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Evaluation of Ecological Supply-demand Synergy of Park Green Space in the Main Urban Region of Zhengzhou City

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Abstract

As important types of green spaces in the urban green space system, park green spaces are closely related to the urban residents. Research on park green spaces mainly focuses on the functions and the accessibility, and the synergy between supply and demand of park green spaces remains to be studied. This paper aims to promote the synergistic development between park green spaces and residents, and provide a scientific basis for the construction of an efficient park green space system and sustainable urban development. Based on the perspective of the supply-demand synergy of the ecological function of park green spaces, this paper took the main urban region of Zhengzhou City as the study area. An evaluation system of synergy degree of supply and demand was constructed using network analysis method, quantitative model of supply-demand synergy and analytic hierarchy process to study the characteristics of synergistic evolution between park green spaces and residents in the space-time dimension. The results show that the overall synergy degree of the study area increased from 0.1522 to 0.4256 from 2000 to 2020, and the overall supply index was always lower than the overall demand index. According to the results above, the authors proposed the optimizing strategies of increasing the number and green area of parks and improving connectivity between parks. Based on the top-down planning system, this study suggests bottom-up supply and demand evaluation and synergistic optimization, which can promote the efficiency of the ecological function of park green spaces, and solve the mismatch of supply and demand resources between the old and new urban areas.

Introduction

In the past few decades, China's urbanization development has been characterized by high density, high intensity, high speed, super height and large scale. While people enjoy the convenience brought by urbanization, the rapid growth of the urban population has brought great pressure to the urban environment. As a result, most people expect to improve the living environment by increasing urban green spaces. The nature of urban green spaces serving the people determines that there is a close supply and demand relationship between green spaces and residents (Wolch, Byrne, and Newell 2014). However, under the background of intensive urban development, the contradiction between the green land and the residential land is increasingly prominent. How to balance the supply and demand relationship between urban green spaces and residents has become an urgent problem to be solved.

Park green spaces (PGSs) are important parts of urban green spaces, which mainly have recreational, ecological and landscape functions (CJJ/T85–2017). This paper selects the PGSs in the main urban region of Zhengzhou City as the research objects, and constructs a quantitative synergetic evaluation system from the perspective of ecological supply and demand balance. This paper aims to promote the synergistic development between PGSs and residents by analyzing the synergy levels and types and putting forward targeted optimization strategies, so as to provide a scientific basis for the evaluation and planning of the layout of PGSs in the future.

Background and Literature Review

In urban ecosystem, PGSs provide a lot of ecosystem services (ESs) for urban areas, and the spatial layout of PGSs affects their ESs value (Daily 1997). However, when evaluating and planning the construction of PGSs, simple indicators such as per capita green space area are often used, which cannot reflect the spatial pattern of PGSs, let alone measure the relationship between supply and demand. In recent years, scholars have proposed some indicators to evaluate PGSs from multiple perspectives, such as accessibility (Lin et al. 2021), service efficiency (Guo et al. 2019) and supply-demand ratio (Liu et al. 2022). More research is needed on the supply-demand evaluation of ESs value of PGSs.

The synergetic theory encourages the development of the synergetic relationship in competition and cooperation to form a dynamic model of systematic and orderly development (Haken 1978). Synergy degree (SD) can quantitatively represent the synergy level from disorder to order between the ecological supply of PGSs and the demand of residents. At present, the quantitative model of SD is widely applied to the measurement of the interaction and coupling relationship among various factors in urban development (Xin et al. 2021) and ecological environment (Chen et al. 2019). In the field of green space system planning, this model is mainly used for the synergy measurement of functions and performance of green spaces (Dennis and James 2017). However, current understanding of the SD between PGSs and residents remains limited.

Methods and Data

Located in the south of North China plain, the main urban region of Zhengzhou City (34°16′-34°58′N, 113°27′-113°52′E) presents a spatial pattern of the new urban area surrounding the old urban area (Fig. 1). Township-level administrative regions were selected as research units, with 81 units in the study area. In 2020, the main urban region of Zhengzhou City had a permanent population of about 6.84 million with a total area of 1035.37km^2. From 2000 to 2020, the number of PGSs in the study area increased by 218, and the area increased by 5852.68 ha, accounting for 5.66% of the study area (Table 1). Compared with the old urban area, the number and area of PGSs in the new urban area were significantly increased (Fig. 2).

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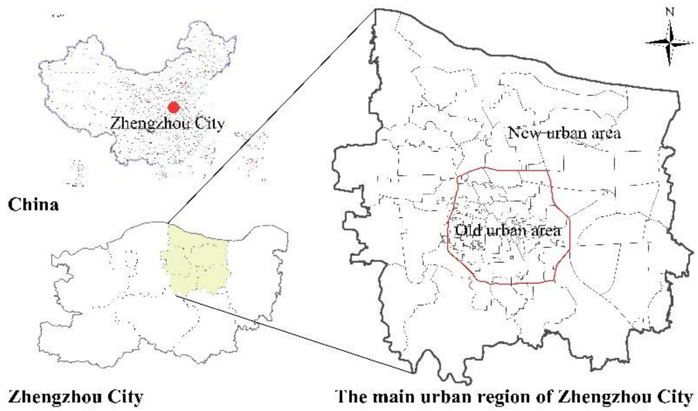

Figure 1. Location map of the main urban region of Zhengzhou City

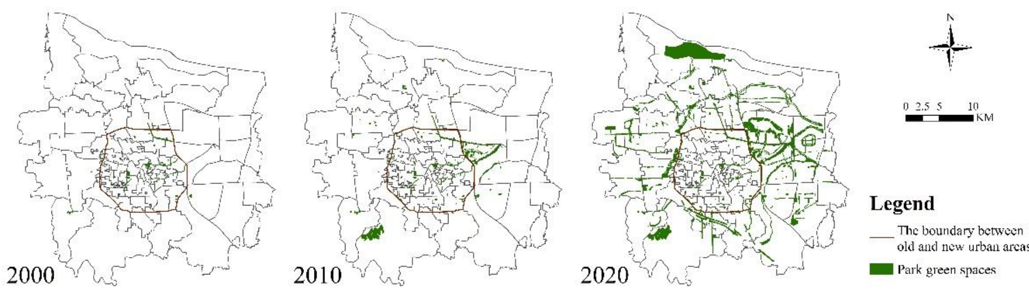

Figure 2. Distribution maps of PGSs from 2000 to 2020

Table 1. The number and area of PGSs from 2000 to 2020

Year	The number of PGSs			The area of PGSs (ha)			The proportion of PGSs in urban area
	The old urban area	The new urban area	Total	The old urban area	The new urban area	Total	
2000	22	3	25	173.06	49.16	222.22	0.21%
2010	60	46	106	253.28	797.32	1050.60	1.01%
2020	76	167	243	336.84	5738.06	6074.90	5.87%

According to the synergetic theory, the ecological supply subsystem of PGSs and the ecological demand subsystem of residents were constructed. Based on the studies on the evaluation of urban ESs (Liu et al. 2018; Wang et al. 2019), four indicators were selected to evaluate the ecological supply subsystem of PGSs (Table 2). All indicators were calculated by the physical assessment method (PAM) (Zheng et al. 2008). In the ecological demand subsystem of residents, it is assumed that the residents in each research unit are evenly distributed, and the population density of each research unit is taken as an indicator to reflect the basic demand of residents (Table 2).

Table 2. The evaluation indicators of the ecological supply and demand subsystems

Subsystem	Indicator	The property of the indicator	The weight of the indicator
Ecological supply subsystem of PGSs	Carbon sequestration and oxygen release	positive	0.2048
	Climate regulation	positive	0.3381
	Air purification	positive	0.1690
	Water conservation	positive	0.2881
Ecological demand subsystem of residents	Population density of each research unit	positive	1.0000

After processing the original data with the Min-Max normalization method, Analytic Hierarchy Process (AHP) (Saaty 2008) was used to calculate the weights of ecological supply indicators (Table 2). On this basis, a quantitative model of supply-demand synergy was constructed to calculate the comprehensive evaluation index (CEI) and the SD of supply and demand subsystems (Shi et al. 2021). The network analysis method in ArcGIS software was used to simulate the service scope of PGSs under real road conditions, and the CEI of each PGS was allocated to corresponding study units according to the proportion of service areas. Finally, the SD of each study unit was obtained and 5 synergy levels were divided. When SD is less than 0.4000, the supply-demand subsystem is at the level of lack of synergy; when SD is greater than or equal to 0.4000, the supply-demand subsystem is at the synergetic level. Combining the synergy levels with the CEI of supply and demand subsystems, 5 synergy types were divided (Table 3).

Table 3. Classification of the levels and types of supply-demand synergy

SD (synergy degree)	**Synergy levels**	**Synergy types**		
		$CEI_{supply} > CEI_{demand}$	$CEI_{supply} < CEI_{demand}$	$CEI_{supply} = CEI_{demand}$
0.8000≤SD < 1.0000	Advanced synergy	Hysteretic demand	Hysteretic supply	Supply-demand balance
0.6000≤SD < 0.8000	Intermediate synergy			
0.4000≤SD < 0.6000	Basic synergy			
0.2000≤SD < 0.4000	Mild lack of synergy	Deficit demand	Deficit supply	
0.0000≤SD < 0.2000	Severe lack of synergy			

The data for this paper were drawn from primary sources: (1) Landsat7 ETM images data (2000/08/27, 2010/07/06, 2020/08/25) from the USGS website (https://www.usgs.gov/); (2) PGSs data in 2000, 2010, 2020, which were obtained by field investigation and visual interpretation based on satellite images; (3) Population data at the township level in 2000, 2010, 2020 from China's fifth, sixth and seventh population censuses; (4) Road data in 2000, 2010, 2020 from

OpenStreetMap website (https://www.openstreetmap.org/) and field investigation; (5) Net Primary Productivity (NPP) data in 2000, 2010, 2020 from the USGS website (MOD17A3HGF Version6 product); (6) Leaf Area Index (LAI) data in 2000, 2010, 2020 estimated by LAI-NDVI regression equation (Li, Zhou, and Yao 2015), and NDVI data came from the satellite images.

Results

Over the past two decades, the synergy level of each unit has been improved to varying degrees, and the overall trend is on the rise (Fig.3). In 2000, 28 units could not be evaluated because the CEI of the supply subsystem or demand subsystem was 0, and there were 3 synergy levels in the remaining 53 units. The level of mild lack of synergy had the largest number of units (29 units), most of which were distributed in the old urban area. There were only 2 units with a basic synergy level, which accounted for the least proportion in the study area and distributed in the old urban area. In addition, 22 units were at the level of severe lack of synergy, scattered between the new and old urban areas. The overall synergy level in 2000 was the mild lack of synergy, reflecting the lack of park resources and uneven population distribution at that time. In 2010, a total of 72 units calculated the synergy levels. Similar to 2000, there were 3 synergy levels in the study area, and the level of mild lack of synergy still accounted for the largest proportion (47 units). The number of units with a basic synergy level increased to 6, mostly in the old urban area and near the boundary between the new and old urban areas. The number of units with the level of severe lack of synergy decreased to 19, most of them located in the new urban area. During this period, the overall synergy level of old urban units was still higher than that of new urban units. In 2020, there were 4 synergy levels in 81 units. The intermediate synergy level was added in the study area, and 4 units near the boundary between the old and new urban areas were upgraded to this level. The units of the basic synergy level accounted for the largest proportion (39 units), followed by the units of the level of mild lack of synergy (36 units). The level of severe lack of synergy is reduced to 2 units, both located on the edge of the study area. The overall synergy level in 2020 was elevated to the basic synergy level. Compared with 2000 and 2010, the overall synergy level in 2020 had significantly improved. It is worth noting that the synergy level of units in the new urban area had exceeded that of units in the old urban area, reflecting the achievements of the construction of PGSs in the new urban area.

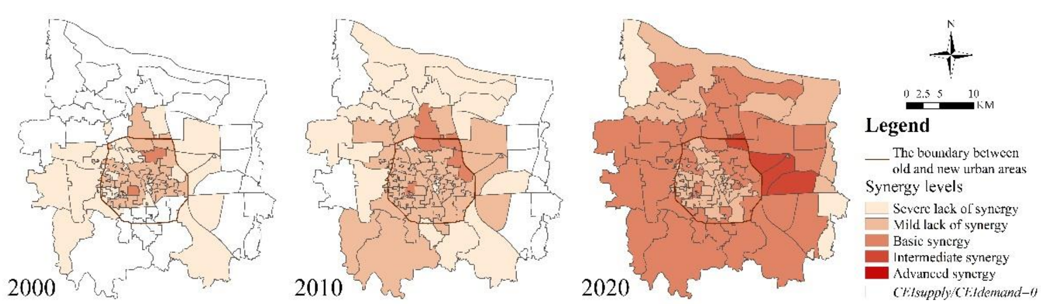

Figure 3. Distribution maps of ecological supply-demand synergy levels of PGSs from 2000 to 2020

Synergy type reflects the state of balance between the supply subsystem and the demand subsystem. There were 3 synergy types in 2000, among which the deficit supply type accounted for the largest proportion (46 units). This type means that the ecological supply of PGSs is lower than the ecological demand of residents, and the subsystems of supply and demand are in a state of disorder. The hysteretic supply type (2 units) also means that the supply is lower than the demand, but the subsystems of supply and demand are relatively coordinated. In addition, 5 units were the deficit demand type, that is, contrary to the deficit supply type, the ecological supply of PGSs is higher than the ecological demand of residents. In 2010, the number of units of the deficit supply type remained the largest (55 units), and the number of units of the hysteretic supply type increased to 6. It is worth noting that the units within the old urban area are all of these two types, reflecting the contradiction between the concentration of population and the lack of PGSs in the old urban area. The units of the deficit demand type increased to 11, all located in the new urban area. In 2020, the hysteretic demand type appeared in the study area, including 28 units, all located in the new urban area, reflecting that the newly built PGSs effectively improved the supply of these units. The units in the old urban area were still the hysteretic supply type (15 units) and deficit supply type (33 units). The number of units of the deficit demand type was reduced to 5, all in the northern part of the new urban area. In general, the overall ecological supply of PGSs in the study area was always less than the demand of residents. However, the increment of ecological supply in the new urban area was large and met the demand of residents in most units (Fig. 4). From the perspective of landscape architecture, what needs to be solved is the insufficient supply of PGSs in the old urban area.

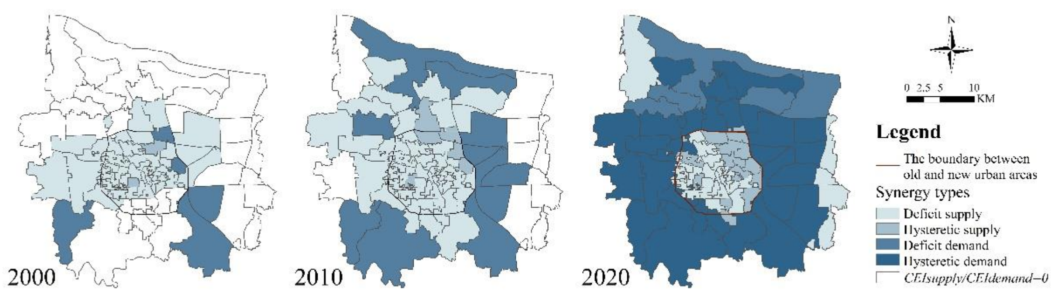

Figure 4. Distribution maps of ecological supply-demand synergy types of PGSs from 2000 to 2020

Discussion and Conclusion

According to the temporal and spatial evolution analysis of the ecological supply-demand synergy of the PGSs, the supply and demand subsystems in the study area have always been in a state of lack of synergy and imbalance, which is not conducive to the ecological effect of the PGSs. As public resource with significant spatial attributes, it is difficult for PGSs to reach the balance between supply and demand directly through market regulation. Therefore, the comprehensive improvement of the supply side can actively intervene in this balance by optimizing the allocation of park resources in order to explore targeted optimization strategies. Firstly, the optimization strategy of increasing the green area of the PGSs can be adopted. On the one hand, the proportion of green spaces in existing PGSs can be appropriately increased based on reasonable allocation of park land. On the other hand, combined with the land use map, the maximization coverage model in ArcGIS software can be used to screen out suitable sites for the construction of new PGSs to reduce service blind areas. Secondly, belt parks can be built to improve the connection between PGSs. As a major type of greenway, belt park can connect originally isolated park patches, thus promoting the exchange of material, energy and species between parks and narrowing the resource gap between different units. Similarly, the maximization coverage model can be applied to screen out suitable construction sites of belt parks as transmission corridors of the ecological supply of PGSs.

At present, the problems of low supply efficiency and unbalanced spatial layout of PGSs not only exist in many cities in China, but also in the United States and Europe. This study quantified the temporal and spatial evaluation of the SD between the ecological supply-demand of PGSs, and the results show that in the past 20 years, the spatial mismatch between PGSs and residents also existed in the main urban region of Zhengzhou City. In particular, the contrast between the changes in supply-demand SD between new and old urban areas is significant. Through the optimization of the supply side, a more synergetic relationship will be formed between supply and demand subsystems, thus contributing to the sustainable development of the city. In subsequent studies, smaller scale studies such as block as a unit can be considered, and the introduction of big data such as the mobile signal data and the Point of Interest (POI) data can more accurately guide the construction of PGSs and resource regulation between new and old urban areas.

Acknowledgements

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