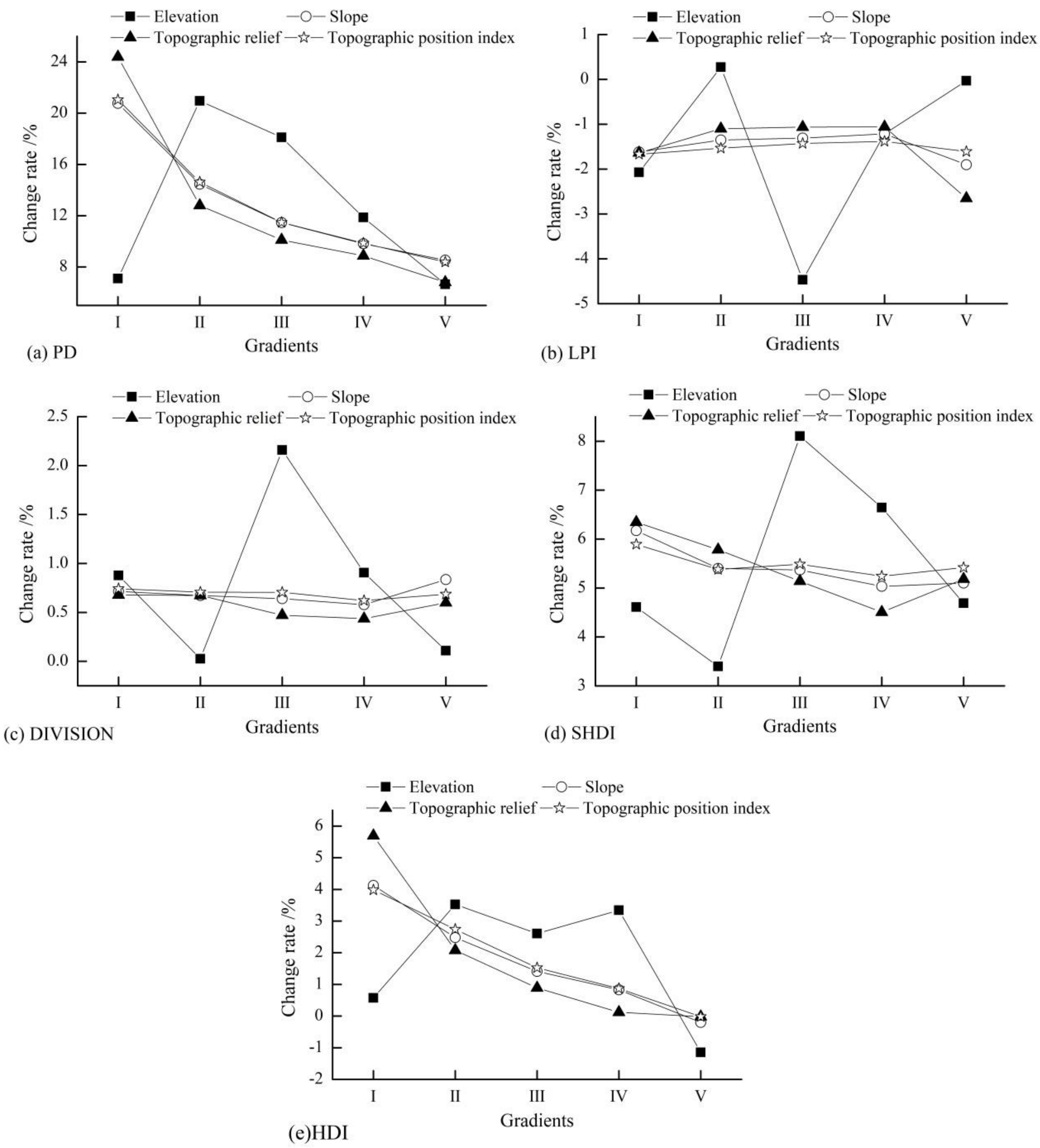

Figure 3. *The change rates of the landscape fragmentation indices and the HDI in the topographic gradients from 2000 to 2020 (PD, patch density; LPI, largest patch index; DIVISION, landscape division index; SHDI, Shannon's diversity index; and HDI, Human disturbance index)*

Correlations between the landscape fragmentation indices and the HDI

Positive correlations were found between the PD, DIVISION, SHDI, and the HDI from 2000 to 2020 in the entire study area, and a negative correlation was found between the LPI and the HDI. The correlation between the PD and the HDI was higher than those between the other three landscape fragmentation indices and the HDI (*Table 3*).

The PD was found to be positively correlated with the HDI in all gradients of the four topographic indices from 2000 to 2020. Between 2000 and 2020, the LPI was positively correlated with the HDI in elevation gradients I and II, but was negatively

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correlated with the HDI in the other elevation gradients. From 2000 to 2020, negative correlations were found between DIVISION, SHDI, and the HDI in elevation gradients I, II, and IV, whereas positive correlations were found in elevation gradients III and V. Between 2000 and 2020, most gradients of the slope, topographic relief, and topographic position index, namely gradients I to IV, the LPI, DIVISION, and SHDI were positively correlated with the HDI (*Table 4*).

Table 3. *The correlation coefficients between the landscape fragmentation indices and the HDI in the entire study area*

Area	PD	LPI	DIVISION	SHDI
Total study area	0.45385	-0.17067	0.09019	0.04560

PD, patch density; LPI, largest patch index; DIVISION, landscape division index; and SHDI, Shannon's diversity index

Table 4. *The correlation coefficients between the landscape fragmentation indices and the HDI in the topographic gradients*

Topographic gradients	Fragmentation index	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Elevation gradients	PD	0.29847	0.81281	0.36031	0.34956	0.26154
	LPI	0.29072	0.46184	-0.3308	-0.34342	-0.38066
	DIVISION	-0.32005	-0.39243	0.34642	-0.30603	0.45333
	SHDI	-0.18899	-0.24865	0.20767	-0.19470	0.39184
Slope gradients	PD	0.47283	0.47230	0.43889	0.38037	0.31778
	LPI	0.33736	0.27686	0.14898	0.06687	-0.07851
	DIVISION	0.34104	0.23798	0.05982	0.04619	-0.16188
	SHDI	0.20936	0.14088	0.02308	0.03037	-0.12651
Topographic relief gradients	PD	0.38703	0.51769	0.42482	0.32785	0.18221
	LPI	0.43061	0.30841	0.07350	0.09301	-0.08670
	DIVISION	0.52438	0.25065	0.06519	0.22167	-0.13414
	SHDI	0.37167	0.09480	0.06932	0.14039	-0.06890
Topographic position index gradients	PD	0.52555	0.45966	0.43521	0.36801	0.31038
	LPI	0.36184	0.33415	0.19532	0.08068	-0.14515
	DIVISION	0.37129	0.30998	0.11540	0.02650	-0.22038
	SHDI	0.21442	0.18969	0.05518	0.02147	-0.18457

PD, patch density; LPI, largest patch index; DIVISION, landscape division index; and SHDI, Shannon's diversity index

Discussion

Driving mechanism of the impact of the HDI on landscape fragmentation

Previous studies have found that changes in natural and anthropogenic landscapes can reflect the degree of disturbance caused by human activities, and the impact of human activities on landscape fragmentation can be reflected by changes in landscape types (Liu et al., 2021). Against the background of rapid urbanization and industrialization, anthropogenic landscapes (e.g., urban land, industrial and mining land) in mountain cities

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have increased significantly, while natural landscapes (e.g., grassland and shrubbery) have decreased significantly, which has led to a rapid increase in the degree of interference from human activities (*Tables 2, 5* and *6*). Under the influence of strong human interference, a significant increase in anthropogenic landscapes has destroyed the contiguity of the original landscapes, leading to an increase in the degree of landscape segmentation, poor connectivity between landscapes, and intensified landscape fragmentation (De Montis et al., 2017). In the process of rapid urban development, the massive increase of anthropogenic landscapes (e.g., urban residential land, roads, industrial and mining land) has occupied cultivated land and the natural landscape surrounding the city, which has resulted in the mosaic of the original natural landscape and landscape heterogeneity. Thus, the increases of the PD, DIVISION, and SHDI, as well as the decline of the LPI, were found in the present study. Moreover, positive correlations were found between the PD, DIVISION, SHDI, and HDI, and a negative correlation was found between the LPI and HDI (*Tables 3*, *5* and *6*).

Table 5. *The overall changes of landscape types from 2000 to 2020 (unit: hm^2)*

Time	Paddy fields	Non-irrigated farmland	Forests	Shrubbery	Grassland	Water bodies	Urban land	Rural residential areas	Industrial and mining areas
2000	91086	139584	72190	320999	153779	9224	7527	4138	5809
2020	77810	139005	79834	311405	136376	13956	21373	4146	20431
2000-2020	-13275	-579	7644	-9594	-17403	4733	13846	8	14622

Table 6. *Transaction matrix between landscape types from 2000 to 2020 (unit: hm^2)*

	Paddy fields	Non-irrigated farmland	Forests	Shrubbery	Grassland	Water bodies	Urban land	Rural residential areas	Industrial and mining areas
Paddy fields	71939	1013	600	2504	1890	679	5599	770	6091
Non-irrigated farmland	743	121518	1102	7997	3873	685	994	134	2538
Forests	495	835	67216	1503	414	795	395	45	492
Shrubbery	2232	7702	5356	287724	10581	2822	1481	366	2735
Grassland	2165	7565	5334	11042	119333	666	2713	159	4801
Water bodies	100	293	119	312	122	8232	36	4	6
Urban land	8	9	48	107	32	0	7313	0	12
Rural residential areas	79	53	11	60	73	48	1079	2611	123
Industrial and mining areas	50	15	50	156	58	30	1762	57	3632

Spatial formation mechanism of landscape fragmentation and the HDI

The formation of the spatial patterns of mountain landscape fragmentation and the degree of human disturbance are closely related to the distribution characteristics of human activities and the landscape pattern under terrain constraints (Bucała, 2014; Zhang et al., 2021). The southern region of the study area is relatively flat, which is conducive to various human activities. This region became the priority for changes in paddy fields, urban land, and industrial and mining land from 2000 to 2020 (*Fig. 4*). As a result, the change of the degree of human disturbance was found to be prominent in this area (*Fig. 2*). It is worth noting that the areas in which the terrain is heavily cut are characterized by a limited intensity of human activity, resulting in relatively small changes in landscape fragmentation and the HDI in these areas, namely the central and northern regions of the study area (*Figs. 2* and *4*).

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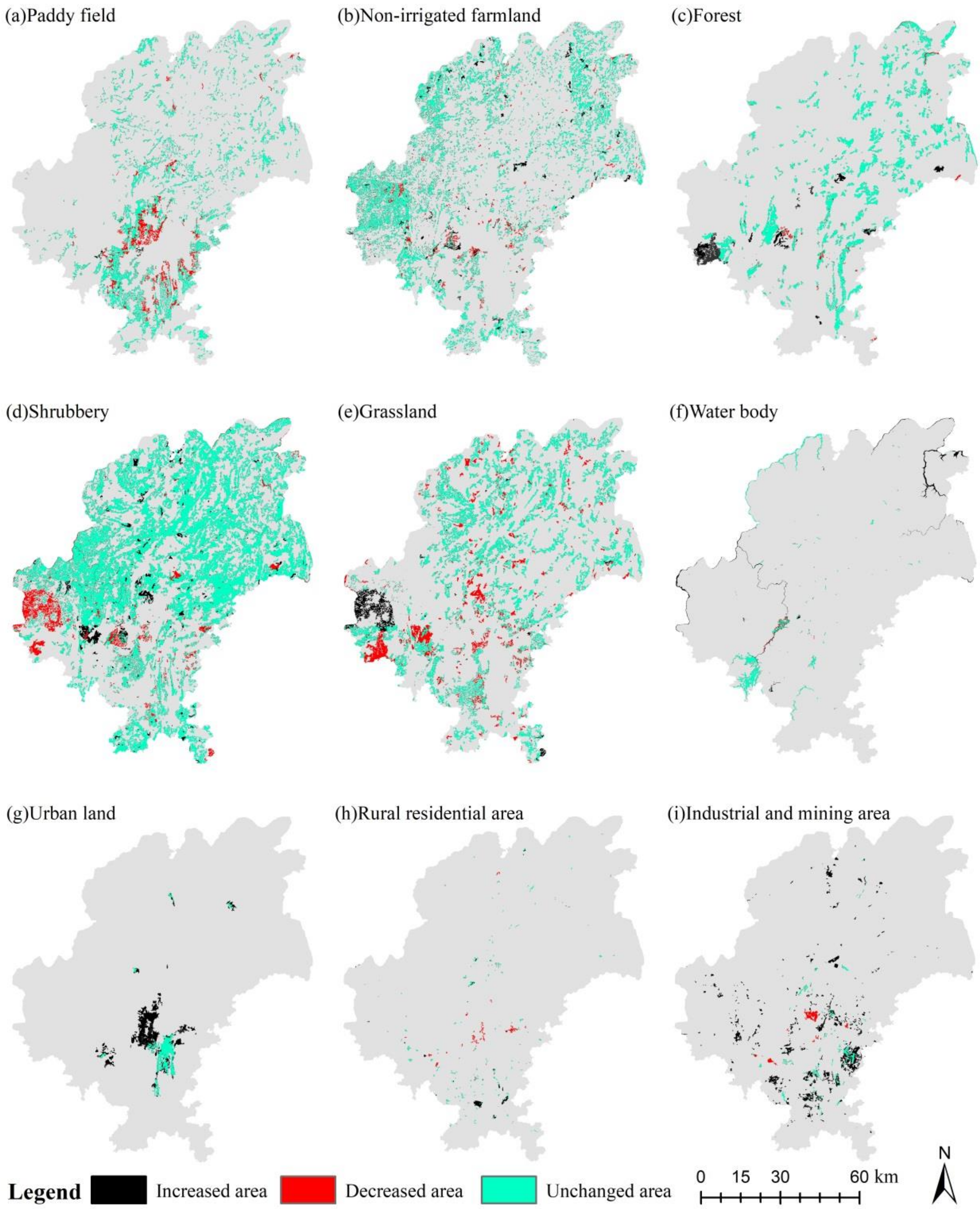

Figure 4. *The spatial patterns of the changes in landscape types from 2000 to 2020*

Topographic gradient formation mechanism of landscape fragmentation and the HDI

Previous studies have shown that human activities and landscape patterns are deeply affected by different terrain (van Beynen and Bialkowska-Jelinska, 2012; Sun et al., 2020). Areas with relatively low gradients of the slope, topographic relief, and surface cutting degree have become priority areas for the increase of various human activities under the influence of the rapidly growing social economy. These areas are the highlight of regions with a prominent degree of interference of human activities and serious landscape fragmentation. With the increase of the gradients of the slope,

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topographic relief, and surface cutting degree, the area of the anthropogenic landscape has gradually decreased and the area of the natural landscape has increased, which has significantly reduced the intensity of human interference and reduced the degree of landscape fragmentation. However, the effects of the elevation gradient on the HDI and landscape fragmentation were obviously different from those of the slope, topographic relief, and topographic position index gradients. For example, the results of this study showed that the change rates of the HDI in elevation gradients II, III, and IV were obviously higher than those in gradients I and V, while the changes rates of the HDI from gradients I to V of the slope, topographic relief, and topographic position index gradually declined. The cause of this phenomenon is that sloping farmland and shrubbery are the dominant landscapes types in elevation gradients I and V, respectively. This is not the core area of the expansion of human activities, and the impact of human activity is relatively low in these areas. Conversely, from gradients I to V of the slope, topographic relief, and topographic position index, the substantially reduced anthropogenic landscape (e.g. urban land, rural residential areas, and industrial and mining areas) has significantly reduced the intensity of human activities, and has thus weakened the degree of human interference (*Figs. 3* and *5*).

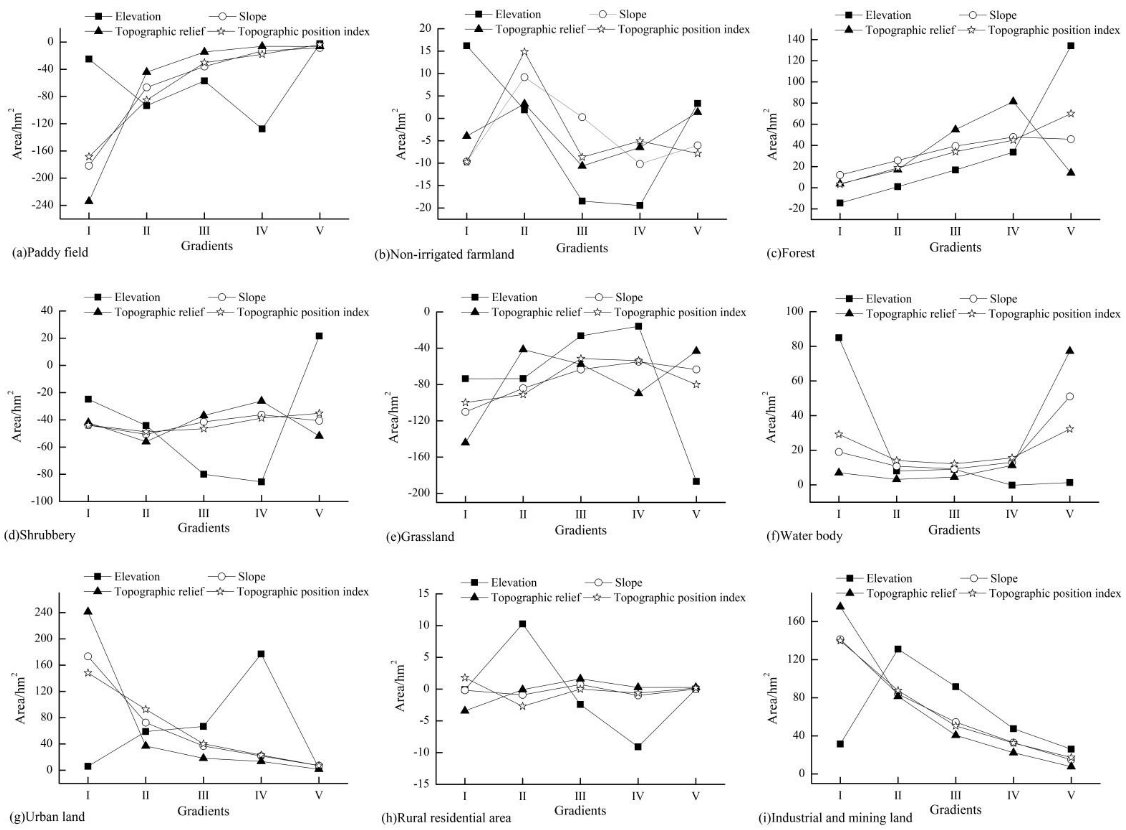

Figure 5. *The changes in the areas of landscape types in the topographic gradients from 2000 to 2020*

Landscape management

Because human activities and landscape fragmentation in mountain cities exhibit terrain differences, landscape management should be performed according to different

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terrains. For areas with concentrated anthropogenic landscapes with low gradients of the slope, topographic relief, and topographic position index, it is suggested that more green infrastructure and natural landscapes (such as urban green land and water bodies) be established, and that landscape connectivity and the proportion of the natural landscape be increased. For areas with high gradients of the slope, topographic relief, and topographic position index, afforestation should be strengthened to form a contiguous distribution of the natural landscape, alleviate landscape mosaic patterns, and reduce the proportion of the human landscape. Ecological corridors can also be established to increase landscape connectivity and reduce landscape fragmentation.

Conclusion

Under the influence of rapid urbanization and industrialization, it was found that the HDI and most landscape fragmentation indices increased in the mountain city under study, but the LPI decreased. The change rates of the HDI and landscape fragmentation in the relatively flat southern region were obviously higher than those in other topographic areas. The HDI decreased with the increase of the gradients of the slope, topographic relief, and topographic position index, but significant differences were found in the changes of different landscape fragmentation indices in the gradients of all four topographic indices. Excluding the LPI index, positive correlations were found between the other landscape fragmentation indices and the HDI. The correlations between the landscape fragmentation indices and the HDI were close in the gradients of the slope, topographic relief, and topographic position index, whereas the correlations between them were significantly different in the elevation gradient. The changes of the landscape type in different topographic gradients were found to be an important factor that affects the terrain gradient characteristics of the degree of human disturbance and landscape fragmentation. Relatively flat terrain areas should be considered the core area of future landscape management, and alleviating the intensity of human activities and the degree of landscape fragmentation should be the main goals of future landscape management in this area.

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Conflict of interests. The authors declare no conflict of interests.

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