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Assessing the effects of topographic gradients on landscape patterns: The study case of Tingjiang river basin, China

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ABSTRACT

With the progress of urbanization, the natural geographical characteristics of different river basins have also undergone tremendous changes, and bring many environmental and social issues. It is of great significance to the sustainable development of river basins to reveal the relationship between topographic and landscape patterns. Therefore, we selected Tingjiang river basin, utilizing remote sensing images from 1991, 2004, and 2017, as well as the digital elevation model (DEM) data, we computed a topographic classification system consisting of four levels (Low level, Low-medium level, Medium-high level, High level). This approach enables us to study the gradient impact of topography and investigate the mechanism influencing the landscape pattern. The results show: (1) Low-medium and medium-high topographic levels are dominant in the research sites, accounting 49.35% and 38.47%, respectively. (2) Bare land showed a significant decrease while construction, cultivated, and forest land increased from 1991 to 2017. (3) Forest land is mainly concentrated in the middle-high and high-topographic levels whereas construction land, cultivated land, water area and bare land are mainly concentrated in the middle-low and low-topographic level. (4) The landscape pattern significantly varies with the topographic gradient, where the conversion to construction land is widespread in the low-topographic area, while alternation between cultivated land and forest land mainly occurs in the medium-low and medium-high topographic areas. Consequently, these findings provide insights into the impact of topography on river basin landscape pattern, which could guide sustainable development in the future.

1. Introduction

The advantageous natural resource present in river basins have historically drawn humans towards settling and thriving in these areas, resulting in the birth and growth of numerous civilizations. As the cradle of civilizations across the globe, the dynamic changes occurring in river basins have had significant effects on human survival and development. However, with the rapid advancement of urbanization, the natural geographical characteristics of various river basins have also undergone tremendous changes [1]. Irrational urban development has resulted in the loss of various natural land use types, eroded by excessive construction, which inflicts harm upon the river basin's natural ecosystem, generating a plethora of environmental and social problems [2–4], such as the heat island effect [5,6], air pollution [7–9], soil erosion [10,11] and ecosystem imbalance [12]. These issues may ultimately lead to the eventual

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collapse of civilization. Once the ecosystem of the river basin is destroyed, it will directly and indirectly affect the other regions which connected to the basin, and its destructive power will be huge and incalculable [13]. Therefore, it is of utmost importance to thoroughly study and pay extensive attention to the scientific and rational construction in river basin regions [14,15].

In order to promote the sustainable development of river basin regions, experts and scholars worldwide have conducted extensive research on the landscape patterns of such regions [16,17]. This research has revealed that various factors, including climate [18,19], soil [20], biodiversity [21,22] and social economy [23], contribute to the formation of river basin landscape patterns, which in turn affect land use change. Research also shows that we should pay attention to the relationship between land use types and ecosystem services in order to better cope with the impact of urbanization [24,25]. Irrational land use distribution leads to unreasonable distribution of various landscape patterns, and the coordinated development between various land use types, resulting in many environmental problems, which can exacerbate the heat island effect and air pollution effects [26], leading to traffic congestion and economic losses [27]. In addition, due to the heat island effect and the impact of air pollution, it can greatly reduce the living comfort of urban residents, and even affect people's mental and physical health [28]. Therefore, both environmental and socio-economic problems brought about by the change of river basin landscape patterns will be challenges that we must deal with [29,30].

Existing studies on landscape patterns in river basins primarily focused on investigating spatiotemporal variations and underlying drivers for land use cover changes [31,32]. These studies have provided many important recommendations for the development of river basin areas. However, the existing studies on such patterns have predominantly focused on metropolitan or plain areas, with relatively scant attention given to river basins in mountainous cities [29,33,34]. Additionally, the study of river basins landscape pattern has mainly focused on the driving and conversion mechanism of land use cover change, as well as the characteristics of landscape pattern [35]. It is important to note that landscape patterns are closely related to gradients and that river basin landscape patterns are greatly influenced by elevation, slope, and topographic features [36,37]. Previous studies have mainly stayed on topographic gradients [38], and it is difficult to avoid the dimensional impact of different proportions of different land use types areas under topographic gradients. Therefore, in order to better understand the influence of topographic gradient on the change of landscape pattern in river basin, we selected Tingjiang river basin as the research object, which located in Fujian province, China. Referring to previous studies, and combined with the requirements of landscape heterogeneity and complexity in Tingjiang river basin, we examined the ecological significance of the landscape pattern index, and the monitoring of the impact of landscape spatial patterns on ecological process [39,40]. Specifically, we studied the landscape pattern change characteristics of Tingjiang river basin from the perspective of topographic gradients to: (1) quantitatively characterize the distribution frequency of different land use types for different terrain gradients through the distribution index model; (2) analyze the influence mechanism of different topographic gradients on urban landscape pattern in Tingjiang river basin; (3) Provide guidance for the geographical design and spatial management of the Tingjiang river basin. This study can provide a reference for landscape governance and sustainable development in mountainous river basins.

2. Materials and methods

2.1. Study area

Tingjiang river basin is located in the southwestern of Fujian province, China, within the coordinates of 115°59′E–117°10′E and 24°28′N-26°02′N, with a land area of 3104.16 km^2 (Fig. 1). Tingjiang river basin has a humid subtropical monsoon climate with an average precipitation between 1500 and 2000 mm [41]. Abundant forestry resources and well-protected native ecosystems, with a forest coverage rate of 74%, play an extremely important role in regional ecological stability. It is also recognized as the hub for scientific research, educational and cultural preservation of the "Hakka Culture (Western Fujian) Ecological Protection Experimental

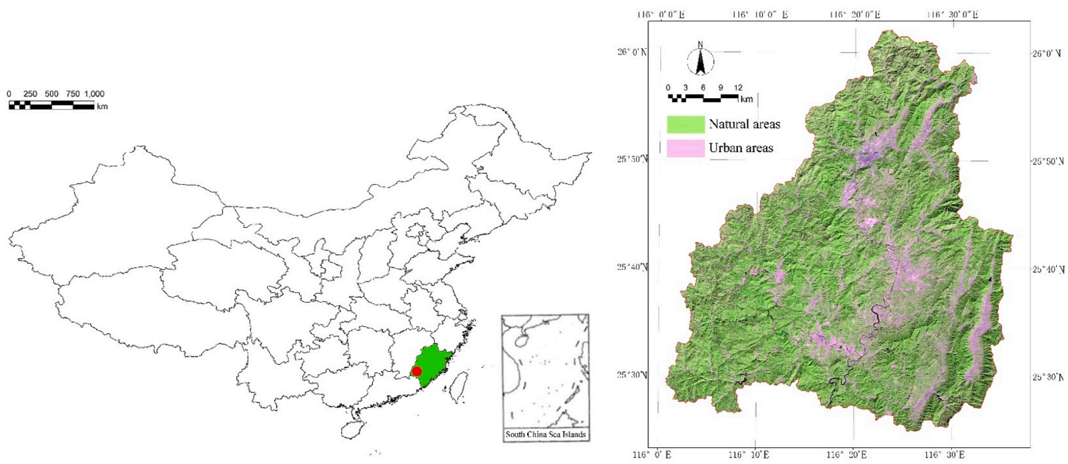


Fig. 1. The location of Tingjiang river basin.

Zone". Having been selected as one of the first batch of practice and innovation bases for the realization of the "Lucid waters and lush mountains are invaluable assets" policy, the Tingjiang River Basin is also among the first batch of demonstration cities (counties) for national ecological civilization construction initiative. Tingjiang river basin is a mountainous and hilly area with complex topographic, which is the southern section of Wuyi Mountain [42]. The topographic is relatively complex, so the social and economic development of different regions varies greatly.

2.2. Data sources and processing

The land use types data for the years 1991, 2004, and 2017 were obtained from the Geospatial Data Cloud (http://www.gscloud.cn). The remote sensing data for 1991 and 2004 were acquired from Landsat 4–5 TM, whereas the remote sensing data of 2017 were obtained from Landsat 8 OLI TIRS with definition of 30 m * 30 m. The data image collection period was from June to October. To better describe the topographic characteristic of Tingjiang river basin, we utilized the 1:50000 Fujian Digital Elevation Model (DEM) with spatial resolution of 30 m * 30 m for topographic gradient analysis.

2.3. Study methods

2.3.1. Analysis of land use types and landscape patterns

Based on ENVI 5.3 software, the remote sensing images of Tingjiang river basin in 1991/2004/2017 were preprocessed by image stitching, geometric correction, cropping, fusion and enhancement. We then performed the supervised classification with ENVI5.3 software and conducted image interpretation of the remote sensing images based on the Land Use Classification of GBT21010-2017. Considering the characteristics of regional land use types in the Tingjiang river basin, we divided the Tingjiang river basin into 5 types, including construction land, cultivated land, forest land, water area, and bare land. Then, to ensure classification accuracy met research requirements, we sampled and verified land-use interpretation results through field inspections, achieving an accuracy above 90%. We adopt the Number of Patches (NP), Patch Density (PD), Edge Density (ED), Landscape Shape Index (LSI), Area Weighted Mean Patch Fractal Dimension (AWMPFD), Mean Shape Index (MSI), CONTAG and Shannon's Diversity Index (SHDI) to analyze the landscape pattern of Tingjiang river basin (Table 1).

2.3.2. Classification of elevation, slope and topographic gradient

Based on the distinctive characteristics of the hilly terrain and the topography of the Tingjiang River Basin, we use the natural breakpoint method to categorize the elevation into four levels [43]. According to the slope classification of the International

Table 1
The description of landscape metrics.

Landscape metrics	Expression	Expression description	Ecological significance
Number of Patches, NP	$NP = n$	n refer to the number of patches of land use type	Its value reflects the number of patches
Patch Density, PD	$PD = NP/A \times 10000 \times 100$	NP refer to the number of patches; A refer to the landscape area	The number of patches per unit area of a certain type of landscape element in a landscape
Edge Density, ED	$ED = \frac{\sum_{k=1}^{m'} e_{ik}}{A} \times 10000$	e_{ik} refer to the edge length between patch types i and k in the landscape	When the ED value is smaller, it indicates that the total edge length in the landscape is shorter and there are fewer contact surfaces
Landscape Shape Index, LSI	$LSI = 0.25 \sum_{k=1}^{m} e_{ik}^{*} / \sqrt{A}$	e_{ik}* refers to the edge length between patch types i and k in the landscape	When the LSI value approaches 1, it indicates that the shape is closer to the square; When the LSI value is higher, it represents a more irregular shape
Area Weighted Mean Patch Fractal Dimension, AWMPFD	$AWMPFD = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[\left(\frac{2 \ln 0.25 P_{ij}}{\ln a_{ij}} \right) \left(\frac{a_{ij}}{A} \right) \right]$	P_{ij} refer to the circumference of patch ij, m refers to the type of patch, n refer to the number of patch type i	AWMPFD = 1 represents the simplest square or circle in shape, while AWMPFD = 2 represents the most complex patch type in circumference.
Mean Shape Index, MSI	$MSI = 0.25 \sum_{k=1}^{m} (p_i * \sqrt{(a_i)}) / n$	p_i and a_i refers to perimeter and area of patch i, respectively. n refer to the number of patch type i	MSI is equal to 1 when all patches are circular (for polygons) or square (for rasters (grids)) and it increases with increasing patch shape irregularity.
CONTAG	$CONTAG = 100 \times \left[1 + \frac{\sum_{i=1}^{m} \sum_{k=1}^{n} [P_i \bullet P_{ik} \bullet \ln(P_i \bullet P_{ik})]}{2 \ln(m)} \right]$	P_i refer to the proportion of the area of a specific patch type i to the total landscape area， $P_{ik} = e_{ik} / \sum_{k=1}^{m} e_{ik}$ ， P_{ik} refer to the proportion of adjacent grids containing any two patch types, and m is the number of patch types	The value ranges from 0 to 100. When the value is 0, it indicates that it is only adjacent to another type of patch, and its value increases as the number of adjacent patch types increases. When the value reaches 100, it indicates that the patch of that type is evenly distributed in the landscape
Shannon's Diversity Index, SHDI	$SHDI = -\sum_{=1}^{m} (P_i \bullet \ln P_i)$	P_i refer to the proportion of patch type i area to the total landscape area	When the value of SHDI is higher, it indicates higher landscape diversity. The smaller the SHDI value, the worse the landscape diversity

Geographical Union's Committee on Landform Survey and Landform Mapping regarding the application of geomorphic details, as well as the topographic characteristics of the Tingjiang River Basin, we have divided the slope into five levels. Our study utilizes a topographic index model to more precisely elucidate how the topographic gradients respond to fluctuations in mountainous urban landscape patterns. The topographic index was composed by two topographic factors, elevation and slope [44]. The topographic index can accurately quantify the topographic profile of a certain area, which can helpful to quantitatively analyze the temporal and spatial variation characteristics of land use types on the topographic gradient [45]. The calculation of topographic index was:

$$T = \log[(E / E_0 + 1) \times (S / S_0 + 1)] \tag{1}$$

where T is refers to topographic index;E and E_0 are the elevation value of any point in the space and the average elevation value of the study area, respectively; S and S_0 are the slope value of any point in the space and the average slope value of the study area, respectively.

Based on the actual situation of the research area, the quantitative reclassification method was used to classify the topographic level. The 10 topographic level were divided into 4 topographic classifications: low, low-medium, medium-high, and high.

2.3.3. Analysis of distribution index

The investigation of how topographic factors affect landscape pattern can be simplified as the distribution frequency of various landscape types on different topographic gradients. In order to avoid the dimensional influence caused by the different proportions of different land-use areas under the topographic gradient, we adopt the distribution index model to quantitatively characterize the distribution frequency of each land-use type on different topographic gradients [46,43]. The calculation of distribution index was calculated as:

$$P = (S_{ie} / S_i) / (S_e / S) \tag{2}$$

where P is the distribution index, S_{ie} is the area of the i_{th} land-use type distributed in the topographic interval e; S_i is the total area of the i_{th} land-use type in the study area; S_e is the total area of the topographic interval e in the study area; S is the total area of the study area. When the $P < 1$, it means that the topographic e is not the dominant topographic of the land-use type. When the $P > 1$, it indicates that the topographic e is the dominant topographic of the land-use type distribution, and the larger of P, the more dominant the advantage.

3. Results

3.1. Spatial distribution characteristics of different topographic gradients

The Tingjiang river basin is situated at an elevation range of 300–800 m, which is predominantly covered by hills (86.24%), primarily distributed in the central region (Table 2 and Fig. 2a). The terrain in the central Tingjiang river basin exhibits lower elevation, while the surrounding hilly areas have higher elevation levels. A large portion of the basin area has a slope gradient of >15 (60.04%), and the area with a slope gradient of <15 is 39.96%, primarily located in the central region (Table 3 and Fig. 2b). The topographical analysis reveals a high-level surroundings and low-level middle terrain type in Tingjiang river basin (Fig. 2c). Furthermore, the basin terrain is mainly composed of low-medium elevation level (49.35%) followed by medium-high elevation level (38.47%) (Table 4). The lower elevation occupies 11.58%, whereas the higher elevation covers only 0.6%. Based on the aforementioned analysis of elevation, slope, and topography, it becomes clear that the basin's plain landform is mainly concentrated in the central region.

3.2. Land use types change characteristics under topographic gradient

Interpreting the land-use types of Tingjiang river basin in 1991 (Fig. 3a), 2004 (Figs. 3b) and 2017 (Fig. 3c), the results show that the bare land decreased by 244.16 km^2 from 1991 to 2017, while the forest land increased by 123.11 km^2 in total, with an annual change rate of 0.49%. It shows that the soil erosion control in Tingjiang river basin had achieved remarkable achievement [47]. With the governance of soil erosion in Tingjiang river basin, part of the bare land had also been converted into cultivated land, which showed increased by 67.02 km^2 in the past 16 years. The area of construction land increased year by year, with a total increase of 47.47 km^2 from 1991 to 2017. It shows that the urbanization construction in Tingjiang river basin develops year by year (Table 5).

Based on the distribution index data of land use types in 1991, 2004, and 2017, it can be observed that the distribution patterns for cultivated land (Fig. 4a), water areas (Fig. 4c), and construction land (Fig. 4e) remained relatively stable. However, forest land

Table 2
The elevation classification of Tingjiang river basin.

Elevation range (m)	Elevation classification	Area (km^2)	Area ratio (%)
800–1500	1	146.51	6.03
500–800	2	854.52	35.18
300–500	3	1240.16	51.06
200–300	4	187.73	7.73

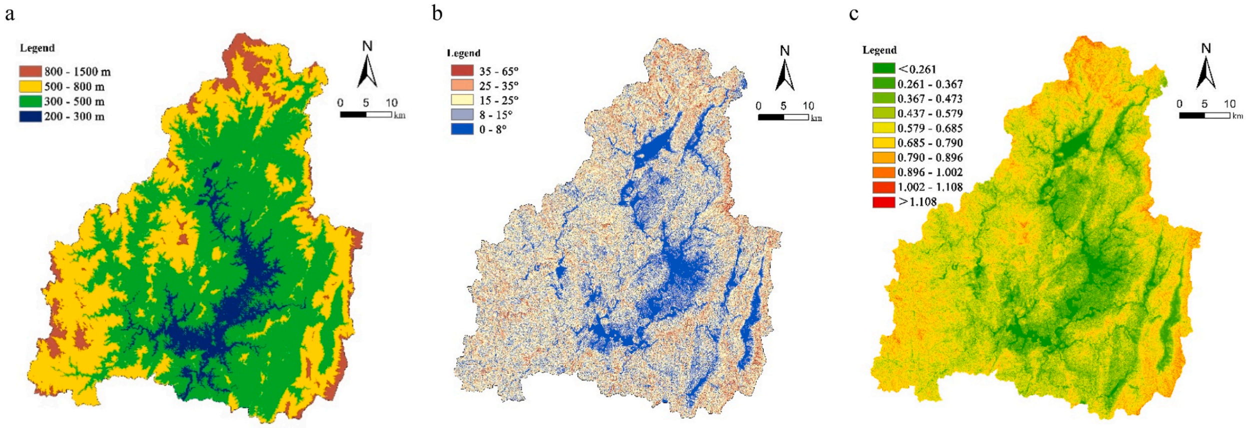


Fig. 2. Analysis of Tingjiang river basin topographic gradients. a. Map of elevation classification; b. Map of slope grade; c. The map of topographic index.

Table 3
The slope classification of Tingjiang river basin.

Slope range (°)	Slope classification	Area (km^2)	Area ratio (%)
35–65°	1	46.57	1.92
25°–35°	2	372.46	15.33
15°–25°	3	1039.52	42.79
8°–15°	4	555.14	22.86
0°–8°	5	415.23	17.10

Table 4
The topographic classification of Tingjiang river basin.

Topographic classification	Topographic level	Classification range	Area (km^2)	Area ratio (%)
Low level	t1	< 0.261	107.32	4.42
	t2	0.261–0.367	173.99	7.16
Low-medium level	t3	0.367–0.473	247.71	10.2
	t4	0.473–0.579	392.59	16.16
	t5	0.579–0.685	558.34	22.99
Medium-high level	t6	0.685–0.790	532.62	21.93
	t7	0.790–0.896	306.61	12.62
	t8	0.896–1.002	95.19	3.92
High level	t9	1.002–1.108	13.80	0.57
	t10	> 1.108	0.75	0.03

(Fig. 4b) and bare land (Fig. 4d) showed slight fluctuations. With the exception of forest and bare land, the distribution indices for other land use types decreased as the topographic index increased. The primary distribution segment for cultivated land was t1-t4, with a distribution index between 0 and 4.04. From 1991 to 2017, the cultivated land tended to shift towards higher elevations and slopes. The forest land distribution index ranges from 0 to 2, and in 1991 the distribution index in t1-t5 was lower than in 2004 and 2017. However, the distribution index in the t6-t10 segment was higher in 1991 than in 2004 and 2017, indicating that soil erosion control was becoming more effective in the Tingjiang river basin, particularly for forest land at lower topographic levels. Changes in the distribution index of bare land corresponded to changes in forest land. In 1991, the advantage of bare land was prominent in lower level topography. With soil erosion control measures, the bare land in lower and low-medium topographic levels were systematically managed by 2017, resulting in a corresponding decrease in the distribution index of bare land. The distribution advantage of construction land ranges from 1 to 3, with a distribution index of 0–8. In 2004 and 2017, the distribution index at t1-t2 was lower than in 1991, while at t3-t10 it was higher than in 1991. This suggests that urban construction gradually expanded to low-medium and medium-high topographic areas.

3.3. Topographic gradient variation of landscape pattern

In terms of landscape pattern (as shown in Table 6), the AWMPFD remained relatively stable over the study period, hovering around 1.38 on average. Meanwhile, NP, PD, ED, LSI, MSI, and SHDI all exhibited a pattern of decreasing first, then increasing.

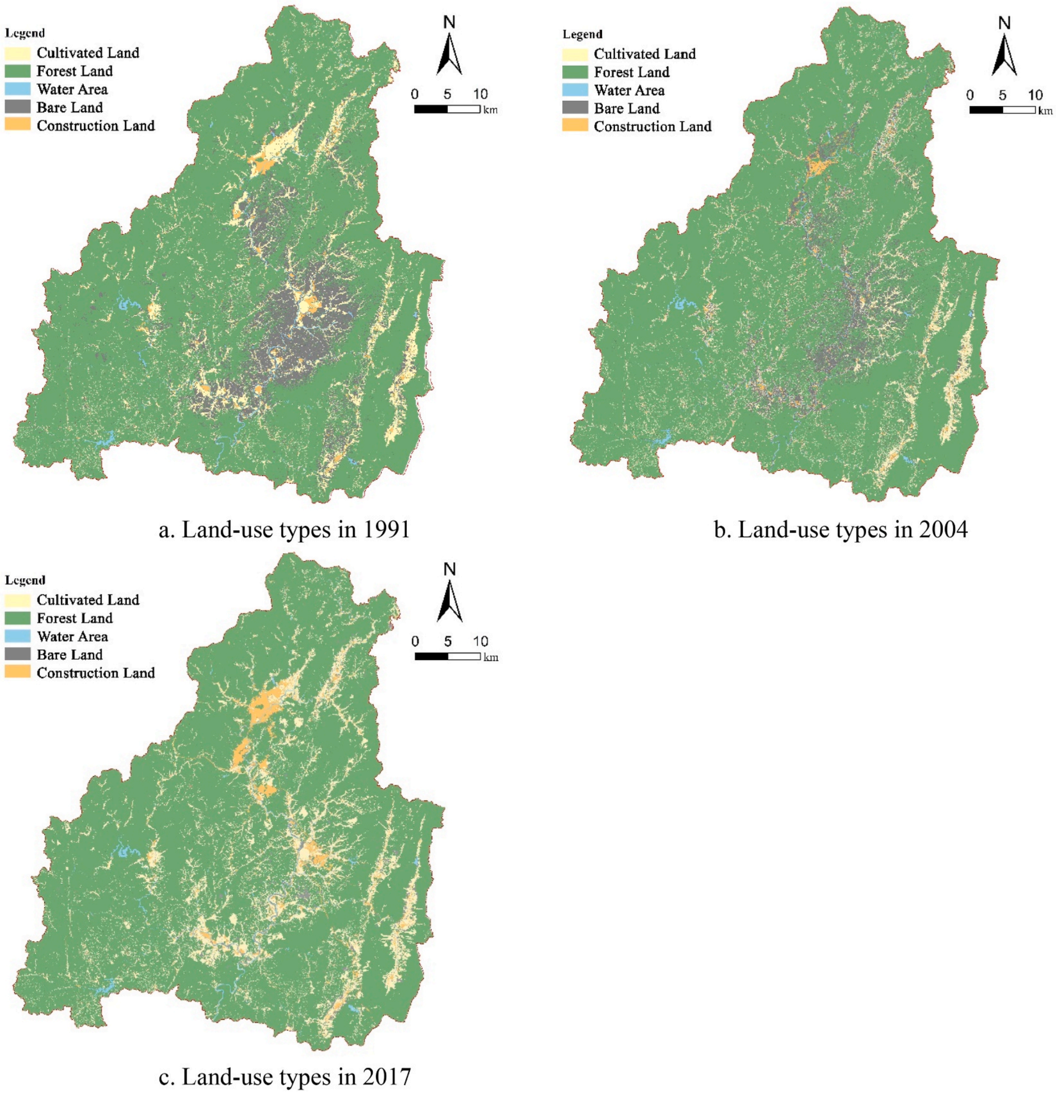


Fig. 3. Tingjiang river basin land-use types from 1991 to 2017.

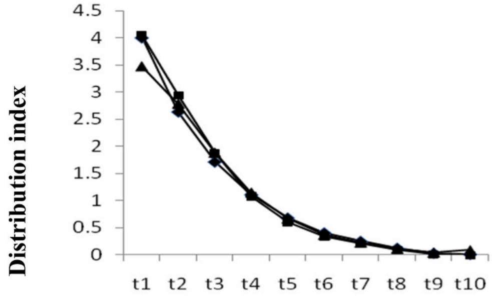
Table 5
Variation of land-use types from 1991 to 2017 in Tingjiang river basin.

Years	Variable parameters	Cultivated land	Forest land	Water area	Bare land	Construction land
1991–2004	U/km^2	−5.76	171.93	−0.80	−168.5	3.14
	K/%	−2.38	9.29	−3.40	−59.77	10.22
	R/%	−0.19	0.69	−0.27	−6.76	0.75
2004–2017	U/km^2	72.78	−48.82	7.37	−75.66	44.33
	K/%	30.81	−2.41	32.45	−66.71	130.96
	R/%	2.09	−0.19	2.18	−8.11	6.65
1991–2017	U/km^2	67.02	123.11	6.57	−244.16	47.47
	K/%	27.70	6.65	27.95	−86.61	154.58
	R/%	1.89	0.49	1.91	−14.33	7.45

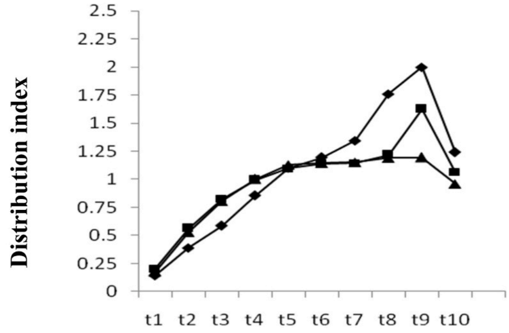
NoteU refer to absolute variation, K refer to relative change rate, R refer to annual change rate.

CONTAG gradually increased over time, indicating a tendency for scattered plaques inside Tingjiang river basin and a decrease in their degree of aggregation. These changes suggest that urbanization is progressing in the Tingjiang River Basin.

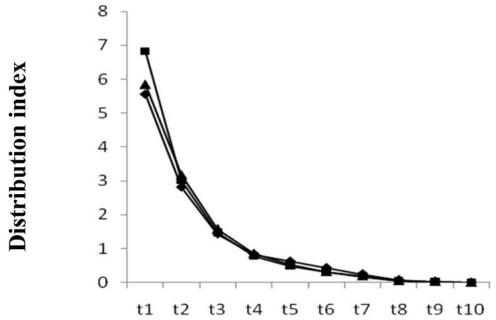
Looking at the landscape pattern index across different topographic levels in the basin in 1991, 2004, and 2017, we can see that the t4 level was the inflection point for NP value (Fig. 5a), which increased overall from 1991 to 2017. In terms of time series, PD value was



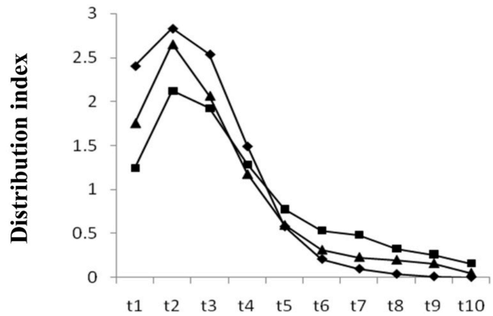
a. Variation of cultivated land on topographic gradient



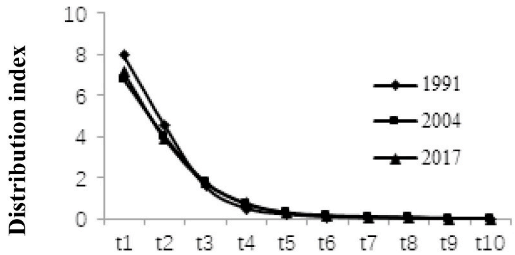
b. Variation of forest land on topographic gradient



c. Variation of water area on topographic gradient



d. Variation of bare land on topographic gradient



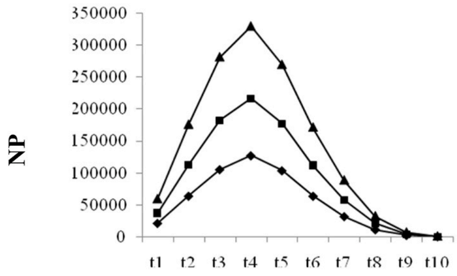
e. Variation of construction land on topographic gradient

Fig. 4. Change of various land-use types on topographic gradient.

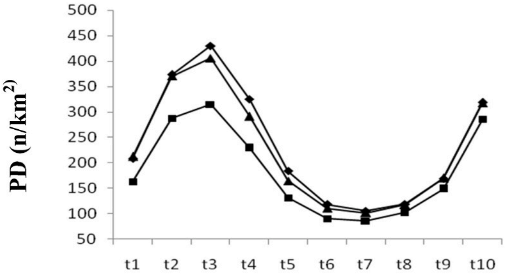
Table 6
Comparison of landscape pattern indexes of Tingjiang river basin from 1991 to 2017.

Years	NP	PD (n/km^2)	ED (m/0.01 km^2)	LSI	MSI	AWMPFD	CONTAG (%)	SHDI
1991	59788	24.68	98.89	123.62	1.48	1.38	68.64	0.79
2004	35828	14.78	65.60	82.72	1.29	1.37	71.42	0.58
2017	46742	19.23	92.50	115.97	1.63	1.38	72.92	0.66

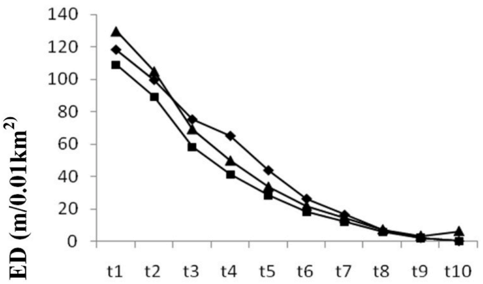
consistently lower in 2004 than in the other two periods (Fig. 5b). This data suggests that landscape fragmentation in the basin was mainly occurring in the low-middle level topographic areas. ED decreased gradually as the topographic index increased (Fig. 5c). SHDI reached its peak at the t1 topographic level then decreased progressively as topographic level increased (Fig. 5d). The trends of AWMPFD (Fig. 5e) and MSI (Fig. 5f) were similar, both peaking at t4-t8. LSI showed a pattern of decreasing then increasing, with the value in 2004 significantly differing on t2-t7 topographic levels from those in 1991 and 2017 (Fig. 5g). CONTAG increased gradually along with the increase of topographic gradient, and the maximum fragmentation and patch distribution discontinuity was more pronounced in low topographic areas than high areas (Fig. 5h).



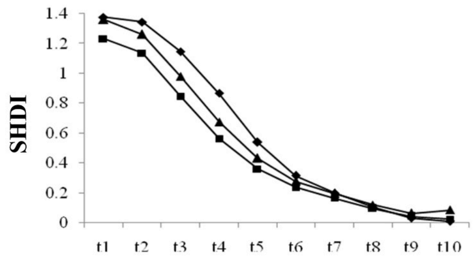
a. Variation of NP on topographic gradient



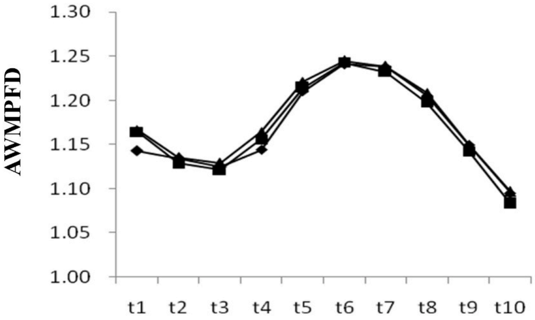
b. Variation of PD on topographic gradient



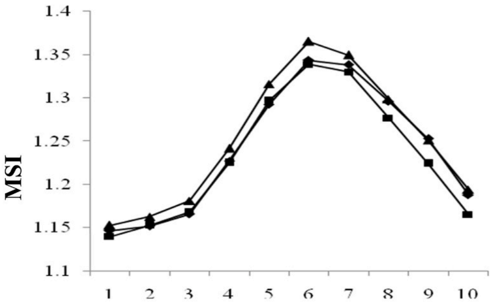
c. Variation of ED on topographic gradient



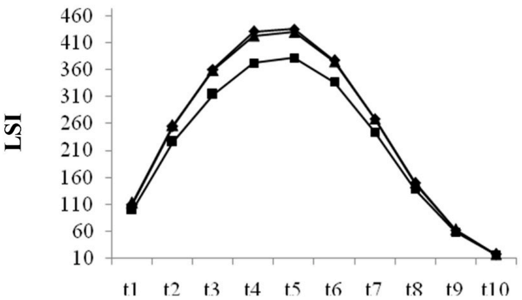
d. Variation of SHDI on topographic gradient



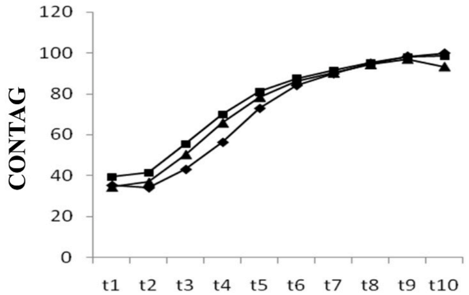
e. Variation of AWMPFD on topographic gradient



f. Variation of MSI on topographic gradient



g. Variation of LSI on topographic gradient



h. Variation of CONTAG on topographic gradient

1991 2004 2017

Fig. 5. Variation in landscape pattern index under topographic gradient.

4. Discussion

4.1. The influence of topographic gradient effect on land use types

Through our research, it is concluded that there was a significant relationship between topographic gradient and urban land use types. Our study on the evolution of land use patterns from 1991 to 2017, in response to topographic gradients, also highlights the transformation of natural land to fulfill the demand for urban development and construction [48]. As urbanization progresses, the topographic gradient of construction land has expanded to encompass areas with medium-high topography. This is similar to Jia et al.' s findings that the constraining of topographic factors weakened as the urbanization progressed [35]. Despite the shortage of flat land in the Tingjiang river basin, some construction land is compelled to be built on higher topographic levels to cater to the increasing demand for urban land [49]. Therefore, with the growing desire for green spaces in cities, the stronghold of construction land on low-level topography has been broken. However, residents in mountainous regions avoid living in areas with excessively high topography due to the complexity of the terrain.

Our research results also have an interesting finding that the change in Tingjiang river basin's forest land was different from most studies, with an increase of 123.11 km^2 from 1991 to 2017. This unique trend can be attributed to Tingjiang's status as a model region for soil erosion control in China, where efforts to conserve soil and water, and promote ecological conservation forest construction, have expanded forest land distribution on low and middle-level topography. Consequently, this has improved the service function of Tingjiang's forest ecosystem [50]. The gradual shift of cultivated land to the high-middle level topographic was also related to the process of urbanization. With the advancement of the urbanization process, the economic development and social population of cities had increased rapidly, and the cultivated land happens to be a flat site with a lower topographical level in the city. As Jingchao et al.' s research, urbanization was more likely to occur in plains and hilly areas and a majority of people tend to live in these areas in the future [51]. Therefore, this had also led to cultivated land becoming an important source of construction land in urban development, and ultimately led to the encroachment of urban cultivated land by other land-use types. However, China still exercises control over the area of cultivated land in order to ensure food security, leading to a movement of cultivated land from low and low-medium topography to higher elevation and slope. Urbanization also takes place more prominently in plains and hilly areas, and as such, cultivated land is susceptible to being repurposed for urban development, leading to a loss of valuable resources.

4.2. The effect of topographic gradient on landscape pattern

With the advancement of urbanization, the urban landscape pattern had undergone tremendous changes. The frequent conversion of landscape patches with different land-use types has resulted in increased NP and PD, particularly in areas with low-medium level topographic. Most urban construction activities were mainly distributed in low, low-medium level topographic positions, while cultivated land, bare land, and construction land were mainly concentrated in low-medium topographic positions. The changes of ED and SHDI indicated that the landscape patches are divided and eroded by urbanization in the low topographic, resulting in created more individual patches, and the edges of patches also became more complex [52]. The increasing dispersion between landscape-type patches has made land use types more complex, leading to greater diversity in the landscape types found in low-level topographic areas [51]. This implies that urban construction activities tend to focus on areas with lower topographic relief. In contrast, higher topographic areas are primarily composed of forest land, which demonstrates greater landscape monotony due to fewer high-intensity urban construction activities.

From the time scale, the SHDI showed a trend of decreases and then increases. This is because positive human disturbance dominated by soil and water conservation dominated from 1991 to 2004, which gradually improved the soil and water loss phenomenon in Tingjiang river basin. This is in line with 's research, Guo et al. (2021) who declared that soil erosion distribution depends on both anthropogenic activities and natural conditions [53]. From 2004 to 2017, urbanization development was the dominant factor, with construction land encroaching on other land-use types and increasing the heterogeneity of SHDI. This is in line with Walt 's research, which indicated that urbanization and associated patterns and processes can affect the species composition and prevalence of certain plant traits in natural areas [54]. From the time scale, CONTAG increases gradually with the increase of topographic gradient, and these sections were dominated by forest land, indicating that the CONTAG was higher in areas with less human disturbance [53]. The highest fragmentation and patch distribution in the landscape occurred in low-level topographic areas, suggesting that urban construction activities were concentrated in areas with lower topography [51].

4.3. Construction strategies of urban landscape pattern

Influenced by topography and landforms, urban construction activities in the river basin mainly developed in the lower topographic areas [34]. However, the migration of human beings from the mountains into the plains also led to a large concentration of people in the plains area. From 1991 to 2017, the construction land increased by 47.47 km^2, and the NP and PD of the construction land also increased significantly, indicating the disorderly expansion of the construction land in the central region. Therefore, during future construction in the river basin, rational development of construction land in the low topographic area should be given priority, and there should not be hasty conversion of cultivated land or forest land disorderly. Moreover, natural land-use types such as water area, cultivated land or forest land cannot be converted into construction land disorderly. By improving the construction of public facilities in the surrounding satellite cities and improving the urbanization construction and social service level in these areas [55], then we can retain the population of these areas and even attract the population of the central areas to move to the low-medium and medium-high topographic area [56]. This would reduce demands for construction land during urbanization in the central region and alleviate the environmental and social problems associated with population concentration. Accordingly, we also propose the following development strategies: (1) Ensuring optimization of land resource management and landscape patterns during future urban development in Tingjiang River basin. (2) Undertaking allocation and adjustment of the landscape structure in different topographic gradient areas based on local conditions. (3) Enhance and synchronize the nexus between urbanization development and safeguarding of the ecological environment at the regional level. Guarantee the ecological roles, like preserving water resources and reducing soil erosion, of the forested landscape. This will foster the enduring progress of a state of balance between humanity and nature.

4.4. Limitation

From the perspective of topographic gradient, this study investigates the dynamics of landscape patterns in mountain river basins, offering valuable guidance for the construction and sustainable development of Tingjiang River basins. Despite these findings, this research has some limitations. Firstly, the accuracy of the 3030 remote sensing images restricts our ability to comprehensively assess the transformation characteristics of the landscape pattern. Conducting future studies with higher-precision remote sensing images could enhance accuracy. Secondly, aside from the impact of topographic gradient [23], socio-economic factors also influence the change of watershed landscape pattern. Future research could incorporate these considerations. As there are multiple factors at play in the evolution of river basins landscape pattern, multi-source data analysis will be conducted to provide more valuable references.

5. Conclusion

This paper presents a comprehensive analysis of the distribution index of land use types and landscape patterns index in a river basin from 1991 to 2017, based on the study of land use types data and DEM data. The analysis is approached from the perspective of topographic gradient index, revealing the spatiotemporal variation characteristics and direction of landscape patterns in different topographical regions. This study goes beyond the traditional approach of single gradient effect analysis based on elevation or slope. By combining the topographic gradient with landscape pattern analysis, this paper offers valuable insights into the rational layout of land-use types in river basin planning and provides a scientific basis for urban development in the Tingjiang river basin.

Author contribution statement

Xiaoling Xu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Jingwen Dong: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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