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Original Research

Analysis of the Green Space Landscape Pattern and Driving Forces in Hefei Binhu New Area

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Abstract

Taking Binhu New Area (BNA) as a case study, based on multi-period (2005, 2012, 2020) Landsat remote sensing images, the landscape pattern index and grey relational analysis (GRA) were chosen to quantitatively examine the dynamic change process and driving mechanism of green space landscape patterns. The results showed: (1) From 2005 to 2020, the green space area in BNA showed increases at first and decreases later with the highest degree of dynamic change found in regional green space. (2) Urban green space showed increased diversity and good connectivity, but its green patch was simple with a decreased degree of sprawl. The green patch also showed a tendency towards homogenization, aggregation, and simplification. The patch shapes of park green space, attached green space, and protective green space are relatively simple and there are blind spots in the distribution. (3) Population growth and industrial structure changes are the main driving forces of the changes in green space landscape patterns in BNA. Besides, urban planning and policies also play a big part in these changes. The research results can provide a reference for green space planning and construction in BNA.

Keywords: urban green space, landscape pattern, dynamic change, driving force, Binhu New Area

Introduction

As an important part of the urban ecosystem, urban green space affects urban sustainable development [1]. Urban green spaces not only purify the air [2], absorb dust and noise and regulate the microclimate [3] but also beautify the environment, reduce residents' stress and promote healthy living [4]. As urbanisation accelerates, economic development and human activities become increasingly destructive to the urban green landscape, leading to the fragmentation of the original green space and a tendency for the ecological environment to deteriorate [5]. How to protect and rationally plan urban green spaces and give full play to their ecological, social and economic benefits has become an issue that needs to be addressed in rapidly urbanizing areas. Therefore, understanding the process and causes of changes in the landscape pattern of green spaces is essential for formulating green space planning and construction strategies and improving the quality of the regional landscape and ecological environment.

Previous studies on urban green space landscape patterns have mainly focused on the macro level [6]. Most of the research studies urban green spaces from the perspective of land cover types and changes in spatial patterns [7]. For example, Liu et al. [8] systematically analysed changes in land use and landscape patterns; Woldesemayat et al. [9] extracted land cover data

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to assess urban expansion and spatial changes in urban green spaces in Addis Abeba from 1989 to 2019. Although they have analysed changes in the landscape pattern of green spaces and their relationship to the urbanization process, they have yet further to study the various types of urban green spaces. However, each type of green space has a different function in the urban green space system and responds differently to urban development and human activities. It is, therefore, necessary to classify and study the changes in landscape patterns of each type of green space. With the development of remote sensing information technology, using multi-time series remote sensing images provides a method for studying the dynamic changes of urban green space landscape patterns [10]. For example, Conine et al. [11] analysed the landscape pattern of green areas in the study area based on geographic information technology, constructed a landscape evaluation model and optimised the ecological network of urban green areas. Using multi-temporal Landsat data, Zhu et al. [12] explored the spatial and temporal changes in the landscape pattern of land use in the watershed.

A detailed study of green space landscape patterns includes not only a quantitative study of green space landscape patterns, but also an understanding of the underlying drivers behind their change [13]. The driving forces of urban green space landscape change mainly included natural, socioeconomic, and policy factors [14]. Previous research on urban green space drivers has mostly used qualitative analysis methods or some simple enumeration and description. Due to the limitations of objective conditions in different places, a more complete system of drivers has not yet been formed. The quantitative research methods in some studies have mostly used regression analysis [10], analysis of variance and principal component analysis [15]. However, the above method necessitates a large sample size, and there may be multiple collinearities between driving forces that lead to inaccurate quantitative results. This problem can be well addressed by grey relational analysis (GRA), which is designed for data systems with fewer data samples and more complex green landscape patterns [16].

As for research area selection, researchers are less concerned with medium and small cities that are experiencing rapid urbanization [17]. Since its construction in 2006 as a window for Hefei's external display, Binhu New Area (BNA) has undergone a remarkable change in its green landscape pattern. Therefore, choosing BNA to study the change in urban green space landscape patterns is more representative than using a traditional administrative area.

BNA was selected as the research object, analyzing its spatial-temporal evolution and driving mechanism of green space landscape pattern. The research purposes are: (1) to analyze the spatio-temporal evolution of various types of green space landscape patterns in BNA from 2005 to 2020 to explore the positive and negative ecological effects of the dynamic changes in green space landscape patterns (2) quantitatively study the driving mechanism of the evolution of the green landscape pattern in BNA (3) to improve reference, provide a workable method of green space landscape pattern optimization for other similar new urban green space planning and construction.

Materials and Methods

Study Area

The BNA is part of Hefei, Anhui Province in eastern China, with geographical coordinates ranging from 117.13 to 117.24°E, 31.28 to 31.50°N (Fig. 1), and covering a total area of 196 km^2. The planning area is bounded by Chaohu Lake to the south, the Second South Ring Road to the north, the Hu-Rong Freeway to the west, and the Nanfei River to the east. The study area has a subtropical monsoonal humid climate with distinct monsoons and four distinct seasons [18]. It has an average annual temperature of 15.7ºC, average annual precipitation of 1000 mm, about 2100 h of sunshine, and average relative humidity of 77% [19]. Since the construction of BNA on 15 November 2006, the rapid urbanization process has eroded some urban green space, and the green space landscape pattern has changed significantly.

Data Source

The data of this study comes from Landsat7 and Landsat8 remote sensing images [20]. The construction time of BNA was divided into three phases, namely, 2005, 2012, and 2020 (Table 1). After preprocessing by ENVI5.3, the remote sensing image map of the study area over the years was obtained.

Auxiliary data is taken from Hefei City Master Plan (2006-2020), and Hefei City Master Plan (2011-2020). The socio-economic data comes from the Hefei Statistical Yearbook and Baohe District National Economic and Social Development Statistics Bulletin.

Classification and Extraction of Urban Green Space

According to the Urban Green Space Classification Standard (CJJ/T85-2017), Hefei City Master Plan (2006-2020), the green space types in BNA are grouped into park green space (PAGS), protective green space (PGS), attached green space (AGS), regional green space (RGS) and ecological green space (EGS). Because of the special nature of land used in Niujiaodawei and Dongdawei, and considering their ecological tourism value, they are divided into EGS in this study. Then, using ENVI software, SVM supervised classification and visual interpretation are combined to extract the overall information of green space (Fig. 2).

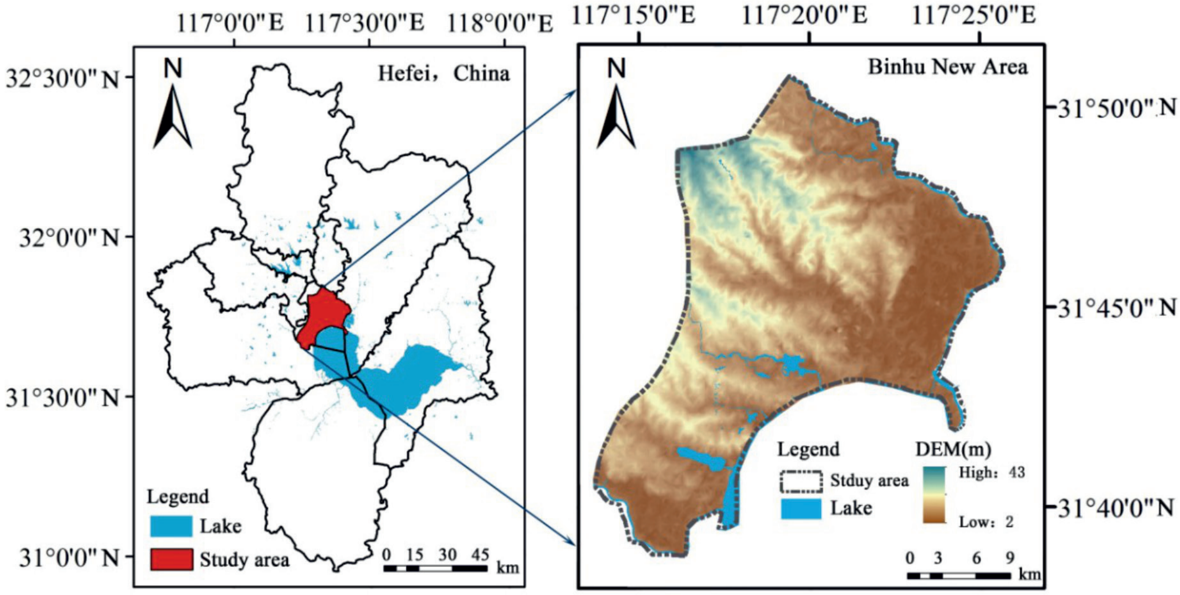

Fig. 1. Location map of Binhu New Area.

Table 1. Details of Landsat remote sensing images.

Acquisition time	Sensor	Cloud coverage [%]	Spatial resolution [m]	Projection coordi-nate system
April 15th, 2020	Landsat8 OLI	0.6%	30	WGS-84
April 1st, 2012	Landsat7 ETM+	0.19%	30	WGS-84
April 14th, 2005	Landsat7 ETM+	0.55%	30	WGS-84

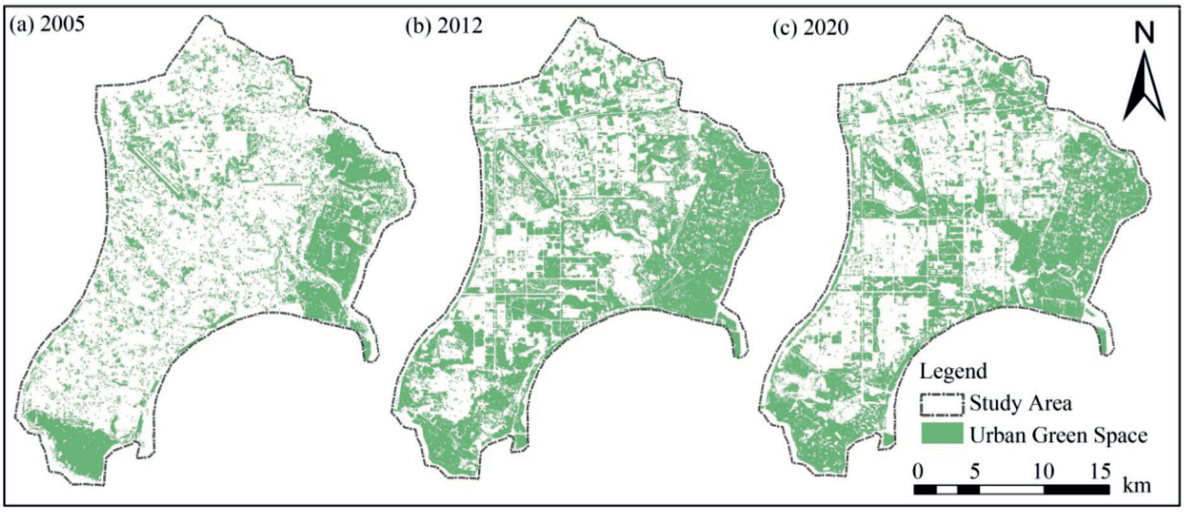

Fig. 2. Location map of Binhu New Area.

The Kappa coefficients were tested after interpretation, and the results were all higher than 0.85, meeting the research requirements. Finally, the extracted green space information map is converted into vector files and imported into ArcGIS10.2, which gives attributes to each green patch and complete green space information quantization in BNA (Fig. 3).

Dynamic Change Degree (DCD)

This indicator is used to describe the dynamic change of various green space types in the study area [21], and its expression is:

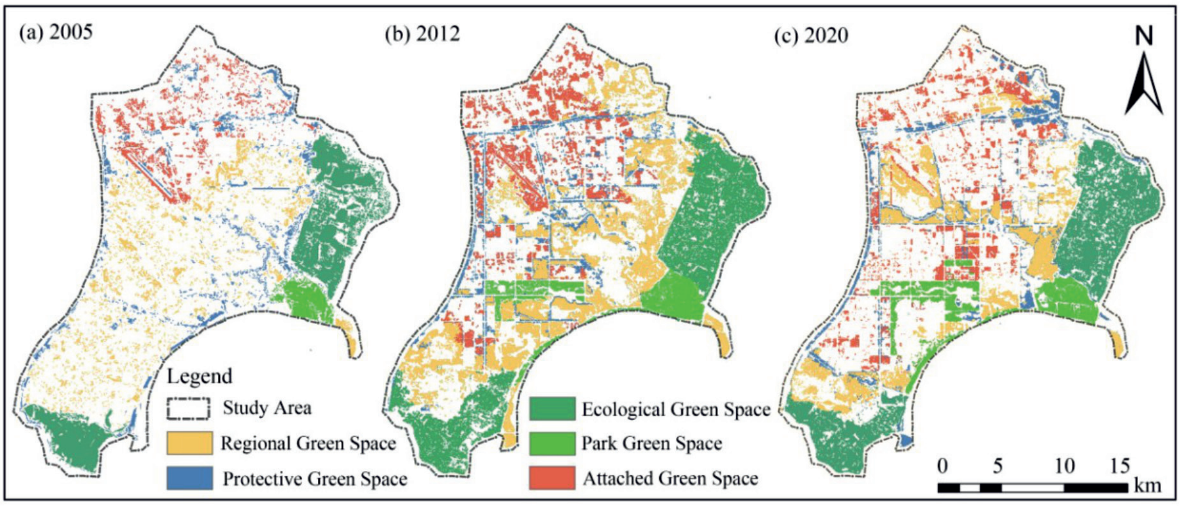

Fig. 3. Location map of Binhu New Area.

$$K = \frac{U_b - U_a}{U_a T} \times 100\% \tag{1}$$

In the formula: K represents the DCD of a green space type, T represents the period with year as a unit, U_a and U_b represent the area of a green space type at the beginning and the end of period T [22].

Landscape Pattern Index

From types and landscape levels, this paper selects the total class area (CA), the number of patches (NP), the patch density (PD), largest patch index (LPI), Landscape Shape index (LSI), aggregation index (AI), Shannon's diversity index (SHDI), Shannon's evenness index (SHEI) and contagion (CONTAG), and analyzes the area, fragmentation degree, shape characteristics, aggregation degree and diversity of green patches in BNA. FRAGSTATS 4.2 software is used for calculation, and the settlement results are plotted to improve the visualization of the results.

Index System Construction of Driving Forces

As natural factors have a weak impact on the urban scope at a shorter and smaller scale, socio-economic factors are the main driving force of urban green space landscape pattern change [23]. Therefore, following the principle of representativeness, scientificity and availability, this paper selects 15 socio-economic indicators that reflect the population status, residents' income status, overall economic level, industrial structure, domestic and foreign trade, urban construction, government financial revenue, and expenditure in the study area (Table 2). In addition, policy factors and urban planning factors related to rapid urbanization are also considered.

Grey Relational Analysis (GRA)

With the help of mathematical analysis software MATLAB, 15 socio-economic factors were selected as independent variables, CA, NP, PD, AI, CONTAG, SHDI, SHEI, and LSI were selected as dependent variables, and GRA was established to calculate the correlation coefficient. The calculation process is as follows:

$$\gamma_{ij} = \frac{1}{n}\sum_{k=1}^{n} \frac{\min_i \min_k \Delta_i(k) + \xi \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \xi \max_i \max_k \Delta_i(k)},$$

$$\Delta_i(k) = \left| x_j(k) - x_i(k) \right| \tag{2}$$

Among them, x_i and x_j are independent and dependent variable series respectively. γ_{ij} is the grey relation between the green space landscape pattern index x_i and the quantitative factor x_j. ξ is a coefficient, usually $\xi = 0.5$; $k = 1, 2, ..., n$ is the time series.

Results

Analysis of Dynamic Change of Urban Green Space

In 2005, the total area of green space was 55.73 km^2. EGS and RGS are the main types of green space, accounting for 41.83% and 26.90% respectively. PAGS has the smallest area measuring only 3.46 km^2. From 2005 to 2012, the urban green space area of BNA increased from 55.73 km^2 to 106.86 km^2, an increase of 51.13 km^2 (Fig. 4). RGS changed the most and its area increased by 25 km^2. In 2012, RGS became the main type of green space, with an area proportion of 37.42%. From 2012 to 2020, the total area of green space in

Table 2. Socioeconomic indicators system.

First-grade indexes	Secondary indicators
The population status	S1: Total household register population
	S2: Proportion of non-agricultural population
Residents' income status	S3: Per capita income of urban residents
	S4: Rural per capita net income
Overall economic level	S5: Regional GDP
Industrial structure	S6: Proportion of primary industry
	S7: Proportion of secondary industry
	S8: Proportion of tertiary industry
	S9: Output of the construction
	S10: Industrial output value
Domestic and foreign trade	S11: Total retail sales of consumer goods
	S12: Total import and export volume
Urban construction	S13: Social fixed-asset investment
Government financial revenue and expenditure	S14: Fiscal revenue
	S15: Local financial expenditure

BNA decreased by 16.88 km^2. PAGS, AGS, and PGS accounted for relatively small proportions, but they showed a gradual growth trend. By 2020, the green space area of BNA was 89.98 km^2, and the coverage rate of green space was 45.91% (Fig. 4).

As shown in Fig. 5, from 2005 to 2020, the green space area of BNA showed a trend of rapid growth first and then a slow decline. From 2005 to 2012, the overall green space of BNA grew rapidly. The DCD of RGS was 20.85%, which was the fastest growth rate. AGS and PGS increased rapidly, with DCD of 19.74% and 19.65% respectively. From 2012 to 2020, the overall green space area of BNA decreased slowly, with a total DCD of -1.97%, and each green space type gradually stabilized. RGS decreased rapidly, with a DCD of -5.74%. PGS growth slowed down, with a DCD of 3.58%. DCD of AGS, PGS, and EGS was relatively small.

Analysis of Landscape Pattern Change of Urban Green Space Type

Dynamic Analysis of Landscape Fragmentation of Each Green Space

Landscape heterogeneity shows landscape fragmentation, which is reflected by NP and PD [24]. Table 3 shows that the fragmentation degree of each green space type from 2005 to 2012 is consistent as follows: RGS>PGS>AGS>EGS>PAGS. The patch area of RGS was small, large in number, and wide in

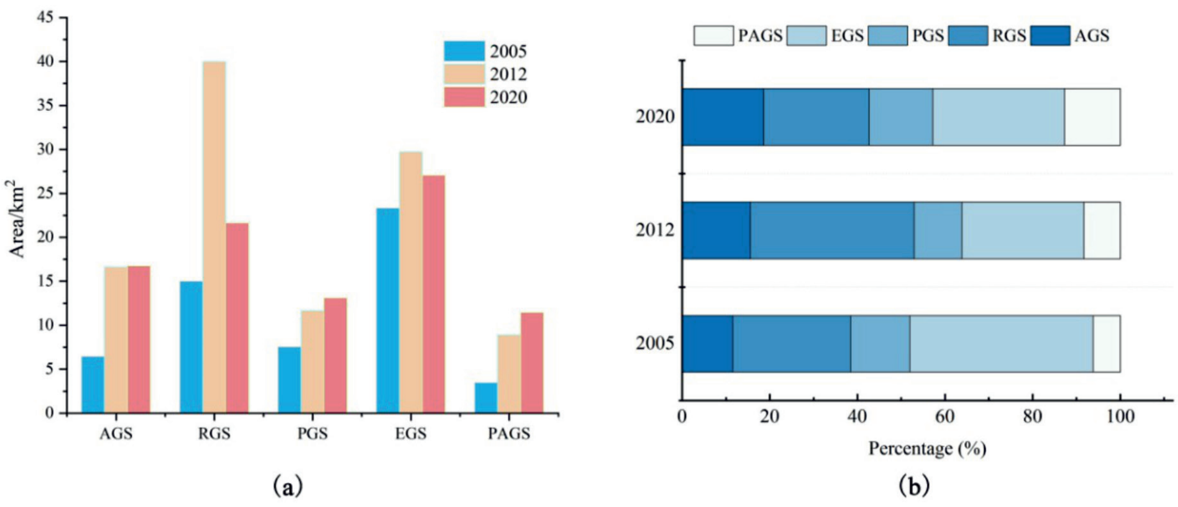

Fig. 4. Area and percentage of green space, a) area of green space types, b) percentage of green space.

Table 3. NP and PD of each green space type.

Types	2005		2012		2020	
	NP	PD. hm^{-2}	NP	PD. hm^{-2}	NP	PD. hm^{-2}
AGS	582	10.44	569	5.32	907	10.08
RGS	2764	49.60	1514	14.17	603	6.70
PGS	667	11.97	674	6.31	936	10.40
EGS	136	2.44	82	0.77	76	0.84
PAGS	26	0.47	58	0.54	108	1.20

distribution. In 2005 and 2012, NP reached 2764 and 1514 respectively, and the fragmentation degree was significantly higher than that of other green space types. At the same time, the fragmentation degree of RGS decreased the fastest, with its PD decreasing from 49.6/hm^2 to 14.17/hm^2, decreasing by 35.43/hm^2. The fragmentation degree of PGS and AGS was high, and the patch area was small.

From 2012 to 2020, the fragmentation degree of patches of various types of green space was as follows: PGS>AGS>RGS>PAGS>EGS. RGS was fully developed and utilized, partially converted into construction land and urban green space, and the fragmentation degree showed a downward trend. The distributional range of PGS was more extensive, and its fragmentation degree is on the rise. The fragmentation degree of EGS remained at a low level. PAGS patch fragmentation degree was low but there is a slow upward trend, indicating that the park construction activities in recent years to a certain extent increased the fragmentation degree of PAGS, indicating an ecological development.

Dynamic Analysis of Landscape Aggregation Degree of Each Green Space

In 2005, the order of aggregation degree of all green space types was: EGS>PAGS>AGS>PGS>RGS. In 2012 and 2020, AI of each green space type ranked as follows: EGS>PAGS>RGS>AGS>PGS. The EGS has a large area and concentrated distribution. The AI is above 89 %, the highest aggregation degree, and the change is small. Most of the PAGS is built by the river, and the distribution shows typical aggregation, with AI reaching more than 85%. With the acceleration of urbanization, AI of PAGS shows a downward trend, indicating that the park construction activities in recent years have expanded the distribution range of PAGS, which is conducive to the overall ecological benefits of PAGS. The change in RGS aggregation degree was the largest, with AI increasing from 57.1% in 2005 to 80.13% in 2020, increasing by 23.03%, indicating that under the influence of human activities, the RGS aggregation degree showed a significant increasing trend. PGS and AGS are widely distributed and mainly present linear distribution, and the degree of aggregation is relatively weak (Fig. 6).

Dynamic Analysis of Shape Characteristics of Each Green Landscape

In 2005 and 2012, the order of LSI of each green patch was as follows: RGS>PGS>AGS>EGS>PAGS. Except for RGS, the LSI of each green space was less than 40, and the shape was simple (Fig. 7). In 2020, the order of LSI from large to small was as follows: PGS>AGS>RGS>EGS>PAGS. The LSI of regional green patch decreased the most, from 63.07 in 2005 to

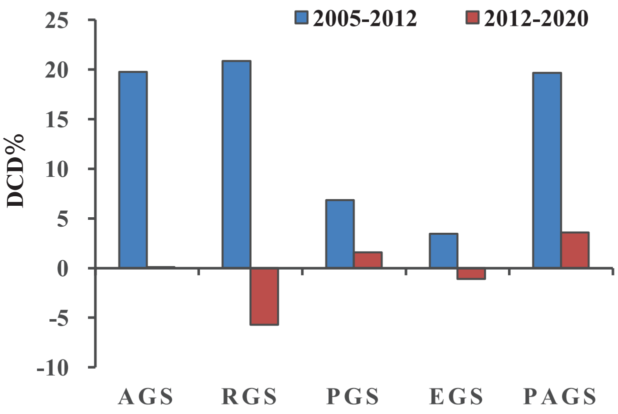

Fig. 5. DCD of urban green space.

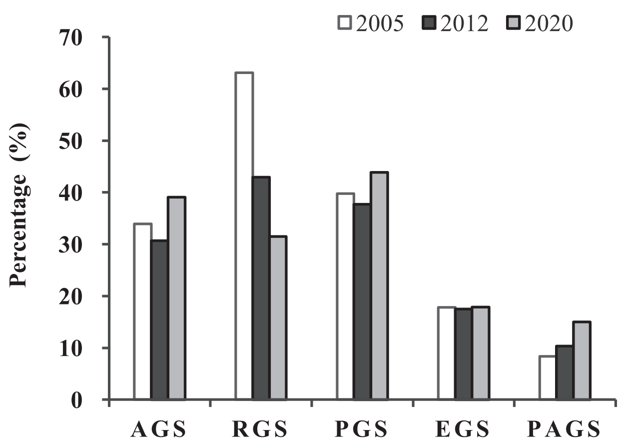

Fig. 6. LSI of each green space.

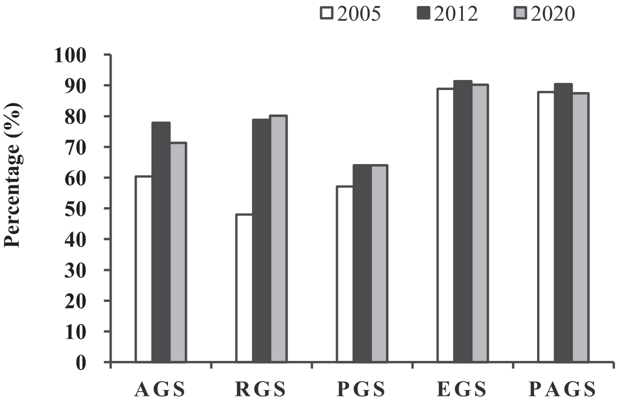

Fig. 7. AI of each green space.

31.51 in 2020, decreasing by 31.56, indicating that the shape of regional green patch tends to be simplified, and the intensity of human activities has a negative effect of biodiversity protection and biological information exchange. The changing trend of AGS and PGS is consistent, and LSI shows a fluctuating upward trend, indicating that the patch shape tends to be complicated, which is more conducive to the play of edge effect. The ecological green patch shape is relatively simple and maintains a relatively stable state. PAGS has a regular shape and low complexity. Its LSI is lower than 16, and it has a weak relationship to the surrounding environment, which is adverse to the creation of diversified landscape space.

Analysis of Landscape Pattern Change of Overall Green Space

It can be seen from Table 4 that from 2005 to 2020, the SHDI of the overall green space in BNA increased from 1.44 to 1.56, an increase of 0.12, indicating that the overall green patch type and the landscape diversity of urban green space increased, which was conducive to promoting the energy flow and material cycle of the green ecosystem. SHEI showed an upward trend, from 0.89 to 0.97, an increase of 0.08, and the types of green space tended to be uniform.

The upward trend of AI fluctuation indicates that the overall green landscape has a trend of agglomeration. After 2012, urban construction activities increased, and the degree of green space aggregation decreased slowly. LPI showed a downward trend, from 27.11% to 20.38%, decreasing by 6.73%, while EGS remains the most dominant green space type, its dominance has emerged. CONTAG decreased from 54.31% to 44.21%, indicating that the extension degree of different patches in each green space type landscape showed a downward trend, and the connectivity of dominant patches in the landscape decreased.

Analysis of the Driving Force of Urban Green Space Landscape Pattern Change

Socio-Economic Factors

According to the eight landscape pattern indexes, the average correlation degree of the proportion of the secondary industry, household registration population at the end of the year, the proportion of the tertiary industry, the proportion of the non-agricultural population, and the proportion of primary industry was more than 0.90, indicating the strongest association with the change of green space landscape pattern. It shows that population growth and industrial structure are the main driving forces for the change in green landscape patterns in BNA. The correlation degree of gross output of construction, total import and export, per capita income of urban residents, rural per capita net income, social fixed asset investment, and GDP is between 0.75 and 0.9, indicating that urban construction, foreign trade, residents' income level, urban construction, and local economy have a certain influence.

It can be seen from Fig. 8 that various driving forces have different impacts on different landscape indices. The first three related factors affecting green space area are gross output value of construction industry > proportion of non-agricultural population > proportion of the tertiary industry. The order of correlation between NP and PD is basically the same. The first three correlation degrees are the proportion of the second industry > the proportion of the first industry > total household register population. The overall correlation degree of NP is slightly higher than that of PD. The first three correlations of LSI are ranked as follows: the proportion of the secondary industry > the proportion of the primary industry > total household register population. The correlation order of SHDI and SHEI is the same and is consistent with the first three factors of AI: total household register population > the proportion of the tertiary industry, and the proportion of the non-agricultural population, and the first three correlation coefficients are more than 0.97, explaining that population size and structure and the proportion of tertiary industry are strongly correlated

Table 4. Index analysis of overall green landscape pattern.

Years	LPI [%]	CONTAG [%]	AI [%]	SHDI	SHEI
2005	27.11	54.31	70.22	1.44	0.89
2012	21.87	48.01	82.01	1.46	0.91
2020	20.38	44.21	80.16	1.56	0.97

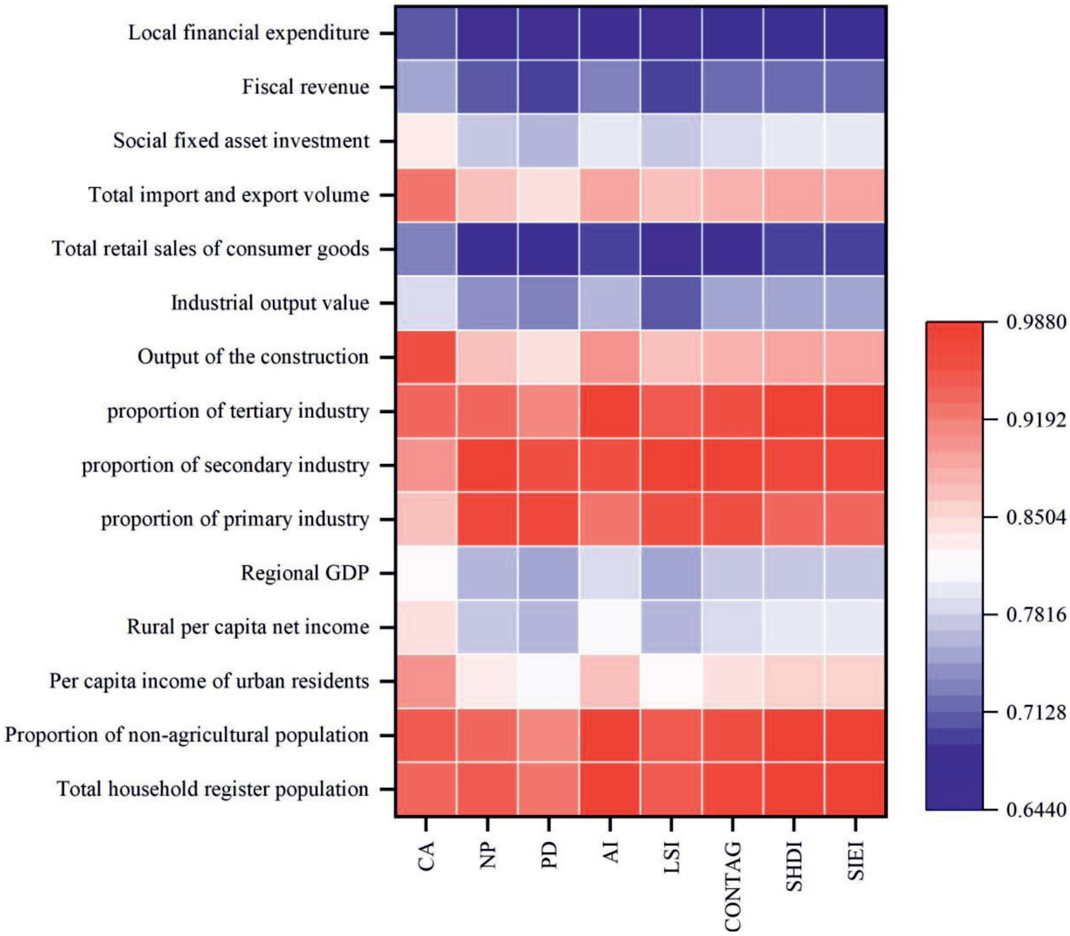

Fig. 8. Grey correlation degree between socio-economic indicators and green landscape pattern.

with the diversity, evenness, and aggregation of urban green space patches. The first three correlations of CONTAG are the proportion of the second industry > total household register population > the proportion of the tertiary industry, and the correlation coefficients are greater than 0.96. The second and third industrial structures and the entire population strongly correlate with CONTAG.

Policy and Urban Planning Factors

The change in urban green space landscape pattern is the result of multiple factors. In addition to the easily quantified socio-economic factors, many factors, such as policies and urban planning, also have a crucial impact on changing urban green space landscape patterns [25]. For example, during the '11th Five-Year Plan' (2006-2015), China proposed to build a resource-saving and environment-friendly society; after the '12th Five-Year Plan' (2011-2015), the Chinese government vigorously promoted the construction of ecological civilization [26]. In response to the requirements of building a modern lakeside city, BNA has taken the creation of a national 'ecological garden city' as its goal, determined the overall structure of 'two axes, one belt and four pieces,' enhanced park construction activities and improved the park construction system. In addition, the Lake Shore New Area has undergone three central planning and revision exercises during the study period. The Hefei city government proposed the '141' Hefei city space strategy in the Hefei city master plan (2006-2020) and BNA was born. With the construction activities such as demolition to green, the green space area increases significantly [27]. In 2011, the Hefei urban master plan (2011-2020) adjusted the Hefei urban space strategy to '1331'. Since then, BNA began to build many parks, which make PAGS shape neat. In 2017, Hefei launched the construction of the Binhu science city. The main urban area of the BNA has been further expanded, causing the reduction of urban green space area, and the shape of green patch tends to simplify.

Discussion

Spatial and Temporal Changes in Green Space Landscape Pattern

We studied the spatial and temporal changes in green space landscape patterns in BNA from 2005 to 2020. The results indicated that BNA’s overall green space landscape had a high degree of aggregation, good connectivity, and increased diversity index, which was conducive to the migration and communication between organisms. This result is different from other researchers' findings of severe fragmentation in the rapid urbanization of small cities [25, 28]. This is because the EGS in BNA has a large proportion and is concentrated, which affects the overall green landscape pattern to a certain extent. However, the rapid urbanization process has also resulted in some problems. At the landscape level, the degree of uniformity of the overall green space is high, and the dominant patch index of green space is reduced, which is consistent with other scholars' research results [24]. At the type level, the PAGS has a regular shape and a distribution blind area; the AGS and PGS have high fragmentation degree, low aggregation degree, and relatively regular patch shape, which cannot give full play to the edge effect of urban green space. Therefore, future planning should strengthen small and medium patches of dark green patches, increase the complexity of park green boundary, better play the edge effect, improve the construction of green space along the city's internal traffic, delimit the ecological red line, protect the Chaohu shoreline, construct Binhu protection forest, increase its ecological protection function, increase the greening construction around new residential areas and public buildings, integrate AGS and improve the ecological benefits of attached green space, take the stock development of the city into consideration, improve the urban occupancy rate, develop roof greening and vertical greening, build the green ecological corridor, ensure the connectivity of various green spaces, and enhance the ecological regulation function of urban green space.

Driving Force Analysis

By quantifying the relationship between socio-economic factors and green landscape patterns, the change in industrial structure, especially the proportion of secondary and tertiary industries, has the most significant impact on urban green landscape patterns. High-tech industries and emerging tertiary industries were cultivated in BNA. Adheres to the development strategy of 'retreating from the second to the third' to promote a more reasonable industrial layout and reduce the damage to the ecological environment, which is worth learning from other small and medium-sized cities. In addition, the change in population and structure is also the driving force for the change of green landscape patterns. Rapid urbanization is accompanied by rapid population growth. The growth of household population and the proportion of non-agricultural population cause increased demand for construction land. Change in population and level of industrialization are driving force for change of green landscape patterns. Therefore, in the future planning of the green space system, attention should be paid to the impact of population changes and industrial structure on the ecological environment of the BNA, and manufactured construction activities should be developed in a direction conducive to the construction of the ecological environment. The existing industrial pattern should be maintained, and the tertiary industry should be vigorously developed to reduce the damage to the ecological environment caused by industrial development.

Limitation and Prospect

The study area is not a traditional administrative division, making socio-economic data more challenging to obtain. Since the size of BNA accounts for 72.59% of the scope of Baohe District, the social and economic data of Baohe District is used to estimate and analyze it. Still, there may be some errors in the results of the driving force analysis. Secondly, although the GRA selected in this study can quantify the correlation between each driving factor and green space landscape lattice, it cannot determine its positive and negative correlation. In addition, many factors such as urban planning and policy are difficult to quantify, so it is necessary to judge their impact on the green landscape pattern according to the actual situation and previous experience. We will further explore the effect of policy factors on green landscape patterns in the future.

Conclusion

Based on multi-period (2005, 2012, 2020) Landsat remote sensing images, the landscape pattern index, and GRA was selected to quantitatively study the dynamic change process and driving mechanism of green space landscape pattern. The results showed that from 2005 to 2020, the overall green area of BNA showed a trend of rapid increase first and then slow decrease. Among them, the largest change is the RGS, and its DCD is 20.85% and -5.74%, respectively. At the landscape level, the overall urban green patch diversity of BNA increases, but there are still problems such as the simple shape of green patches and reduced connectivity of dominant patches. The overall green patch tends to homogenization, aggregation, and simplification. At the type level, the EGS has a high degree of aggregation, and good connectivity, and can play more stable ecological benefits. The patch shape of PAGS is simple and there is a distribution blind area. The patches of AGS and PGS are highly fragmented and the patch shape is relatively regular. Future green space planning should optimize the layout structure of PAGS, increase the complexity of the boundary of PAGS, AGS, and PGS patches, and better play its ecological effect. Population growth and industrial structure change are the main driving factors for the change of green landscape pattern in BNA, and the grey correlation degree is above 0.9. In addition, in a short time scale, urban planning and policy factors also have a great impact on the green landscape pattern of the region.

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Conflict of Interest

The authors declare no conflict of interest.

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