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The Scale-Effects of Different Land Use Types on the Distribution Pattern of Park Green Space at Multiple Grid Scales

—A Case Study on the Main Urban Area of Nanjing, China

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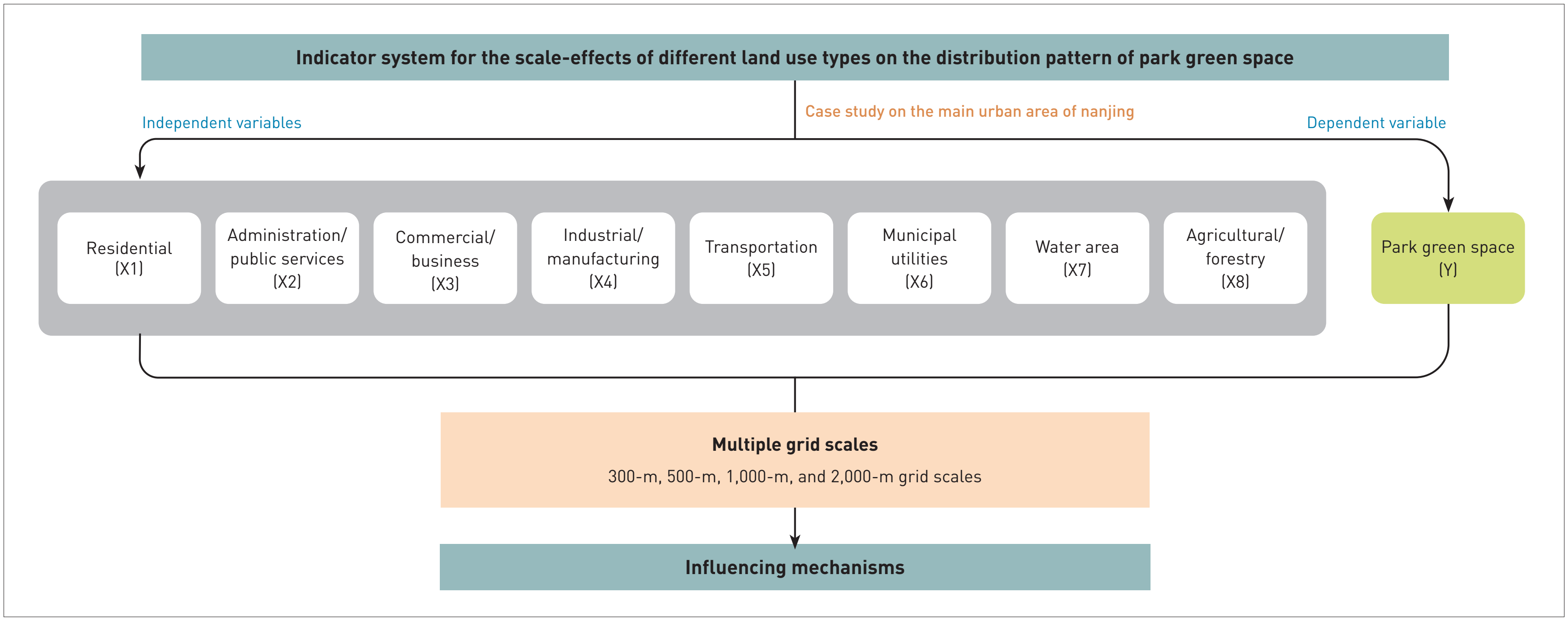
GRAPHICAL ABSTRACT



ABSTRACT

Exploring the scale-effect of different land use types on the distribution pattern of urban park green space (PGS) at multiple grid scales would inform rational allocation and efficient collaborative construction of urban development land at different scales. Selecting 300-m, 500-m, 1,000-m, and 2,000-m grid scales, the research employed Create Fishnet tool in ArcGIS and Geodetector to construct a scale-effect analysis framework that revealed the scale-effects of different land use types on the distribution pattern of PGS at multiple grid scales in the main urban area of Nanjing, China in 2006, 2012, and 2017. Main research results are: 1) the overall distribution pattern of PGS showed the evolution characteristics from polarization to advancing quality and efficiency, while the trend gradually weakened with the increase of grid scale; 2) the scale-effect of other land use types on PGS increasingly enhanced—the larger the grid scale, the more obvious the synergistic or compressive effect; 3) the interactive scale-effects of different land use types gradually enhanced—the larger the grid scale, the more significant the overall factor interaction; and 4) at the 300-m grid scale, the major interaction factors were residential, transportation, industrial/manufacturing, water area, and administration/public services, which gradually changed to residential, water area, and administration/public services up to the 2,000-m grid scale. The findings of this paper are expected to deepen the theory of the coupling between PGS and other land use types, as well as provide scientific support and a basis for efficient allocation, spatial layout optimization, and sustainable development of urban spaces.

KEYWORDS

Urban Development Land; Park Green Space Distribution Pattern; Scale-Effect; Main Urban Area of Nanjing; Geodetector

HIGHLIGHTS

- Constructs a scale-effect analysis framework of different land use types on PGS distribution pattern
- Reveals the scale-effect differentiation and correlations of other land use types on PGS distribution pattern
- Finds that the scale-effects/interactive scale-effects of other land use types on PGS increasingly enhanced as the grid scale grew

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1 Introduction

As the spatial carrier of various urban functional activities, urban development land is key for the exchange of various urban resources and also reflects the change of urban spatial structure[1][2]. In the past half century, issues such as spatial imbalance in urban functions and traffic congestion have become predominant[3][4], leading foreign scholars to focus their research on topics like urban function classification, function evolution, layout optimization, and spatial reconstruction[5]~[8]. These studies delve into the expansion and sprawl of urban space, social issues, land use, etc.[9][10]

Relevant studies in China started relatively late, with many of them summarizing the general theories of urban spatial construction in western regions[11][12], analyzing the morphology and evolution mechanisms of urban space[13][14], and exploring the system and the development path of China’s urbanization[15]. In recent years, relevant research has taken urban development land as a whole, mainly focusing on its expansion intensity, morphological evolution, and dynamic simulation[16][17]. However, such research has mostly paid attention to a certain type of urban development land (e.g., industrial, public service, residential lands) and often studied the spatial layout, morphological characteristics, and evolution of the land (e.g., industrial spatial evolution and reconstruction, the analysis of the evolutionary patterns of public service spaces)[18]~[23], while less attention has been paid to the internal systems of urban development lands and their interactions.

Park green space (PGS) is a major part of urban green space (GS), and critical to urban ecological security and citizens’ recreational opportunities[24]. Early studies on PGS were mainly quantitative research on landscape patterns[25][26], plant allocation[27][28], and landscape evaluation[29][30]. Recent studies have shifted their focus onto ecological effects, with accessibility[31][32], social equity[33][34], service capability[35][36], and environmental effects[37][38] emerging as hot topics. China’s urbanization has catalyzed the rapid growth of urban development land, profoundly changing the spatial pattern of different land use types and related interaction mechanisms[15]. Most PGS is distributed adjacent or nested within other urban development lands (mainly residential, public service, and commercial and business lands), often having synergistic or competitive relationships in their functions.

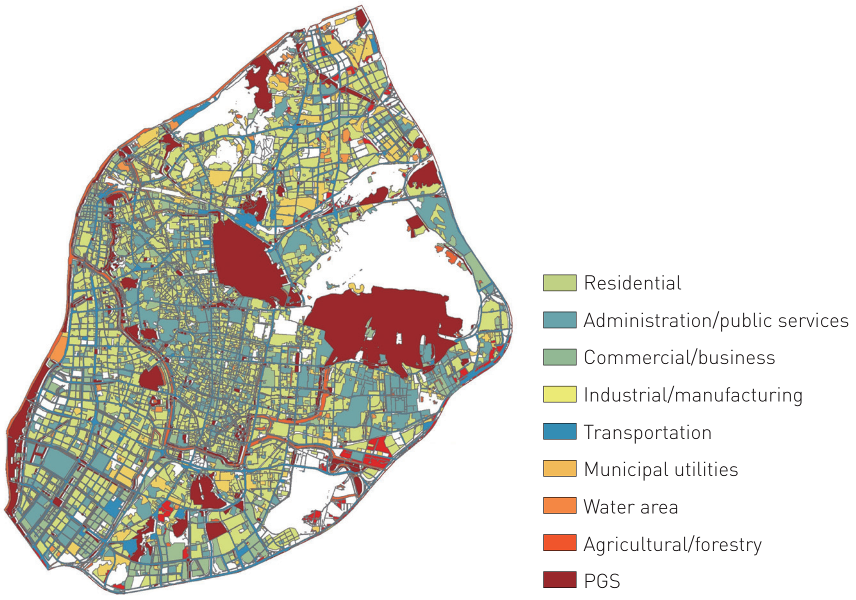
The coupling theory of GS and urban development[39] has laid a theoretical foundation for the study of PGS and other urban development lands, which has supported the emergence of the research on PGS system planning and evaluation, and the coupling of regional GS planning ideas with spatial planning systems[40][41]. Most studies on PGS and other urban development lands focus on the spatial configuration relationship between single urban development land type (e.g., transportation, public service lands) and PGS in layout, accessibility, and equity from a static perspective[42]~[45]. Studies have been conducted on the overall relationship between PS/PGS and other urban development lands. For example, some explored the spatio-temporal correlation characteristics between PGS and other urban development lands[46], and the effect of other urban development lands on GS distribution pattern[47]. However, most of them centered on a single grid scale; whereas PGS, alongside other urban development lands, presents characteristics of varying scale sizes, complex distribution layouts, and intricate evolutions[24]. Larger grid scales are conducive to uncovering macroscopic, geographical layouts, while smaller grid scales are inclined to examine micro-spatial configurations. Therefore, a series of questions, including how the distribution patterns of PGS can be impacted by other urban development land types at varied grid scales, and how the scale-effects changes over time, need to be answered.

With the help of Create Fishnet tool in ArcGIS and Geodetector, this study builds an analysis framework that reveals the scale-effect of different land use types on the distribution pattern of PGS at multiple grid scales, so as to provide theoretical support for spatial planning of urban PGS at different scales①.

2 Research Methods

2.1 Study Area

Nanjing is one of the central cities located in the middle of the lower reaches of the Yangtze River in eastern China, and is also one of the first batch of National Famous Historical and Cultural Cities and National Garden Cities. The city has started its rapid development since 2000, with the built-up area② increasing from 201 km^2 to 868 km^2 in 2020, forming an urban spatial structure of “one core city and three satellite towns.” In the process of urbanization, PGS construction in Nanjing has been significantly improved: the PGS area and per capita PGS area increased from 17.25 km^2 and 8.79 m^2 in 2000 to 78.50 km^2 and 16.09 m^2 in 2020, respectively③, while the residential and transportation lands in the city increased from 42.35 km^2 and 7.15 km^2 in 2000 to 223.82 km^2 and 163.72 km^2 in 2020, respectively④. This paper selected the main urban area, characterized by a concentration of various land use types and a larger ratio of PGS, as the study area (Fig. 1), which is enclosed by the western bank of the Yangtze River and the city’s expressways, comprising approximately 243 km^2. This study area is representative for the research on the scale-effect of different land use types on the distribution patterns of PGS at different grid scales.



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1. Spatial distribution of urban development land of the study area.

2.2 Data Sources and Classification

Considering time span and data availability, the land-use-status data of Nanjing’s urban master plans in 2006, 2012, and 2017 were selected for this study. The data for 2006 were mainly adopted from the Nanjing Urban Master Plan (2007–2020), and those for 2012 and 2017 were mainly sourced from Nanjing Bureau of Planning and Natural Resources. These data are considered authoritative, normative, and applicable. ArcGIS 10.6 software was used to vectorize maps and to identify and unify land use types.

Referencing the classifications of urban development lands in recent research[48]~[50], combined with the Standard of Urban Land Classification and Planning Construction Land Standard (GB 50137–2011), the Land Use Classification (GB/T 21010–2017), and Nanjing’s codes for urban land classification, this study examined 8 other land use types within the study area—residential, administration/public services, commercial/business, industrial/manufacturing, transportation, municipal utilities, water area, and agricultural/forestry—to reveal their impact on PGS distribution pattern.

2.3 Analysis Methods

2.3.1 Grid Cell Division

Scale is a basic concept in Ecology and Geography, and scale-effect is a broadly studied topic: research subjects generally exhibit scale-dependence, meaning that the essential characteristics of

① Although in China’s land use regulation system PGS is classified as a sub-type of GS, the current policies increasingly focus on the allocation of PGS and relevant studies will facilitate the regulation and control of PGS planning and design. Besides, there are already a series of research on the interrelations of PGS and other urban development lands.

② Data source: Statistical Yearbook from the Nanjing Municipal Bureau of Statistics portal website.

③ Data source: Statistical Yearbook from the Nanjing Municipal Bureau of Statistics portal website.

④ Data source: China Urban Construction Statistical Yearbook, compiled by the Ministry of Housing and Urban-Rural Development of the People’s Republic of China.

a given research subject can only be discovered at a particular observational and analytical scale[51]. Scale can be conceptualized within a three-layer framework: real, analytic, and practical[52]. The analytic scale refers to "the epistemological structure of scale, which can be subdivided into realistic, hierarchical, and constructivism understandings"[52], such as macro–meso–micro and global–local scales. National–regional–local–individual scales and different grid scales are primarily applied in current multi-scale studies on urban spatial evolution and impact analysis[53]~[55].

The planning requirements for the "5-, 10-, and 15-minute Community-life Circle" were set out in the Territorial Spatial Master Planning of Nanjing (2021–2035)[56] and the Standards for Urban Residential Area Planning and Design (GB50180–2018)[57], and the Nanjing Planning Guidance of 15-minute Community-life Circle[58] further proposed the construction of "5(10)-,15-, 30-minute Community-life Circle" in urban area. Based on these planning requirements and visions, the analysis scale is divided by the 5-, 10-, 15-, and 30-min walking distance—i.e., 300-m, 500-m, 1,000-m, and 2,000-m grid scales.

2.3.2 Geodetector

Geodetector, proposed by Jinfeng Wang and Chengdong Xu, "is a new statistical method to detect spatial stratified heterogeneity and reveal the driving factors behind it"[59]. It can be used to identify the interactions among multiple factors and to analyze factors that affect spatial differentiation (e.g., urban tourism resources, population, ecological environment)[60]~[62]. In this paper, factor detection and interaction detection tools were mainly used to explore the impact of different land use types on the distribution pattern of PGS, and to characterize the scale-effect. Specifically, the calculation is as follows:

$$Q = 1 - \frac{\sum_{h=1}^{L} N_h \ \sigma_h^2}{N\sigma^2}, \tag{1}$$

where Q is the value of the differentiation factor, with larger Q indicating a stronger explanatory power for the factor on the scale-effect on PGS distribution pattern; L is the number of land use types; h = 1, 2, ..., L is a specific type; N_h and N represent the unit number of factor h and the unit number in the whole area, respectively; σ_h and σ are the variance of factor h and the variance of the whole area, respectively.

The interaction detection between factors can be divided into five types: nonlinear attenuation, single-factor nonlinear attenuation, double enhancement, mutual independence, and nonlinear enhancement[59].

In this paper, the eight land use types were treated as independent variables (X), and PGS as dependent variable (Y). The GIS fishnet tool was used to create cells at each grid scale, i.e., 300 × 300 m, 500 × 500 m, 1,000 × 1,000 m, and 2,000 × 2,000 m, and 2,836, 1,048, 282, and 79 grid cells of data were obtained, respectively. Spatial Join tool in ArcGIS was used to map the spatial data of PGS and other land use types into fishnet grids, to obtain the corresponding grid data. Finally, the sorted grid data were divided into 10 classes by the natural breaks method and fed into Geodetector.

3 Research Results

3.1 Spatio-temporal Evolution Characteristics of PGS at Different Grid Scales

3.1.1 Temporal Evolution Characteristics

Nanjing's PGS showed a trend of rapid growth within the study period. The area of PGS in 2006, 2012, and 2017 was 26.99 km^2, 29.97 km^2, and 34.03 km^2, respectively. Based on the characteristics such as area, size, number, and distribution pattern of PGS, the stages of PGS development in the study area were divided into polarization, diffusion and expansion, and quality and efficiency advancement (Fig. 2).

(1) Stage of polarization

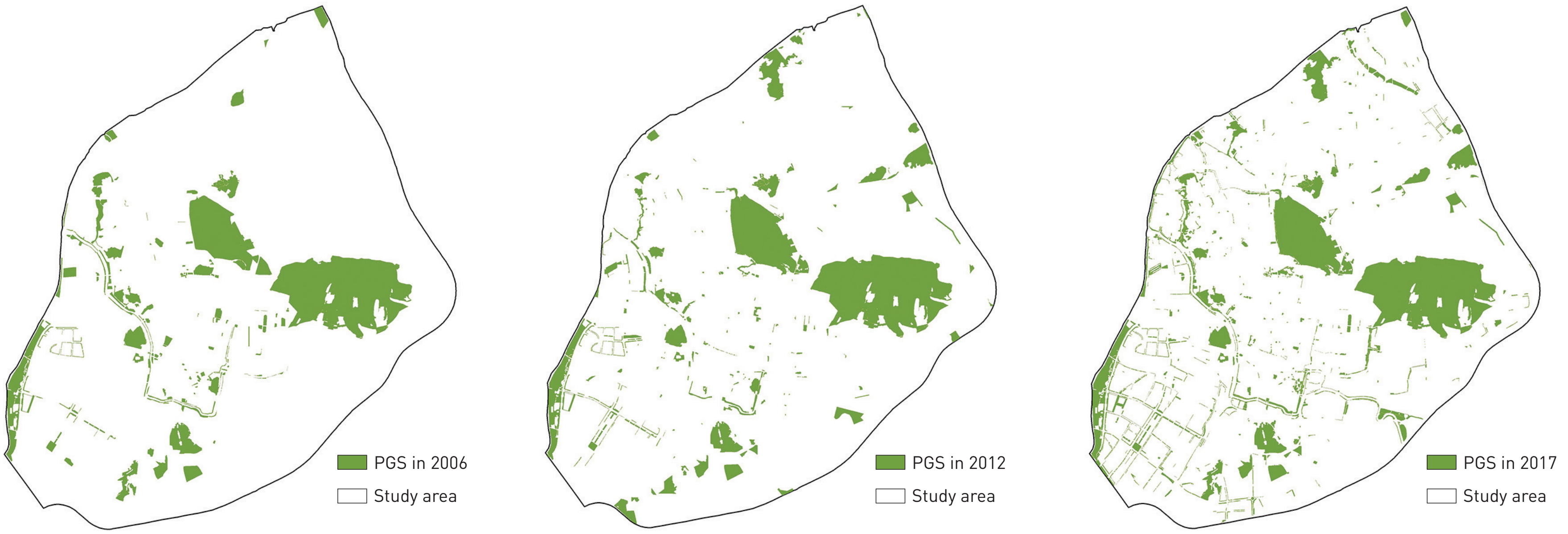
In 2006, the area of PGS was 26.99 km^2, accounted for 11.1% of the total study area. PGS was largely distributed in the Xuanwu Lake and Purple Mountain in the eastern part of the study area, forming the two agglomeration cores; sparse distribution was found in the Yuhuatai area in the south and along the Qinhuai River in the southeast, with little distribution in other districts. In the study area, PGS was not strongly correlated with each other, and its distribution pattern was significantly polarized. The connections between PGS and other land use types were weak, presenting an isolated state.

(2) Stage of diffusion and expansion

By 2012, the area of PGS witnessed a growth to 29.97 km^2. Overall, in addition to the expansion of the existing two agglomeration cores, PGS began to diffuse from southwest to northeast of the study area; the newly built PGS was mainly found around the riverside in the northwest, and along the outer ring in the northeast; also, the size of PGS in the Yuhuatai area increased significantly.

(3) Stage of quality and efficiency advancement

By 2017, the area of PGS reached 34.03 km^2, accounting for 14% of the study area. On the whole, the PGS distribution pattern (e.g., scale, area, and quantity) grew with the improved quality and efficiency. The newly created PGS (particularly small and micro PGS) was mostly distributed in the southwest of the study area, near the riverside, and along the outer ring in the northeast.



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2. The distribution pattern of PGS of the study area in 2006, 2012, and 2017.

3.1.2 Evolution Characteristics of the Distribution Pattern of PGS at Multiple Grid Scales

The area of PGS was preliminarily classified by ArcGIS natural breaks method. In order to better explore the PGS evolution characteristics, the classification threshold at each grid scale was appropriately adjusted and unified. Finally, the area of PGS within each grid cell was divided into five coverage levels: low, relatively low, medium, relatively high, and high (Fig. 3).

Generally speaking, the larger the grid scale is, the more detailed internal characteristics within the grid cell will be ignored; yet, the smaller the grid scale is, the harder it will be to capture the overall spatial layout. Therefore, this paper attempted to clarify the spatio-temporal distribution patterns of PGS by examining the characteristics of each grid scales. Under 300-m and 500-m grid scales, the low, relatively low, and medium PGS coverage cells could be better identified, helping effectively reveal the characteristics of the distribution patterns of small and micro PGS; meanwhile, the 1,000-m and 2,000-m grid scales were used to reveal the spatial layouts of the high and relatively high PGS coverage areas, helping grasp the overall differentiation features of PGS distribution pattern.

(1) PGS at 300-m and 500-m grid scales: from overall polarization to quality and efficiency advancement

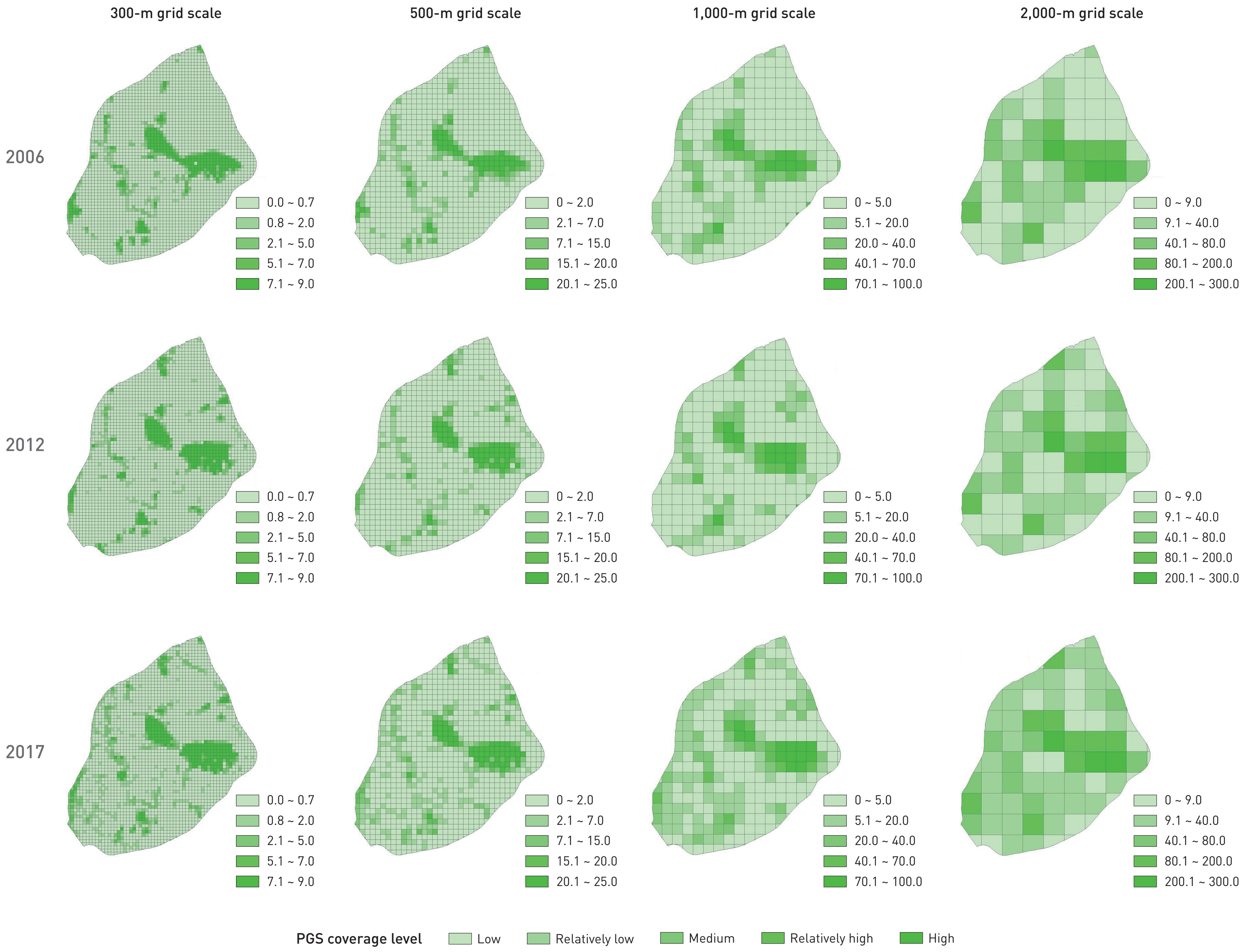
The PGS in Nanjing was initially built on its natural landscapes, with two agglomeration cores in the east of the city characterizing a polarized distribution pattern, and most of the other areas were mainly low coverage areas. After 2012, newly constructed PGS with relatively low and medium coverage were mainly distributed near the outer ring in the northeast and along the northern riverside; the waterfront of the Qinhuai River exhibited a belt and the Yuhuatai area presented a southwest–northeast axis in the distribution pattern of PGS, respectively. In 2017, the number of relatively low and medium PGS coverage cells increased rapidly in the southwest downtown and the riverfront in the northwest, while the low coverage grids gradually decreased.

(2) PGS at 1,000-m and 2,000-m grid scales: from local aggregation to diffusion

In earlier years, the areas with relatively high and high PGS coverage were mainly clustered in the Xuanwu District and its surrounding areas, showing significant local aggregation characteristics. In 2012, only the low and medium coverage areas of the northeast outer ring increased slightly. In 2017, PGS increased significantly, expanding outward from local gathering areas, and the growth was concentrated around the western riverbank and the northeastern outer ring.

3.2 Geodetector Analysis of the Scale-Effect of Different Land Use Types on the Distribution Pattern of PGS at Multiple Grid Scales

Independent variables include residential (X1), administration/public services (X2), commercial/business (X3), industrial/manufacturing (X4), transportation (X5), municipal utilities (X6), water area (X7), and agricultural/forestry (X8). Firstly, the areas



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3. The distribution pattern of PGS of the study area at multiple grid scales in 2006, 2012, and 2017.

within all the units were standardized to eliminate the dimensional differences by large discrepancies in size. Then, a Pearson correlation test was conducted between the dependent variable (PGS) and these independent variables at multiple grid scales. The results showed that positive values represented synergistic scale-effects, while negative values represented compressive scale-effects. Finally, the scale-effects of different land use types on PGS distribution pattern were explored by using Geodetector for differentiation factor detection and interaction detection.

3.2.1 Factor Detection

During the study period, the overall scale-effect of different land use types on the distribution pattern of PGS increased gradually, and the effect strengthened as the grid scale grew. Across the gird scales, the negative effect of transportation land remained consistently significant, while those of residential and industrial/manufacturing lands weakened as grid scale increased; water area competed at earlier stages and then synergized; the negative effect of commercial/business land and the positive effect of administration/public services increased significantly over time; the negative effect on agricultural/forestry declined stage by stage (Fig. 4).

At the 300-m grid scale, residential and transportation lands negatively affected the distribution pattern of PGS, showing a significant spatial competition. In 2012, the two land use types together accounted for 40.77% of the study area (60.84 km^2 and 38.22 km^2, respectively). Residential land was often surrounded by urban main roads and branch roads and typically occupied areas exceeding the 300 m × 300 m grid cells. The layout of residential land within the 300-m grid scale was dominant, resulting in a compressive effect on PGS. Due to the "suppressing the second industry and advancing the third industry" policy⑤, industrial/manufacturing land was largely relocated from the historic city area to outer industrial campus, intensifying the compressive effect on large-size PGS in urban fringe areas. Due to the expansion of commercial/business land, its compressive effect on PGS gradually increased; furthermore, these lands were primarily located in the center or sub-center of the city with higher land prices and rental costs, making it difficult to increase the size of public PGS within such areas. The water area presented a trend of synergy after competition. In earlier stages, water areas and PGS were spatially separated and competitive; while, with the construction of belt-shaped and riverside PGS along the Qinhuai River and the moat, the integration of water area and PGS in layout became pronounced, showing an increasingly positive effect of synergy.

At the 500-m and 1,000-m grid scales, the effects of transportation, industrial/manufacturing, and commercial/business were roughly the same as those at the 300-m grid scale, but the effects of water areas and residential land differed. The water area mainly played a promoting role in the construction and development of PGS. Due to the large size of unit area, the compressive effect of small water areas can be considered negligible. The distribution of PGS depended on the water area construction, and the water areas (e.g., Xuanwu Lake, Mochou Lake) effectively stimulated the growth of PGS.

The scale-effect of residential land presented an inverted V-shaped trend—first increase and then decrease. The "increase" was mainly because of the continuous expansion of residential land from 2006 to 2012. Compared with the 300-m grid scale that the cells were mostly occupied by residential land, a small number of PGS were identified in the 500-m and 1,000-m grid cells, indicating a strong spatial competition. The "decrease" was partly

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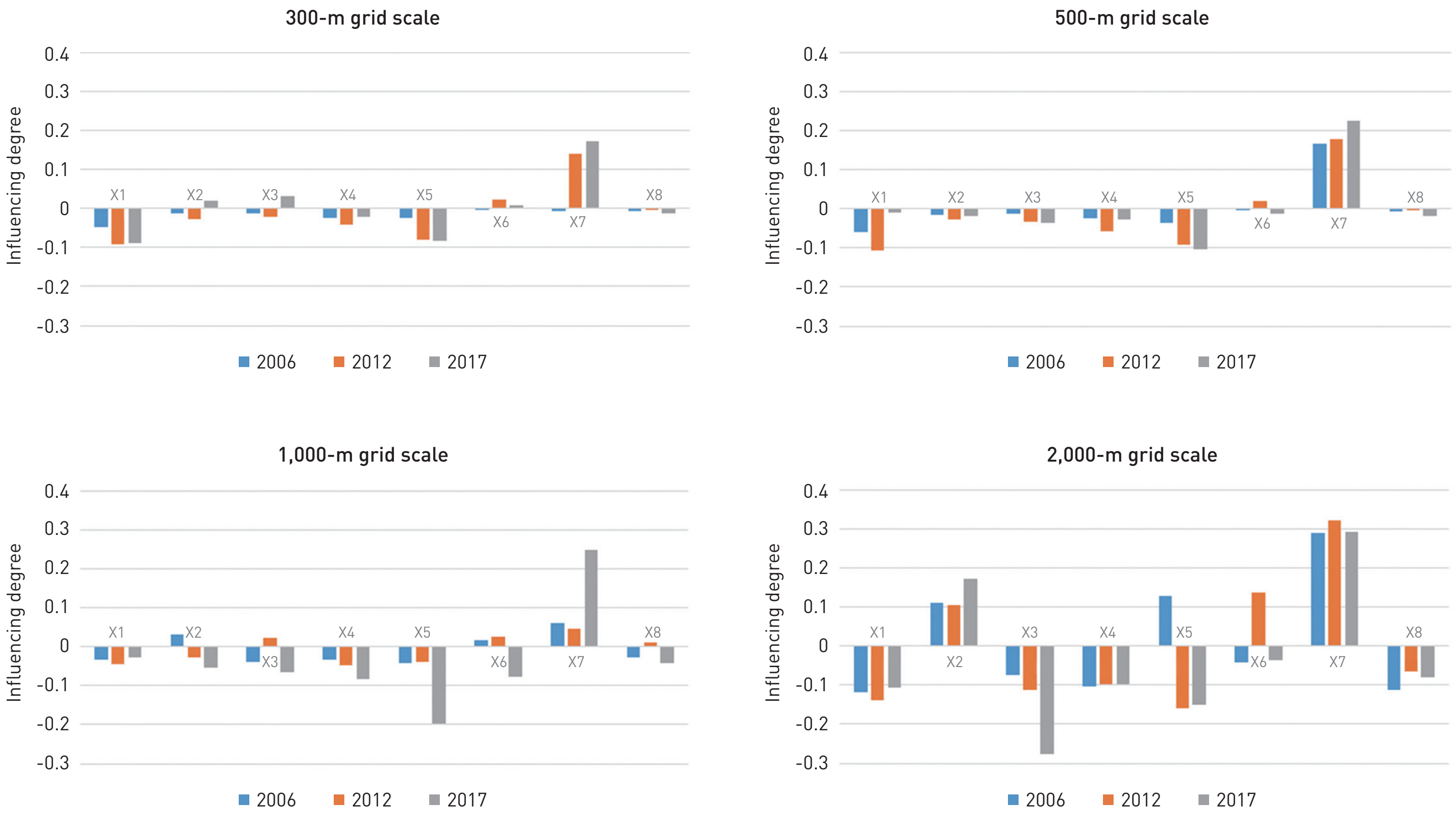
⑤ The policy was proposed by the Nanjing Municipal People's Government to move the secondary industry (particularly industrial production) out of the ancient city.



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4. Different urban development land types on PGS distribution pattern at multiple grid scales.

due to the overall stable size and distribution pattern of PGS, and partly because the smaller PGS in the surrounding communities was scattered in an equilibrium, reducing the negative effect of residential land.

At the 2,000-m grid scale, the scale-effect of transportation, industrial/manufacturing, and water area were consistent with those observed at other grid scales, but the positive effect of administration/public services land increased. This is because the local optimization of public cultural, medical, and educational facilities was gradually promoted, so did the growth of small-size PGS.

The scale-effects of agricultural/forestry and residential lands were diminishing. In 2006, the competitive effect of agricultural/forestry land on PGS in zones such as the Purple Mountain, the southern part of Yuhuatai District, and the western part of Jianye District was significant; however, with the massive reduction of agricultural/forestry land, the interrelations between the two land use types in spatial layout were unconspicuous. Compared with the other grid scales, more residential land and PGS were found in a single 2,000-m grid cell, resulting in a reduced scale-effect of residential land on PGS in general.

The scale-effect of municipal utilities land exhibited a trend of “synergy followed by compression.” The “synergy” was due to the continuous improvement of municipal facilities allocation (e.g., water supply, drainage, gas, heating) and supporting facilities, which drove the construction of local PGS. The “compression” was because of the limited construction space in the later stages, showing a weakened negative effect.

3.2.2 Interaction Detection

The interactive scale-effect among factors on the distribution pattern of PGS can be learned through the interaction detection of Geodetector. The results showed that the interactive scale-effect between two factors were all greater than the scale-effect of each single ones; the interaction types of factors were double enhancement and nonlinear enhancement. At the 300-m and 500-m grid scales, nonlinear enhancement accounted for 84.52%, and double enhancement accounted for 15.48%; while at the 1,000-m and 2,000-m grid scales, nonlinear enhancement accounted for 97.62%, double enhancement accounted for 2.38%, and no independent factors were observed. This study explored the major interaction factors and the interaction mechanisms by analyzing the top five dual-factor combinations of significant interactive scale-effect at each grid scale (Table 1).

Table 1: The major interaction factors and associated scale-effects at varied grid scales

300-m grid scale	500-m grid scale	1,000-m grid scale	2,000-m grid scale
2006			
X1 ∩ X8 (0.0837)	X7 ∩ X8 (0.2926)	X5 ∩ X7 (0.3397)	X1 ∩ X2 (0.8463)
X1 ∩ X4 (0.0812)	X1 ∩ X7 (0.2601)	X4 ∩ X5 (0.3330)	X2 ∩ X7 (0.8081)
X1 ∩ X5 (0.0748)	X5 ∩ X7 (0.2291)	X1 ∩ X7 (0.3300)	X1 ∩ X8 (0.7413)
X1 ∩ X7 (0.0683)	X2 ∩ X7 (0.2277)	X2 ∩ X5 (0.3295)	X1 ∩ X4 (0.7349)
X1 ∩ X2 (0.0634)	X4 ∩ X7 (0.2250)	X1 ∩ X4 (0.3224)	X1 ∩ X7 (0.7290)
2012			
X1 ∩ X7 (0.2224)	X5 ∩ X7 (0.3054)	X3 ∩ X8 (0.395)	X2 ∩ X4 (0.7857)
X5 ∩ X7 (0.2157)	X1 ∩ X7 (0.2835)	X2 ∩ X5 (0.3656)	X6 ∩ X7 (0.7229)
X4 ∩ X7 (0.1828)	X4 ∩ X7 (0.2496)	X5 ∩ X7 (0.3571)	X4 ∩ X7 (0.6976)
X6 ∩ X7 (0.1821)	X2 ∩ X7 (0.2344)	X3 ∩ X7 (0.3249)	X2 ∩ X6 (0.6871)
X2 ∩ X7 (0.1785)	X6 ∩ X7 (0.2272)	X6 ∩ X7 (0.3073)	X2 ∩ X3 (0.6767)
2017			
X1 ∩ X7 (0.2415)	X5 ∩ X7 (0.3492)	X2 ∩ X5 (0.4987)	X5 ∩ X7 (0.8892)
X5 ∩ X7 (0.2342)	X1 ∩ X7 (0.2795)	X5 ∩ X7 (0.4603)	X2 ∩ X5 (0.8764)
X3 ∩ X7 (0.1999)	X2 ∩ X7 (0.2677)	X2 ∩ X7 (0.4199)	X3 ∩ X7 (0.8474)
X2 ∩ X7 (0.1993)	X3 ∩ X7 (0.2675)	X1 ∩ X5 (0.4191)	X1 ∩ X2 (0.8802)
X4 ∩ X7 (0.1902)	X6 ∩ X7 (0.2627)	X4 ∩ X7 (0.4021)	X3 ∩ X4 (0.7817)

Overall, the major interaction factors tended to diversify, and the interaction mechanisms became simpler as the grid scale increased. The major interaction factors in earlier stages were residential, water area, and industrial/manufacturing; by 2012, the major interaction factors were administration/public services, water area, and municipal utilities; and in 2017, those were residential, transportation, water area, and administration/public services.

At the 300-m grid scale, the major interaction factors were residential, transportation, industrial/manufacturing, water area, and administration/public services; as the grid scale increased to 500 m, the interactive scale-effect of industrial/manufacturing decreased, while that of residential, transportation, water area, and administration/public services gradually dominated; at the 1,000-m grid scale, the interactive scale-effect of residential weakened, and that of transportation, water area, and administration/public services became significant; residential, water area, and administration/public services at the 2,000-m grid scale became the factors with the strongest interactive scale-effect of synergy.

The interaction intensity of factors reflects the composition law of the urban spatial structure[63]. The interactive scale-effects among factors of residential, industrial/manufacturing, transportation, water area, and administration/public services weakened as the grid scale increased. The interactive scale-effects between water area and administration/public services were consistently significant across the grid scales and became prominent on the synergy with PGS, strengthening the characteristics of ecological integration of blue-green spaces. The interactive scale-effects between residential and transportation were more pronounced at the 300-m and 500-m grid scales, and due to their wide distribution range and large occupation, they had the most obvious scale-effects on PGS.

4 Discussion

The city is a complex system characterized by multi-scale spatio-temporal relationships[64][65]. This research confirmed previous studies demonstrating that the distribution pattern of GS has been significantly influenced by those of other land use types[47]. Due to the fact that residential and transportation lands accounted for more than 40% of the total area of the studied city, together with the high population density and land use intensity, residential, transportation, and administration/public services lands had a stronger scale-effect on PGS distribution pattern. However, since the close connection between PGS and residential land and residents' high demand for PGS, compared with the compressive effect of residential land on the more naturalized GS[47], the negative scale-effect of residential land on PGS gradually weakened, and the two tended to be synergistic.

This study provides evidence for the research on the scale-effects of PGS at multiple gird scales. In this research, the scale-effects were gradually differentiated as the grid scale increased, and both positive and negative effects significantly intensified. The interactive scale-effect of each land use type on PGS was also significant, but tended to simplify as the grid scale grew.

Different urban areas are dominated by varied land use types, and PGS also exhibited noticeable scale-type variety: when observed at smaller grid scales, the distribution patterns of residential, transportation, and other land use types were relatively balanced, seeing a weaker scale-effect on PGS; at larger grid scales, the distribution pattern of each land use type became polarized, and the dominant land use types emerged, observing stronger scale-effects on PGS.

Additionally, the interaction mechanisms of factors may reflect the constitution laws of urban land use[63], for which administration/public services, water area, and industrial/manufacturing were found as the major interaction factors, reflecting in the spatial characteristics of the study area, including the local optimization of administration/public services, the synergic effect of water areas with PGS, and the local aggregation of industrial/manufacturing land. As the grid scale decreased, the clustering of land use types (e.g., residential, transportation) was increasingly significant, and the interaction mechanisms became more complex, where major interaction factors were residential, transportation, industrial/manufacturing, water area, and administration/public services.

Considering the research results at different grid scales, this paper attempts to propose several optimization strategies for future planning and design of urban development lands of Nanjing.

1) Building a multi-scale blue-green network by leveraging the synergic effect of water area on PGS. At the grid scale of 2,000-m, a coordinative planning of water systems of the city is suggested, which should focus on expanding green belts along the Qinhuai River, the moat, and other water bodies. At the 1,000-m and 500-m grid scales, spatial connections of blue-green network should be strengthened to encourage the growth of PGS. Small and micro PGS can be created to complement the construction of the city's branch waterways or facilitate the restoration of the disappearing historical water areas at the 300-m grid scale.

2) Constructing a multi-scale residential–transportation–PGS network to mitigate spatial conflicts and strengthen connections. Residential and transportation lands have a strong compressive effect on PGS, so future efforts should be made to enhance the connectivity between PGS and residential and transportation lands at different scales: at the grid scale of 2,000-m, the connections between residential land and long-distance, large PGS should be strengthened with urban expressways and main roads to meet residents' occasional needs during holidays; at smaller grid scales, a slow-driving system can be constructed with branch road networks and open blocks, the allocation of micro PGS (e.g., pocket parks) can be enriched, and the improvement of the entrances and exits of PGS and the usage efficiency of daily PGS.

3) The scale-effects of industrial/manufacturing, commercial/business, administration/public service, agricultural/forestry, and municipal utilities lands on PGS distribution pattern were relatively weak across the grid scales. These factors can be combined to improve the overall connection level. PGS on the urban edges can serve as ecological buffers or protective transition areas to alleviate industrial/manufacturing lands' strong compressive effect on PGS or their excessive isolation in distribution. Cultural events, health care and healing activities, educational science exhibitions, and sports programs can be introduced into the commercial/business and administration/public service lands in the city center; it is also advisable to enhance protection and increase the integration of natural and semi-natural habitats with agricultural landscapes, so as to address the weak synergistic effect and lag in the provision of agricultural/forestry lands and PGS and to promote a beneficial complementarity between agricultural landscapes and PGS. It is essential to promote the coordinated layout of PGS and municipal utilities and improve municipal utilities (e.g., supply facilities, environmental facilities) to better serve residents, where large municipal utilities land can beautify the environment and enhance the city's image by adding PGS.

5 Conclusions

Based on the analysis at multiple grid scales—300-m, 500-m, 1,000-m, and 2,000-m—this paper revealed the differentiations of PGS distribution pattern in the main urban area of Nanjing from 2006 to 2017, and further explored the scale-effects of different land use types on PGS distribution pattern with the help of Geodetector. Main research findings as follow.

1) The distribution pattern of PGS showed an evolution from polarization to quality and effieciency advancement across the grid scales, which weakened as the grid scale increased. At each grid scale, the distribution pattern of PGS initially presented characteristics of polarization and then transformed towards advancing quality and efficiency.

2) The scale-effects of different land use types on PGS gradually strengthened, with a more pronounced effect observed at larger grid scales. In 2006, only residential, transportation, and water area lands generated a roughly equal significant effect on PGS distribution pattern. Subsequently, the negative effect of commercial/business land and the positive effect of administration/public services increased significantly, becoming increasingly prominent on the overall distribution pattern of PGS. At the 300-m grid scale, the scale-effects of residential, transportation, industrial/manufacturing, and water area were prominent; while up to the 2,000-m grid scale, the scale-effects of agricultural/forestry, municipal utilities, and administration/public service gradually increased, and the divergence of major interaction factors' scale-effects intensified.

3) The interactive scale-effects of different land use types gradually enhanced. With the increase of grid scale, the overall interaction effect of factors was more significant, but the major interaction factors simplified. At the 300-m grid scale, the major interaction factors were residential, industrial/manufacturing, transportation, water area, and administration/public services; as the grid scale increased, the interactive scale-effect of residential and transportation lands weakened; finally, residential, water area, and administration/public services emerged as major interaction factors at the 2,000-m grid scale. From a temporal perspective, in 2006, the major interaction factors were residential, water area, and industrial/manufacturing. In 2012, the interactive scale-effects of administration/public services, municipal utilities, and water area were strengthened, while those between residential and industrial/manufacturing weakened. In 2017, residential, transportation, water area, and administration/public services became the major interaction factors contributing to the highest synergic effect.

The spatio-temporal differentiation of PGS distribution pattern and the scale-effects of various land use types on it revealed in this study can provide a reference for efficient synergy between PGS and other land use types. Admittedly, there are also a few shortcomings: although this study attempted to use multiple grid scales to better reveal the relevant mechanisms, the modifiable areal unit problem (MAUP) still needs to be further considered in subsequent studies; since the classification of PGS and other land use types are complex, and factors like landforms, historical relics, and policies and regulations also profoundly influence the distribution pattern of PGS, future efforts can be put on the type-scale effects and comprehensive scale-effects among various factors.

Competing interests | The authors declare that they have no competing interests.

REFERENCES

[1] Zhou, G., Li, C., Liu, Y., & Zhang, J. (2020). Complexity of functional urban spaces evolution in different aspects: Based on urban land use conversion. *Complexity*, (2020), 9741203.

[2] Ye, Q., Mo, Z., & Xu, Y. (2019). The expansion and driving forces of the functional space land: A case study of Changsha from 1979 to 2014. *Geographical Research*, 38(5), 1063–1079.

[3] Kraus, L., Wittowsky, D., & Proff, H. (2023). Multi-method analysis to identify criteria interrelations for sustainability assessment of urban transportation services. *Journal of Cleaner Production*, (412), 137416.

[4] Suzuki, T., & Lee, S. (2012). Jobs–housing imbalance, spatial correlation, and excess commuting. *Transportation Research Part A: Policy and Practice*, 46(2), 322–336.

[5] Fiasconaro, A., Strano, E., Nicosia, V., Porta, S., & Latora, V. (2016). Spatio-temporal analysis of micro economic activities in Rome reveals patterns of mixed-use urban evolution. *PLoS ONE*, 11(3), e0151681.

[6] Jucu, I. S., & Voiculescu, S. (2020). Abandoned places and urban marginalized sites in Lugoj Municipality, three decades after Romania's State-Socialist collapse. *Sustainability*, 12(18), 7627.

[7] Scharenbroch, B. C., Trammell, T. L., Paltseva, A., Livesley, S. J., & Edmondson, J. (2022). Urban soil formation, properties, classification, management, and function. *Frontiers in Ecology and Evolution*, (10), 987903.

[8] Dimelli, D., & Kotsoni, A. (2023). The reconstruction of post-war cities—Proposing integrated conservation plans for Aleppo's reconstruction. *Sustainability*, 15(6), 5472.

[9] Martínez, S., & Mollicone, D. (2012). From land cover to land use: A methodology to assess land use from remote sensing data. *Remote Sensing*, 4(4), 1024–1045.

[10] Li, Q., Thapa, S., Hu, X., Luo, Z., & Gibson, D. J. (2022). The relationship between urban green space and urban expansion based on gravity methods. *Sustainability*, 14(9), 5396.

[11] Zhang, J., & Li, C. (2012). The evolution of urban-rural relationship in central cities of China during transformation period. *Acta Geographica Sinica*, 67(8), 1021–1030.

[12] Tang, Z. (1997). Descriptions and explanations of urban spatial structure: A review of research developments. *Urban Planning Forum*, (6), 1–11, 63.

[13] Zhang, T. (2001). The urban restructuring of Chinese cities in 1990s and its dynamic mechanism. *City Planning Review*, (7), 7–14.

[14] Wang, X., Liu, J., Zhuang, D., & Wang, L.(2005). Spatial-temporal changes of urban spatial morphology in China. *Acta Geographica Sinica*, (3), 392–400.

[15] Fang, C. (2009). The urbanization and urban development in China after the reform and opening-up. *Economic Geography*, 29(1), 19–25.

[16] Meng, W., Wang, C., & Li, Y. (2023). Study on the characteristics of spatial expansion in the main urban area of Taiyuan city since 1990. *Geomatics & Spatial Information Technology*, 46(5), 13–16.

[17] Zhao, P., & Wan, J. (2020). The development and innovation of the core algorithm of the integrated model of urban transport and land use. *Journal of Geo-information Science*, 22(4), 792–804.

[18] Liu, W., & Wei, C. (2023). Evolutionary mechanism of rural settlement patterns: A perspective of residential form differentiation. *Geographical Research*, 42(1), 228–244.

[19] Gu, Y., Shen, W., & Song, W. (2023). Spatial differentiation and comparison of urban commercial house and residential house rents in Nanjing. *Scientia Geographica Sinica*, 43(4), 679–689.

[20] Xu, Q., Zhou, C., Ye, C., & Ni, F. (2020). The Spatial differentiation of industry and its evolution mechanism in Guangzhou during 1996–2013. *Acta Scientiarum Naturalium Universitatis Sunyatseni*, 59(4), 43–55.

[21] Li, Q., & Yan, M. (2021). The evolution of Beijing's industrial space distribution from 1949 to 1979: Also on the influence of urban master planning. *Modern Urban Research*, (11), 45–49.

[22] Li, X., Zhang, X., Wen, X., & Li, W. (2021). Spatial pattern evolution analysis of basic public services in Chengdu. *Geomatics & Spatial Information Technology*, 44(4), 57–61.

[23] Zhang, H., Li, Z., & Zhao, Y. (2020). Comprehensive analysis of spatial pattern of public services based on Geographic conditions data in Guiyang city. *Geospatial Information*, 18(6), 6, 44–47.

[24] Shao, D., & Wu, D. (2021). Fractal evolution characteristics of urban park green space layout (1979–2017): A case study of Nanjing. *Landscape Architecture,* 28(3), 113–120.

[25] Harvey, B. J., Donato, D. C., & Turner, M. G. (2016). Drivers and trends in landscape patterns of stand-replacing fire in forests of the US Northern Rocky Mountains (1984–2010). *Landscape Ecology*, (31), 2367–2383.

[26] Peng, J., Liu, Y., Corstanje, R., & Meersmans, J. (2021). Promoting sustainable landscape pattern for landscape sustainability. *Landscape Ecology*, (36), 1839–1844.

[27] Nam, J., & Dempsey, N. (2019). Understanding stakeholder perceptions of acceptability and feasibility of formal and informal planting in Sheffield's district parks. *Sustainability*, 11(2), 360.

[28] Muratet, A., Pellegrini, P., Dufour, A. B., Arrif, T., & Chiron, F. (2015). Perception and knowledge of plant diversity among urban park users. *Landscape and Urban Planning*, (137), 95–106.

[29] Assumma, V., Bottero, M., Monaco, R., & Soares, A. J. (2019). An integrated evaluation methodology to measure ecological and economic landscape states for territorial transformation scenarios an application in Piedmont (Italy). *Ecological Indicators*, (105), 156–165.

[30] Li, C., Barclay, H., Huang, S., & Sidders, D. (2017). Wood fibre value simulation model: A new tool to assist measuring changes in forest landscapes by evaluating forest inventory. *Landscape Ecology*, (32), 1517–1530.

[31] Dony, C. C., Delmelle, E. M., & Delmelle, E. C. (2015). Re-conceptualizing accessibility to parks in multi-modal cities: A Variable-width Floating Catchment Area (VFCA) method. *Landscape and Urban Planning*, (143), 90–99.

[32] Ibes, D. C. (2015). A multi-dimensional classification and equity analysis of an urban park system: A novel methodology and case study application. *Landscape and Urban Planning*, (137), 122–137.

[33] Khattak, M. M. H., Khan, M. A., Din, S. U., Khan, M. Z., & Habib, M. F.

(2023). Examining equity of walking accessibility to green spaces: A case study of Islamabad. *Ain Shams Engineering Journal*, 14(12), 102556.

[34] Zhang, J., & Tan, P. Y. (2023). Assessment of spatial equity of urban park distribution from the perspective of supply-demand interactions. *Urban Forestry & Urban Greening*, (80), 127827.

[35] Seebunruang, J., Burns, R. C., & Arnberger, A. (2022). Is national park affinity related to visitors' satisfaction with park service and recreation quality? A case study from a Thai forest national park. *Forests*, 13(5), 753.

[36] Spera, S. A., Spangler, K. R., Hubert, M. O., & Gorman, M. G. (2023). The effects of climate change on the timing of peak fall foliage in Acadia National Park. *Landscape Ecology*, (38), 2339–2355.

[37] Zhou, H., Wang, J., & Wilson, K. (2022). Impacts of perceived safety and beauty of park environments on time spent in parks: Examining the potential of street view imagery and phone-based GPS data. *International Journal of Applied Earth Observation and Geoinformation*, (115), 103078.

[38] Motazedian, A., Coutts, A. M., & Tapper, N. J. (2020). The microclimatic interaction of a small urban park in central Melbourne with its surrounding urban environment during heat events. *Urban Forestry & Urban Greening*, (52), 126688.

[39] Liu, S., & Liu, B. (2010). Coupling analysis between urban green space and urban development: A case study of Wuxi. *Chinese Landscape Architecture*, 26(3), 14–18.

[40] Ma, T. (2013). Research on the urban green space system planning and design model based on the coupling theory of green space and city space. *Modern Urban Research*, (9), 80–85.

[41] Liu, B., He, W., & Liu, S. (2012). Study of the evaluation and planning of urban green space based on the coupling theory of green space and city space. *Chinese Landscape Architecture*, 28(5), 42–46.

[42] Chang, Z., Chen, J., Li, W., & Li, X. (2019). Public transportation and the spatial inequality of urban park accessibility: New evidence from Hong Kong. *Transportation Research Part D: Transport and Environment*, (76), 111–122.

[43] Fard, A. K., Paydar, M., & Navarrete, V. G. (2023). Urban park design and pedestrian mobility—Case study: Temuco, Chile. *Sustainability*, 15(20), 14804.

[44] Canedoli, C., Bullock, C. H., Collier, M. J., Joyce, D., & Padoa-Schioppa, E. (2017). Public participatory mapping of cultural ecosystem services: Citizen perception and park management in the Parco Nord of Milan (Italy). *Sustainability*, 9(6), 891.

[45] Shan, X., & Yu, X. (2014). Citizen assessment as policy tool of urban public services: Empirical evidence from assessments of urban green spaces in China. *Sustainability*, 6(11), 7833–7849.

[46] Wu, X., Shao, D., & Wu, D. (2023). Spatiotemporal correlation characteristics between park green space and urban functional space in Nanjing—Based on Ripley's k function and POI data. *Chinese Landscape Architecture*, 39(5), 92–97.

[47] Shao, D., & Wu, D. (2021). Geographical Detection of the effect of urban functional space on green space pattern: A case study of Nanjing. *Chinese Landscape Architecture*, 37(9), 31–35.

[48] Shen, Q., Li, C., Zhou, G., & Ma, Z. (2015). The coupling of functional urban spaces: A case study of Changchun from 2002 to 2012. *Geographical Research*, 34(10), 1897–1910.

[49] Hao, F., Zhang, H., & Wang, S. (2021). Spatial accessibility of urban green space in central area of Changchun: An analysis based on the multi-trip model. *Scientia Geographica Sinica*, 41(4), 695–704.

[50] Jiang, J., Dai, F., & Zhang, J. (2019). Urban functional zone recognition and green space evaluation of Shanghai based on POI Data. *Chinese Landscape Architecture*, 35(10), 113–118.

[51] Yue, B., & Liu, Z. (2017). From ecological scale to spatial scale—Application of scale effect in landscape architecture planning and design. *Chinese Landscape Architecture*, 33(8), 77–81.

[52] Liu, Y., & Wang, F. (2011). Concept of scale in human geography and politics of scale—Based on Anglophone human geography since 1980. *Human Geography*, 26(3), 1–6.

[53] Qin, L., & Zeng, G. (2022). Impact of innovation cooperation of different spatial scales on urban innovation performance in the Yangtze River delta region. *Scientia Geographica Sinica*, 42(10), 1747–1756.

[54] Ding, C., Zhang, M., Shu, X., & Peng, P. (2021). Establishing multi-scale urban ecological network: Hefei case. *Planners*, 37(3), 35–43.

[55] Wang, T., & Guo, Y. (2018). Multi-scale study on temporal and spatial characteristics of landscape pattern of Wuhan city under the background of urban expansion. *Urbanism and Architecture*, (18), 46–53.

[56] Nanjing Municipal People's Government. (2022). *Territorial spatial master planning of Nanjing (2021–2035)*.

[57] Ministry of Housing and Urban-Rural Development of the People's Republic of China. (2018). *Standard for urban residential area planning and design (GB50180–2018)*.

[58] Nanjing Bureau of Planning and Natural Resources. (2023). *Nanjing planning guidance of 15-minute community-life circle*.

[59] Wang, J., & Xu, C. (2017). Geodetector: Principle and prospective. *Acta Geographica Sinica*, 72(1), 116–134.

[60] Cao, K., Shen, Z., & Yang, L. (2022). Analysis on the decoupling state and influencing factors of rural revitalization and tourism development level in China. *Ecological Economy*, 38(11), 147–153, 189.

[61] Wei, X., & Yang, L. (2022). Spatial differentiation and influencing factors of self-rated health of urban and rural elderly population in Chongqing. *Medicine and Society*, 35(11), 71–75.

[62] Wang, Y., Hao, L., Xu, Q., Li, J., & Chang, H. (2023). Spatio-temporal variations of vegetation coverage and its geographical factors analysis on the Loess Plateau from 2001 to 2019. *Acta Ecologica Sinica*, 43(6), 1–11.

[63] Sun, J., & Lu, Y. (2023). Mechanism and optimization path of comprehensive land consolidation oriented urban-rural integration. *Journal of Natural Resources*, 38(9), 2201–2216.

[64] Shang, Z. (2011). *A multi-scale study on the evolution of urban spatial form—A case study on Huai'an, Jiangsu* [Doctoral dissertation]. Nanjing Normal University.

[65] Li, S., & Cai, Y. (2005). Some scaling issues of geography. *Geographical Research*, 24(1), 11–18.

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不同用地类型对多网格尺度下公园绿地分布格局的尺度效应
——以南京市主城区为例

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摘要

探索不同用地类型在多网格尺度下公园绿地（PGS）分布格局的尺度效应，可为不同尺度下城市建设用地合理配置和高效协同发展提供基础。本文选取300m、500m、1 000m及2 000m四级网格尺度，利用GIS渔网分析和地理探测器构建了不同用地类型对PGS分布格局的尺度效应分析框架，并揭示了南京主城区2006年、2012年和2017年不同用地类型对PGS的尺度效应的时空差异特征。主要研究结果包括：1）PGS的总体格局呈现从极化到增质提效的演变特征，且该特征随网格尺度的增加逐渐减弱；2）不同用地类型对PGS的尺度效应不断增强——尺度越大，协同或挤压效应越明显；3）不同用地类型尺度交互效应逐渐增强——尺度越大，总体因子交互作用越显著；4）300m网格尺度下的主要交互因子为居住、交通设施、工业、水域和公共管理／公共服务设施用地，2 000m网格尺度下的主要交互因子转变为居住、水域、公共管理／公共服务设施用地。本文的研究结论有望深化PGS与其他用地类型之间的耦合理论，并为城市空间的高效配置、布局优化及可持续发展提供科学依据。

关键词

城市功能用地；公园绿地分布格局；尺度效应；南京主城区；地理探测器

文章亮点

- 构建了不同用地类型对PGS的尺度效应分析框架
- 揭示了不同用地类型对PGS分布格局的尺度效应的差异和相关性
- 发现了不同用地类型对PGS的尺度效应／交互效应随网格尺度的增大而不断增强

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