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Effect of Compactness of Urban Growth on Regional Landscape Ecological Security

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Abstract: With rapid urbanization destroying the ecological environment, scholars have focused on ways to coordinate harmonious development using urban spatial layouts and landscape ecological security. To explore landscape ecological security (the landscape elements, spatial positions and connections that are of key significance to the health and safety of ecological processes) from the perspective of urban form evolution pattern will help to open a new perspective of urban management research, and become the basic work of urban space policy and the implementation of the beautiful China strategy. Based on urban growth and land use data from 356 cities in China, this study applied a geographically weighted regression (GWR) model to quantify the impact of China's urban growth pattern on landscape ecological security at the spatial level. The research results show that: (1) To some extent, the infilling growth pattern has a certain effect on the enhancement of regional landscape ecological security; (2) In the three control variables (DEM, Population density and GDP), the following conclusions are drawn: regional landscape planning should reasonably allocate landscape resources according to the local topographic features to obtain a higher landscape ecological security; The increase of population density leads to the fragmentation and diversity of the landscape in some regions, which makes the landscape ecological security weak; more economically developed areas have stronger landscape ecological security. This paper highlights the importance of urban growth patterns to landscape ecological security. In addition, considering the different urban evolution trajectories in developed and developing countries, this study proposes targeted development recommendations, providing a reference for urban managers to formulate reasonable development policies and to realize sustainable development with the goal of landscape safety management and control.

Keywords: urban growth patterns; landscape ecological security; GWR; China

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1. Introduction

Urbanization promotes social and economic development and improves people's living standards; however, it can also profoundly change the form of the city itself and the structure and function of the urban ecosystem (the maintenance of ecological functions for human well-being is particularly oriented towards a human-dominated landscape and should be emphasized) [1–3], creating a series of urban ecosystem security deterioration problems [4,5]. The urban landscape pattern is the embodiment of urban landscape heterogeneity and the result of urbanization on different scales. Since the 1990s, scholars have noticed that the study of the relationship between process and landscape, based on the urban landscape level, plays an important role in land use planning and management and sustainable development [6]. Since Fragstats software was developed and applied to landscape pattern research, it has achieved an important breakthrough. The research perspective has gradually changed from single spatiotemporal research to multi-time series and multi-spatial scale analysis, and the change phenomenon [7,8], driving factors [9,10] and influence effects [11–13] of urban landscape pattern have been explored in depth. Among them, the study of the driving factors of landscape pattern is helpful to explore its dynamic evolution mechanism, and then regulate the direction, process and effect of landscape pattern change, so as to put forward countermeasures for urban development.

Exploring the impact mechanism of urbanization on landscape pattern change is the key to understanding the impact mechanism of human activities on landscape pattern, process and change. At present, the influencing mechanism of various factors of urbanization on landscape pattern has been successively developed, such as urban–rural construction land policy [14], urban expansion intensity [15], and urban sprawl [16]. However, there remain insufficient quantitative studies on the relationship between urban dynamic processes and landscape ecological security compared with the static patterns. In addition, most of the existing studies focus on the time level, analyzing the erosion of ecological landscape caused by urban land expansion and the destruction of landscape ecological security caused by urbanization. In the context of unbalanced and extensive use of land resources, the lack of spatial dimension information will lead to applicability of the research results. China is currently in the critical stage of overcoming the middle-income trap, and ecological civilization construction has become a major strategy of national development. Based on this, this paper constructs a theoretical framework to assess the impact of urban growth patterns on landscape ecological security at a spatial level; 356 cities in China were used as research areas. This highlights the importance of improving the security and stability of urban structures, alleviating the environmental problems caused by urbanization, and realizing sustainable landscape planning. Such a study can also provide a new understanding of existing urban development–landscape relationships.

Based on the theory and method of landscape ecology, landscape ecological security focuses on the study of landscape spatial patterns and their evolutionary trends, which are mainly characterized by the size, shape, distribution, and mosaic structure of land use patches, and the inter-relationships between these elements constitute the urban ecological security landscape. Any spatial scale of a landscape and its structure will change over time. There are some key parts, elements, spatial positions and connections in the landscape which are of vital significance to the security of landscape change (process). These strategic parts, elements, spatial positions and connections constitute the landscape ecological security pattern. Landscape scale, form, quantity, type, and spatial configuration have important impacts on ecological security. An increase in human activities leads to changes in landscape morphology, fragmentation, and connectivity, ultimately affecting ecological security [17]. At present, the quantitative analysis methods of landscape ecological security mainly include Pressure–State–Response model [18], Minimum Cumulative Resistance model [19,20] and landscape index method [21]. Among these, the landscape index method is a quantitative index that reflects the characteristics of landscape structure composition and spatial configuration by highly summarizing landscape pattern, and can effectively reflect landscape function, dynamics and spatial heterogeneity. The landscape index method based on the geometric characteristics of landscape can effectively reflect the spatial pattern of land use/cover change [22], and effectively represent the relationship between landscape pattern and urban development. It is one of the methods to evaluate regional ecological security, and has become an important quantitative research method in current urban landscape pattern research [23,24]. The purpose of landscape ecological security assessment is to indicate important patches and their locations and spatial connections, namely, to optimize landscape structure and process [25], which can be used as a potential quantitative tool to guide the sustainable development of landscape [26], and its research has important practical significance for coordinating the spatial contradiction between urban development and landscape protection. Based on comprehensive research in different regions of China, it is not difficult to identify that the spatial expansion of cities (including the complex interactions among the natural environment, different organisms, and human society) leads to a decrease in ecological land, an increase in the number of landscape patches, the fragmentation of landscape patterns, and the gradual increase of the morphological complexity of landscape patches, which is one of the reasons for the decline in ecological functions, the aggravation of ecological risks, and the continuous decline of biodiversity [27–29]. The patterns of urban growth significantly influence changes in the urban spatial form, leading it to continuously diffuse outward or become denser and more compact inwardly. Generally speaking, urban growth includes three different spatial patterns: infilling, edge-expansion and outlying. Infilling makes the urban landscape pattern more regular and complete; edge-expansion makes the landscape more broken and complex; and outlying increases the density and diversity of patches [30]. Changes in the ecological risk of an urban landscape are closely related to the evolution of land use types and the rapid growth of the population [31]. Therefore, the expansion of construction land under different urban growth patterns will inevitably bring different impacts on landscape remolding, and eventually form different patterns of landscape ecological security.

Edge-expansion mainly involves encroachment into the farmland around cities, which is an important way for cities to expand. Urbanization and industrialization have expanded construction land into many farmlands. From 1992 to 2015, 2.51×10^4 km^2 of cultivated land was lost due to the expansion of the urban land margin, accounting for more than 75% of the total loss of cultivated land [32] by urban construction land, leading to increases in the fragmentation and decentralization of regional landscape types, and obstacles to sustainable agriculture around cities [33–36].

Outlying patterns mainly occur in emerging areas far away from central cities, and involve the increase in scattered or isolated patches distributed within a region. The connections between patches of outlying growth are mainly through various forms of linear traffic, and the traffic lines create a fragmentation of the landscape. Zhou et al. [37] noted that this type of leaping growth pattern destroyed the integrity of water bodies and hindered the connection between lakes and major surface water networks in the qualitative analysis of the impact of Wuhan's urban growth from 1988 to 2013 on landscape ecological security. This fragmented and reduced ecosystem service functions.

Infilling is considered a form of compact growth in China, and mainly occurs through the reconstruction of urban interior villages. The compact city emphasizes the high density and mixed use of urban land; centralizes the layout of urban functional elements; and promotes effective connections between urban public facilities, employment opportunities, and a public transportation system. However, the intensive development of a city may lead to higher levels of environmental pollution. Highly intensive development may cause changes in the connectivity, fragmentation, separation, and overall landscape morphology of the natural landscape. This may result in a decrease in the natural ecological structure, function, and stability. In addition, infilling development within urban boundaries may be at the expense of urban green space. As such, some scholars believe that compact development can bring benefits within a metropolitan area or a regional area, but adversely impacts small space areas [38].

The discussion above leads to the hypothesis that there is a relationship between urban growth patterns (UGP) and landscape ecological security. The objective of this study was to create a theoretical framework and quantify the impact of UGP on landscape ecological security by: (1) using the Landscape Expansion Index to characterize urban growth pattern; (2) calculating appropriate landscape indexes to characterize the patch area, density, shape, degree of aggregation, and diversity of different areas; and (3) 356 cities in China in 2015 were divided into seven regions according to their geographical location to evaluate the impact of urban growth patterns on landscape ecological security. In addition, to ensure the accuracy of the research results, this study also considered specific control variables, and applied a geographical weighted regression model. The novelty factor of the paper is to explore the impact of urban compact growth pattern on landscape ecological security at a national scale.

2. Methods and Data Sources

2.1. Indicator Selection and Data Source

The urban growth rate (UGR) [39], urban growth intensity (UGI) [40] and urban growth patterns (UGP) [41] are used to describe urban expansion within a study unit in a certain period of time. These indicators express the spatial distribution and growth rate of urban growth, and are key indicators to quantitatively evaluate urban growth in a specific time and space [26]. In this study, the landscape expansion index (LEI) proposed by Liu et al. [41] was adopted as a single index to characterize the form of urban growth; this is expressed as formula (1). LEI analyzes the dynamic changes of two or more time-phase landscape patterns, and mitigates a problem with the traditional landscape index, which is limited to information about the landscape pattern in a certain time-phase. LEI is a landscape metric to evaluate the dynamic pattern of urban growth, and it has been applied in the study of the dynamic spatial structure of urban expansion in many cities at home and abroad [42–44]. A high LEI index means the growth of the city tends towards being more compact. When the LEI value is 0, the patch is considered to be outlying; when $0 < \text{LEI} < 50$, it indicates edge-expansion; and when $50 \leq \text{LEI} \leq 100$, it indicates infilling.

$$\text{LEI} = \frac{A_o}{A_o + A_v} \times 100 \tag{1}$$

where LEI refers the landscape expansion index for a newly grown patch. A_o is the intersection area between the new land use patch buffer and urban built-up area, and A_v is the intersection area between the new land use patch buffer and non-urban land use. In this research, the buffer was set as 1 m.

The landscape index was used to reflect landscape ecological security pattern in this paper. However, the information provided by any one indicator is limited; as such, combining indicators provides a more comprehensive understanding of landscape structure [45]. In addition, the information captured by some landscape indexes may be related, due to their ecological significance or geometric relationship. To avoid redundancy among landscape indexes, and to comprehensively consider patch size, shape, aggregation and diversity, we referred to the selection of core landscape indexes by Leitão et al. [46], and selected landscape indexes from class and landscape metrics to reflect the characteristics of the urban landscape pattern. The class metric was composed of several patches, reflecting patch type information with the same landscape ecological classification. The landscape metric was formed by combining different patch types, reflecting the overall structure and spatial characteristics of regional landscape ecology. The comprehensive selection of these two indices can effectively represent information on the regional landscape ecological pattern.

Therefore, given the criteria above, four indexes were selected to represent the class metric: Percentage of Landscape (PLAND), Largest Patch Index (LPI), Shape Index Distribution (SHAPE_MN) and Patch Density (PD). The research objects included four land types: cultivated land, forest land, grassland, and water area. The indexes selected to represent the landscape metric included the Patch Area Distribution (AREA_MN), Edge Density (ED), Aggregation Index (AI), and Shannon's Diversity Index (SHDI). These multiple indexes were applied to reveal the rule of landscape characteristics from multiple perspectives, and to explain the landscape changes and characteristics of composition. The landscape index was calculated using Fragstats software. The land use data were based on National Land Use/Cover Database of China, at a resolution of 30 m, and the types of land cover include cultivated land, forest land, grassland, water area, settlement place and unutilized land. Table 1 presents the descriptive statistics of these indicators, and the relationship between them and landscape safety description characteristics.

Table 1. Basic information on landscape ecological security indicators used in this study.

Metrics	Indicators	Description
Class metric	PLAND	Measures the percentage of patch type.
	LPI	The percentage of the total area of the largest patch in the landscape.
	SHAPE_MN	Describes the complexity of patch shape: the larger the value, the more complex the patch shape and the lower the landscape ecological security.
	PD	Reflects the degree of urban landscape fragmentation: the higher the value, the higher the degree of fragmentation and the lower the landscape ecological security.
Landscape metric	AREA_MN	Represents the average patch area: the greater the value, the higher the landscape ecological security.
	ED	Reflect the density of landscape patch boundary. The higher the value, the higher the exchange degree between the patch and the outside material energy, the more stable the patch is, and the higher the landscape ecological security.
	AI	Reflects the degree of agglomeration or the extension trend of urban landscape types: the larger the value, the higher the landscape ecological security.
	SHDI	Increases with the increase of patch type and the equalization of the area's specific gravity. The higher the value, the higher the diversity and the lower the landscape ecological security.

The intensification of urbanization, the increase in population density, and the continuous development of the social economy also affect the ecological environment, which affects in turn the stability and function of regional landscape structure [47]. To ensure the accuracy and reliability of the research results, other factors affecting landscape ecological security were also considered. In addition to the UGP, these factors that affect include natural factors, such as regional climate, topography, and urban green land coverage; and social and economic factors, such as the degree of construction for regional development, human activities, road networks, and regional policies [48–51]. To better understand the factors impacting UGP on landscape ecological security, this study selected the control variables as: (1) DEM (Digital Elevation Model); (2) Population density; and (3) GDP. Table 2 summarizes the data sources for all indicators. We only used data from 2015 in our study. This period is chosen because it is of special significance in the development of China's urbanization. Since 2015, China's economy entered a new normal, economic growth slowed down, and demand for urban land expansion weakened [52].

Table 2. Variable data resources.

Variable	Data Source	Year
LEI	National Land Use/Cover Database of China	2015
Landscape Index	National Land Use/Cover Database of China	2015
DEM	National Earth System Science Data Center	2015
Population density	China Urban and Rural Construction Statistical Yearbook	2015
GDP	China Urban and Rural Construction Statistical Yearbook	2015

2.2. Study Area

In order to cover all cities in China as far as possible and carry out the study on a national scale, 356 cities are selected as the study area. China has a vast territory, and cities in different regions have different compactness. In order to test the relationship between urban growth patterns (UGP) and regional landscape safety more scientifically and reasonably, according to geographical division, 356 cities in the survey scope are divided into seven divisions (Figure 1), and the specific partition results are shown in Table 3.

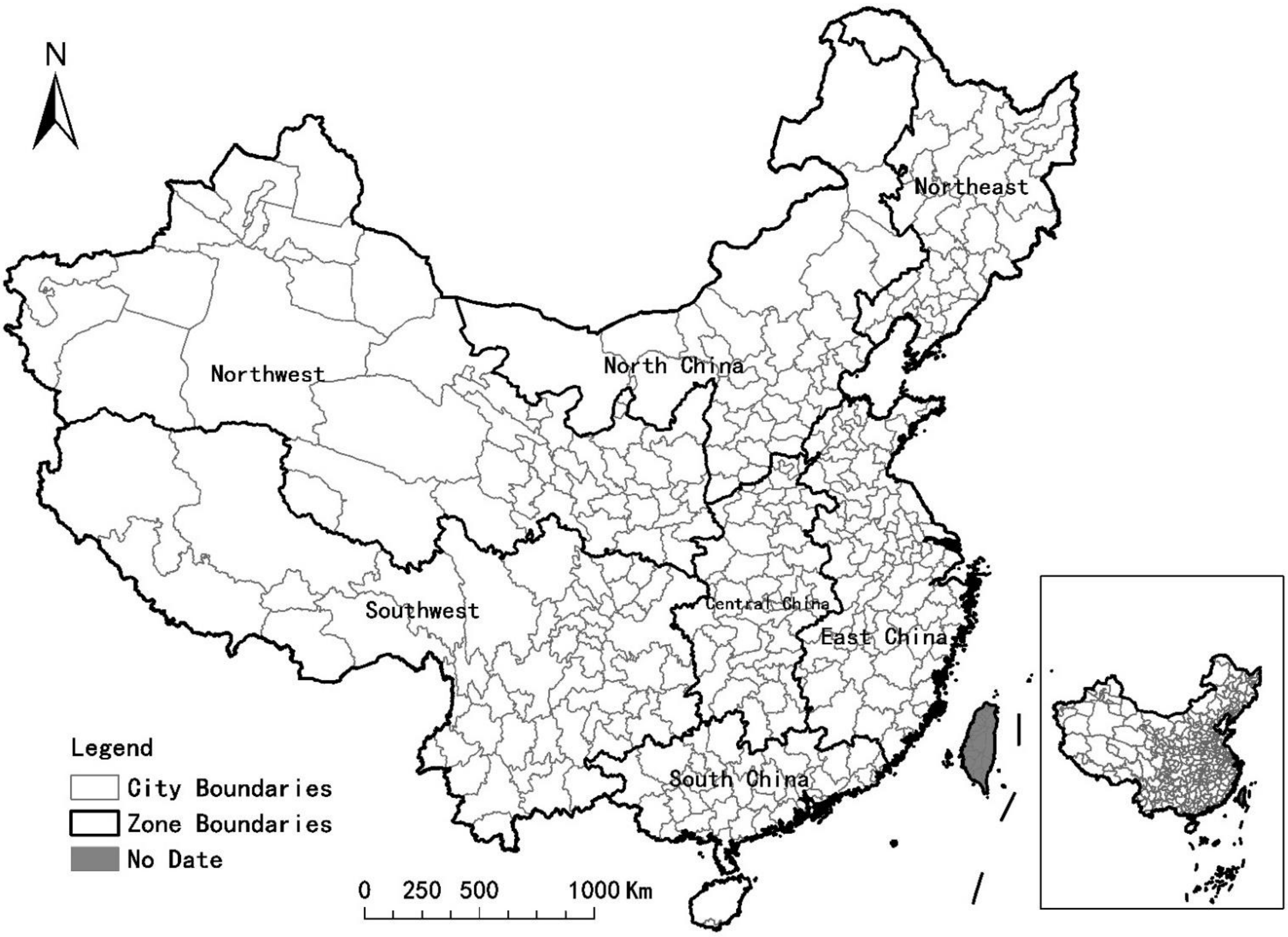

Figure 1. Distribution of the seven divisions in China.

Table 3. Descriptive statistics for the seven divisions.

Region	Included Provinces	Number of Cities
East China	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Fujian	77
North China	Beijing, Tianjin, Shanxi, Hebei, Inner Mongolia	36
Central China	Henan, Hubei, Hunan	47
South China	Guangdong, Guangxi, Hainan	51
Southwest	Chongqing, Sichuan, Guizhou, Yunnan, Tibet	52
Northwest	Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	57
Northeast	Heilongjiang, Jilin, Liaoning	36

2.3. Model Building

Geographically weighted regression (GWR) is a technique that captures changes by calibrating a multiple regression model. By estimating the influence of different regions, the model explores the characteristics of spatial variation and spatial laws, reflecting the spatial non-stationarity of parameters in different spaces. The model is shown in Formula (2). Compared with OLS (Ordinary Least Square) and other traditional regression models, the results reflect more local conditions and conform to realities. In recent years, GWR models have been widely used to quantitatively evaluate regional landscape patterns and driving factors [15,52]. This study analyzed 356 cities in China as research areas. The spatial data for the urban boundaries were obtained from the second National Land Use Survey of China. The p value is used to determine the results of hypothesis testing. The smaller the p value, the more significant the results. The p value criteria selected in this paper are: * Significant at the $p < 0.10$ leve; ** Significant at the $p < 0.05$ level; *** Significant at the $p < 0.01$ level.

$$y_i(u_i, v_i) = \beta_0(u_i, v_i) + \sum \beta_j(u_i, v_i)x_i + e_i(u_i, v_i) \quad (2)$$

where y_i is the explained variable of the ith grid (i.e., landscape pattern indexes); x_i is the explanatory variable (LEI and the three control variables); (u_i, v_i) is the geographic coordinates of the ith grid; β_0 is the coefficient of the constant; β_j is the coefficient of the explanatory variable; e_i represents the random error term.

3. Results and Analysis

3.1. Influence of Urban Growth Patterns on Class Metric Index

LEI is the key variable analyzed in this study. Generally speaking, the higher the LEI index, the more likely the region was to grow in a compact pattern.

First, as shown in Figure 2, the empirical analysis results show that, at the level of $p < 0.10$, the impact of LEI on cultivated landscape is more significant in the northwest and northeast of China. In Northwest China, 50.88% of patches showed a significant negative relationship between LEI and cultivated land PD, and 52.63% of patches showed a significant positive relationship between LEI and cultivated land SHAPE. In Northeast China, LEI showed significant and positive relationship with cultivated land PLAND and cultivated land LPI of 63.89% of the patches. We hypothesized that, in Northeast China, the population aggregation effect brought by the compact growth pattern of infilling protects a large area of cultivated land in the suburbs and rural areas of the region, promotes the centralized development and utilization of contiguous cultivated land resources at the periphery of the city, and alleviates the loss of cultivated land. However, the outlying growth pattern is easy to occupy cultivated land resources, resulting in the decrease of the proportion of cultivated land and the decrease of the largest patch area, which is not conducive to the intensive use of cultivated land. However, in Northwest China, we noticed that, although the compact urban pattern prevented the fragmentation of cultivated landscape, it caused the complexity of cultivated landscape shape. The cultivated land in the west is small and scattered. We speculate that the higher intensity of human disturbance caused by the more compact urban pattern has divided the scarce cultivated land resources, resulting in the irregular landscape patches.

For forest land patches, there are two different results in East China and Northeast China (Figure 3). At the level of $p < 0.10$, 72.73% of patches in East China showed a significant negative relationship between LEI and forest land SHAPE; and in Northeast China, 55.56% of the patches showed a significant positive relationship between LEI and forest land SHAPE. In East China, we hypothesized that, on the one hand, the population is attracted to the urban center by the infilling growth, which helps to maintain the regular shape of the suburban forest landscape; on the other hand, the economy of East China is more developed, so the investment in forest land restoration planning is higher, and the shape of forest land is more regular. On the contrary, in Northeast China, due to the low level of industrial structure, the urban growth depends on forestry to a high degree, and the logging activities are strengthened. Moreover, the increasing population demand brings the embedded development of other land, which leads to the complexity of forest landscape. A study conducted on Lushui River in Changbai Mountain found that human disturbance was the main cause of forest landscape fragmentation in Lushui River, with logging activity being the primary cause [53]. Further, northeast China is the largest natural forest region in China, and compared with the landscape controlled by artificial planning, the fragment index of the natural forest land patches was higher [54], making them more vulnerable to human activities. Therefore, the infilling growth makes the landscape shape of forestland in Northeast China more complicated.

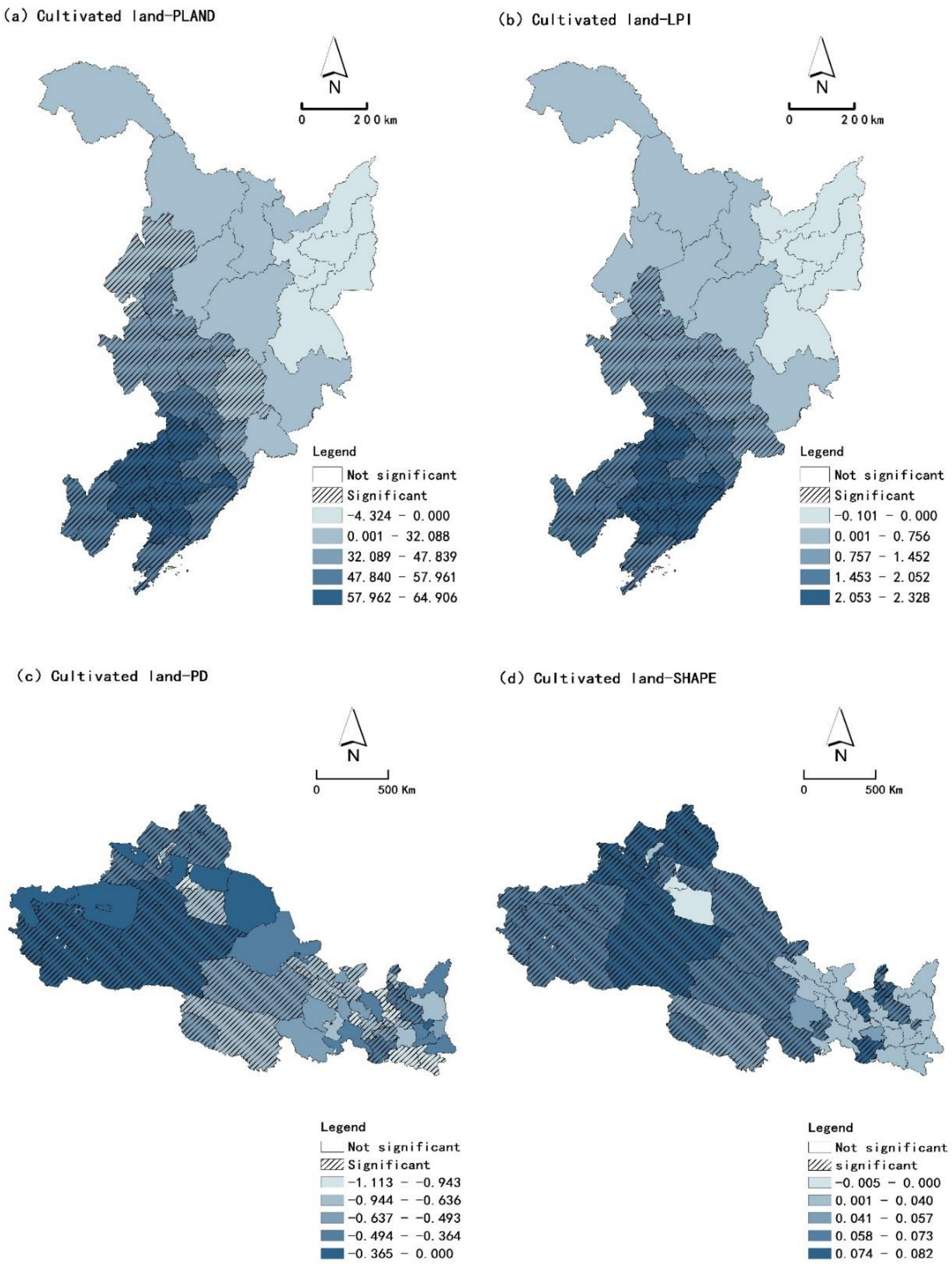

Figure 2. Influence of LEI on cultivated landscape at the level of $p < 0.10$ (**a**) Significant relationship between LEI and cultivated land PLAND in Northeast China; (**b**) Significant relationship between LEI and cultivated land LPI in Northeast China; (**c**) Significant relationship between LEI and cultivated land PD in Northwest China; (**d**) Significant relationship between LEI and cultivated land SHAPE in Northwest China.

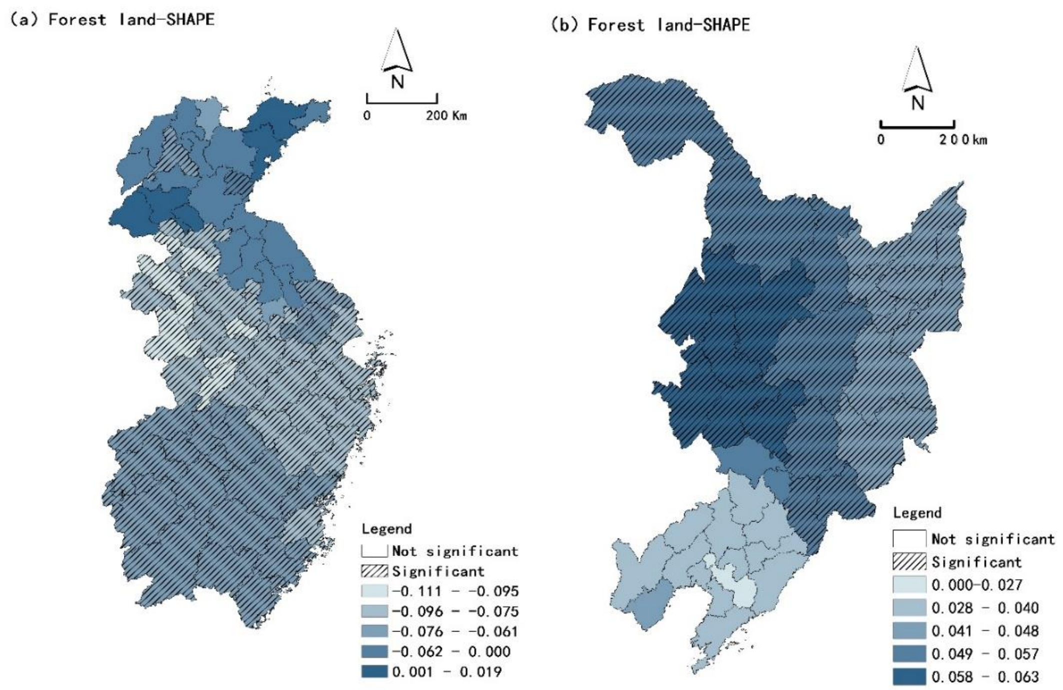

Figure 3. Influence of LEI on forest landscape at the level of $p < 0.10$ (**a**) Significant relationship between LEI and forest land SHAPE in East China; (**b**) Significant relationship between LEI and forest land SHAPE in Northeast China.

For grassland patches, 50.88% of patches showed a significant relationship between LEI and PLAND at the $p < 0.10$ level in Northwest China. Northwest China has the largest grassland resources in China, accounting for more than 40%. The Tibetan Plateau Region located in northwest China is the source of major rivers in China. The protection and development of local grassland resources plays an important role in regulating climate change, water conservation and environmental protection. The empirical results show that the infilling growth plays a positive role in protecting the continuous and intact grassland landscape, while the outlying growth tends to crowd out the grassland landscape. As shown in Figure 4, there is a significant negative relationship between LEI and water area PLAND in most of the patches in East China, and a significant positive relationship between LEI and water area PLAND in Northwest China. In general, compared with East China, water resources in Northwest China are relatively scarce, with a low proportion of landscape water consumption and a high proportion of functional water consumption. The more compact the urban expansion, the more conducive to the concentration of functional water resources. Therefore, the total amount of water area patch and the concentration of water area patches are higher. However, in East China, where water resources are relatively abundant, the water landscape tends to be more divided and occupied due to the urban population gathering caused by the infilling growth, and the ecological risk pressure becomes greater.

3.2. Influence of Urban Growth Patterns on Landscape Metric Index

In general, the ability of LEI to interpret the landscape level index was not strong. The empirical results show that at the level of $p < 0.05$, there was a significant positive relationship between LEI and AI in Central China, and a significant positive relationship between LEI and AREA__MN (Figure 5), indicating that compact growth was beneficial to landscape ecological security in general. When the landscape consists of several large patches or is fully connected by patches of the same category, the degree of agglomeration is higher and the urban landscape is more secure. In Central China, the compact growth of infilling is helpful to increase the average landscape patch area, improve the aggregation degree of landscape patch types, and enhance the landscape ecological security. In addition, in Northeast China, with 52.78% of the patches, the larger the LEI, the larger the ED, indicating that the compact growth in this region promoted the connection and exchange between patches and the outside world, and the more stable the patches were inside, the higher the landscape ecological security was. In South China, there was a negative relationship between LEI and SHDI of 50.94% of the patches as South China has a good endowment of landscape diversity, and outlying growth is more likely to increase landscape diversity, while the more compact the city is, the simpler the landscape type in the region, and the more stable and safer the landscape.

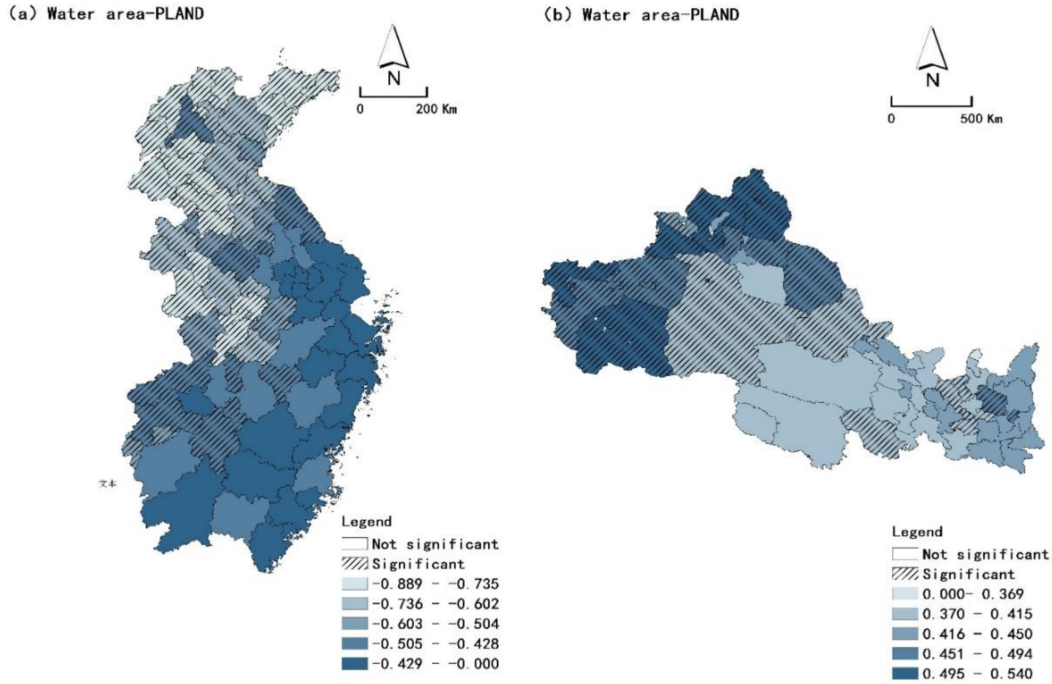

Figure 4. Influence of LEI on water area landscape at the level of $p < 0.10$ (**a**) Significant relationship between LEI and water area PLAND in East China; (**b**) Significant relationship between LEI and water area PLAND in Northeast China.

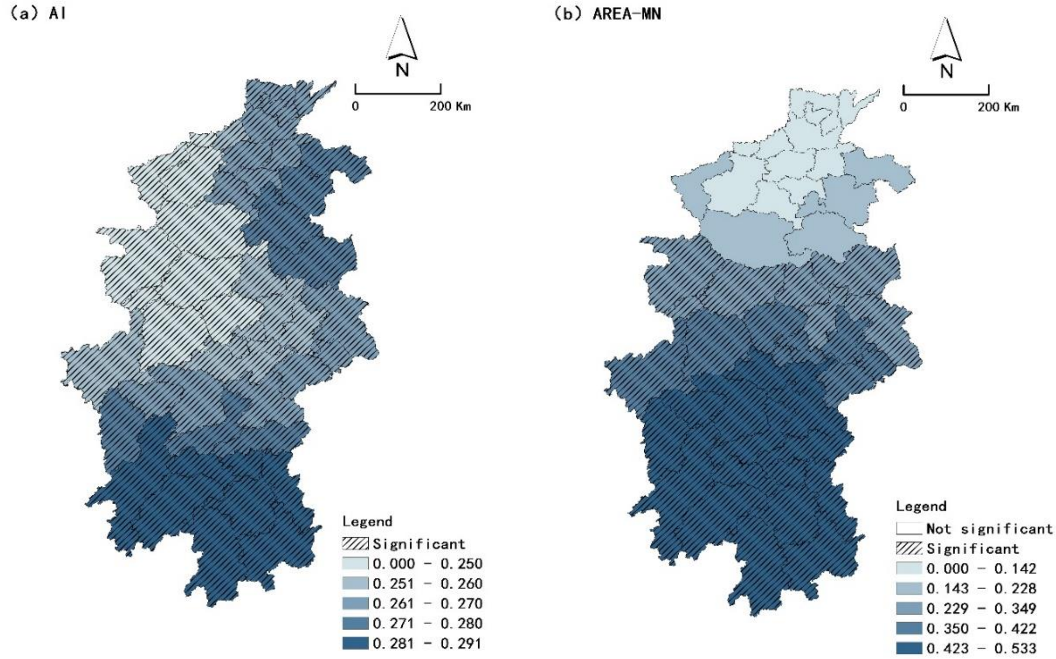

Figure 5. Influence of LEI on landscape at the level of $p < 0.05$ (**a**) Significant relationship between LEI and Al in Central China; (**b**) Significant relationship between LEI and AREA_MN in Central China.

3.3. Influence of Control Variables on Urban Landscape Ecological Security

The empirical results show that the impact of DEM on landscape ecological security is mainly concentrated in East and North China, where the increase of DEM has a significant impact on the landscape fragmentation of cultivated land and grassland. In addition, in eastern and northern China, the higher the DEM, the smaller the proportion of cultivated land and water area landscape, and the larger the proportion of forest land and grassland landscape. Compared with forest land and grassland, cultivated land is suitable to be laid out in hilly and plain areas with lower slopes. Therefore, the higher the elevation, the smaller the proportion of cultivated landscape. In view of these areas, it is suggested to take measures according to local conditions and rationally plan and manage land resources according to terrain characteristics.

Population growth and mobility are the main drivers in urban landscape change. In North China, South China and Northwest China, the increase of population density leads to the fragmentation of cultivated land, forest land, grassland and water area landscape. Meanwhile, the increase of population density in these areas leads to the increase of the proportion of cultivated landscape, improves the agricultural productivity, and promotes the large-scale development of cultivated land resources. In addition, in North China, South China, Southwest China, Northwest China and Northeast China, there is a significant negative relationship between population density and AREA-MN, while in North China, South China and Northwest China, there is a positive relationship between population density and SHDI. The larger the population density, the smaller the average patch area, the higher the heterogeneity and diversity, and the lower the landscape ecological security.

In the seven regions of China, the increase of GDP will bring an increase of AREA-MN and AI, that is to say, economic growth will bring an increase in the average area of landscape patches, the higher the degree of landscape aggregation, and the stronger the landscape ecological security. It can be explained that the more developed the area, the more systematic the planning of land resources, the more efficient the land restoration system, the more attention paid to the protection investment of regional landscape ecological security, and the more reasonable the landscape spatial layout. Therefore, the urban landscape pattern is more secure and stable.

4. Discussion

4.1. Comparison with Existing Research

Land use types and landscape pattern changes are affected by a variety of natural and socio-economic factors. These are inseparable from the government's top-down policy regulation. According to the results, in the northeast region rich in cultivated land resources and the northwest region rich in grassland resources, we have noticed that the compact growth has a positive effect on the protection of large areas of cultivated land and grassland; in the northwest region of water shortage, the compact growth is more conducive to the concentration of functional water sources; in East China, where the regional development level is relatively high, the compact growth promotes the planning and land restoration, and plays a positive role in forest landscape ecological security. Several studies have also somewhat confirmed the positive effects of compact development on urban landscape ecological security. Hou et al. [55] quantified the spatial characteristics of Xian and the relationship between landscape patterns and ecosystem service value through concentric circular buffer zones. The results showed that the PD, ED, and SHDI values of the city center were lowest; and the higher landscape heterogeneity mainly occurred in the urban fringe area 25–30 km away from the city center. A study in Nanchang also found that, during urban expansion, the ecological landscape generally became more fragmented. Edge-expansion accelerated reductions in large green patches, outlying expansion promoted the fragmentation of green landscape units, and infilling weakened those processes [56].

Scholars have tried to explain this phenomenon. For example, Che and Luo [57] proposed that, in urban central areas with a higher level of urbanization (mainly infilling), the expansion of construction land patches has been completed and the patches have been interconnected, reducing landscape fragmentation. However, on the edge of the city (mainly edge-expansion), urbanization is underway, with frequent human activities and significant disturbances. As the city has expanded, construction land has gradually eroded the surrounding cultivated land and natural surface, causing the transformation and interspersion of different land use types, a decline in landscape aggregation, and an increase in fragmentation. The suburbs outside the city (mainly outlying) were found to be mainly composed of plots of farmlands and water bodies, and their landscapes were less fragmented compared to those on the edge of the city. Qian et al. [58] surveyed Shenzhen's urban growth from 1979 to 2017 based on Landsat images. That study found that the green land PLAND, ED, and LPL in infilling areas were significantly larger compared to the other two growth patterns. That study suggested that this may be because outlying and edge-expansion occur mainly in areas with low resistance; however, infilling in the late stage of expansion mostly occurs in areas with high resistance. These places may originally be large green areas or wetlands, or they may be subject to government control policies. However, a more compact city is generally associated with higher economic resources and greater public transportation development. In this context, it is particularly important to balance the ecological space in the city to obtain a reasonable spatial threshold [7]. Several studies focusing on compact urban green space patterns have noted an insufficient per capita green space caused by high population density [59,60]. As such, scholars have begun to focus on ways to introduce creative measures, such as roof gardens, vertical gardens, and other green man-made structural surfaces in compact cities with limited land resources.

In contrast to the scattered distribution of built-up areas caused by outlying and edge-expansion, infilling growth plays a specific role in promoting urban ecological efficiency and resource utilization efficiency. However, our research results found that compact cities with high population densities may increase the risk to urban landscapes, and the degree of land resource abundance and interference from human activities play an important role in the relationship between LEI and landscape ecological security. In the process of urban expansion, it is important to protect large-scale patch resources and reasonably control the population size. This conclusion is also mentioned in other studies. For example, Ma et al. [38] noted that, in times when the impact of human activities was weak, ecological security was mainly related to the landscape area index. With an increase in human activities, the landscape morphology, fragmentation, and connectivity have experienced major changes, leading to changes in ecosystem structure and composition, and ultimately affecting ecological security. Xie et al. [61] proposed that excessive population aggregation and urban expansion lead to the fragmentation of urban living spaces and ecosystems. As a result, when the scale of the city breaks through the carrying capacity of the local resources and environment, external input is needed to maintain the city's operations, increasing its risk and vulnerability.

4.2. International Significance

Ensuring landscape ecological security is closely related to land planning, management, and restoration. Today's ever-increasing levels of human disturbance have led to significant heterogeneous ecosystems in time and space. Major challenges facing those developing urban environments include determining ways to use landscape planning and design to scientifically implement ecosystem planning and management; improving the sustainable development of the city; and slowing the negative effects brought by urbanization. Based on the results of this study, the following suggestions are given for different urban development trajectories in developing countries and developed countries.

Optimizing the pattern of spatial growth and improving the efficiency of land and resources utilization will remain a long-term task for China's land and resources management and regional development. Developing countries such as China are experiencing rapid urbanization growth, and the urbanization level among cities is quite different, the construction land continues to expand, and the fragmentation of urban landscape pattern intensifies [62]. In general, a large number of cities are dominated by edge-expansion growth. The compact growth pattern is mainly present in large cities [63]. Therefore, it is suggested to promote the intensive use of stock land under the guidance of the concept of "compact city", so as to protect the large area of cultivated land and grassland resources outside the city and prevent the disorderly growth of the city. Meanwhile, it is critical to note that strategic planning to conserve green spaces and natural areas is still required within cities when the infilling pattern is more conducive [64]. In addition, the scale of urban population should be controlled reasonably to prevent the fragmentation of land resources caused by excessive population aggregation [65,66]. Implementation of the polycentric city pattern in the compact urban center can be considered to properly evacuate the urban population, promote the decentralization of urban functions, reduce various ecological environmental pollution, and enhance the ecological security of landscape.

Cities in developed countries, such as North America and Europe, have more infilling patches, with stronger trends towards compact urban development. In this development mode, it is important to rationally plan urban land use layouts, distribute the population, prevent excessive population concentrations, increase the diversity of urban land use types, avoid excessive occupation of land resources by construction, protect land resources outside the city, implement greening in urban areas, and construct more water areas.

The research area of this study is China, which has a vast territory and a wide range of latitudes. Due to the differences in geographical location, there are obvious differences in the morphology compactness and landscape characteristics of Chinese cities. From this perspective, our results are more applicable to countries and regions that span multiple latitudes and are able to achieve significant geographical differences in natural landscapes, and we believe that the results are more applicable to larger countries such as Russia, the United States, Canada, and India.

Meanwhile, it should be noted that these countries and China have different urban expansion area, growth rate and urban growth pattern [52]. In view of the national conditions and development track of different countries, our results are not necessarily applicable, but can only be used as a reference. Therefore, we have not put forward too targeted views on other countries or regions. In this case, we encourage the construction of a dynamic urban development model based on the characteristics of urban development, to explore a series of impacts brought by human activities under the concept of compact urban development, and to find a suitable road for urban development. Meanwhile, we can carry out research based on the different national conditions and development trajectory of different countries in the future, analyze their identity and differences, and better promote the international significance of the study.

5. Conclusions

Based on empirical research on 356 cities in China, this study applied a spatial perspective to assess the impact of China's urban growth patterns (UGP) on urban landscape ecological security in 2015. Specifically, the research applied the LEI, selected appropriate indices in class and landscape metrics, and selected specific natural and socio-economic indicators as control variables. The results were analyzed using a geographically weighted regression model. The study demonstrated the impact of the UGP on urban landscape ecological security, and analyzed the significant relationship between multiple indicators and urban landscape safety. The research results are summarized as follows.

First, the compact growth pattern of infilling plays a role in protecting the regional landscape patches to some extent. In terms of class metric, infilling growth in Northeast China with rich cultivated land resources and Northwest China with rich grassland resources, respectively, increases the proportion of cultivated land and grassland in the region. This compact growth pattern attracts people from the urban periphery to the urban center. On the one hand, it promotes the intensive use of land in the urban center. On the other hand, to a certain extent, it also prevents large natural landscape patches around the city from being occupied by construction land. In the northwest region where water resources are scarce, the infilling growth pattern is conducive to the concentration of regional functional water sources and plays a certain role in the protection of regional water resources. In terms of landscape metric, in Central China, Northeast China and South China, the infilling growth pattern has a certain effect on the enhancement of regional landscape ecological security.

Second, the risks caused by compact growth in some regions are also worthy of attention. In East China, where water resources are abundant, attention should be paid to how to avoid water area decline and distribution fragmentation caused by infilling growth. In Northeast China, where regional development is highly dependent on forestry, more attention should be paid to the security degradation of forest landscape caused by infilling growth. In the future, for these types of areas, industrial structure upgrading is an important support to improve the security of forest landscape.

Third, DEM, population density and GDP have different effects. In general, regional landscape planning should reasonably allocate landscape resources according to local topographic features to obtain a higher landscape ecological security. The increase of population density has caused the fragmentation of some regional landscapes, increased the diversity of landscapes, and weakened the security of landscapes. Therefore, we should improve urban and rural system planning to prevent the adverse impact of overpopulation on regional landscape ecological security. In addition, more economically developed areas have stronger landscape ecological security, which confirms the positive role of ecological civilization construction in the process of China's economic development.

Finally, this study applied the perspective of UGP to evaluate urban landscape ecological security. Urbanization is a dynamic and complex process, and future studies could continue the investigation by focusing on UGP and other aspects of urban growth, such as the intensity, speed, and dynamic degree of urban growth. This would provide additional data to support decisions by land and urban planning managers. In addition, the study of urban landscape pattern and future research on urban landscape patterns should start with multiple scales, evaluate changes in spatial heterogeneity on different scales, and discuss these scale effects. There is still a strong spatial signal among regions. There are enough replicates between regions to complete a generalized linear mixed model (GLMM) where the spatial random factors are the categorical regions or other spatial variables [67]. Future research can explore this issue in depth. This would provide a reference for index selection, interpretation of analysis results, and deductions of spatial scales in landscape pattern analysis, and also provides a basis for the formulation of different levels of territorial space control measures such as control planning and detailed planning.

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