

# Pedestrian Flow Characteristics and Optimization Strategies of Comprehensive Parks in the Central Urban Area of Beijing in the Context of COVID-19 Epidemic

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**Abstract** Green space is the main public space in the city and plays an important role in urban environmental health and residents' physical and mental health. The outbreak of COVID-19 has put forward new requirements for urban green space construction in many aspects. Based on the population vitality data of comprehensive parks in the central urban area of Beijing, this paper evaluated urban comprehensive parks in the context of COVID-19 epidemic to reveal the changing process of their use and visit characteristics, and proposed suggestions and strategies to deal with the epidemic in comprehensive parks in the central urban area of Beijing.

**Keywords** Epidemic, Comprehensive park, Baidu heat map, Big data

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At the beginning of 2020, the novel coronavirus came out of the blue, posing a serious threat to people's lives and health. After more than three years of unremitting efforts, China has achieved a major and decisive victory in epidemic prevention and control. In the face of COVID-19 prevention and control, various industries, such as medical and health care, urban planning and social governance, are actively thinking about how to play a maximum role in responding to similar public health emergencies<sup>[1]</sup>. From the perspective of human settlement environment, scholars are more aware of the health benefits of park green space and the importance as a living necessity for residents<sup>[2-9]</sup>. However, most of the current research studies are global and national large-scale and inter-provincial and inter-regional mesoscale, targeting cities or scenic spots, while much less efforts have been dedicated to the use of green space in small scale such as cities under the epidemic situation. Therefore, according to the *Classification Standard of Urban Green Space* (CJJ/T85-2002), comprehensive parks in the central urban area of Beijing were selected as the research object to study the changing process of the use and visit characteristics of urban comprehensive parks in the context of COVID-19 epidemic, in order to provide a reference for the future development planning of comprehensive parks in the central urban area of Beijing for similar public health emergencies.

## 1 Research objects and research methods

### 1.1 Research objects

Based on the *Beijing Urban Master Plan*

(2016-2035), the research area was determined to be the central urban area of Beijing, namely Dongcheng District, Xicheng District, Chaoyang District, Haidian District, Fengtai District and Shijingshan District. According to the data published on the official website of Beijing Municipal Forestry and Parks Bureau, 44 comprehensive parks in the central urban area of Beijing were selected as the research objects (Table 1).

### 1.2 Research methods

**1.2.1 Kernel density analysis.** Kernel density analysis can analyze the clustered and dispersed distribution characteristics of point data, especially reflecting geographical attenuation effect, and is often used to explore the law of data distribution<sup>[10]</sup>. The higher the kernel density, the denser the distribution of point elements. The spatial distribution characteristics of comprehensive parks can be figured out by kernel density analysis.

**1.2.2 Average nearest neighbor index method.** Average nearest neighbor index can get the clustered and dispersed modes of data, and provide optimization suggestions for the distribution mode and subsequent construction of comprehensive parks. Average nearest neighbor analysis would first measure the distance between the locations of comprehensive parks in the central urban area of Beijing, and then obtain the average nearest neighbor distance<sup>[11]</sup>. Nearest neighbor index (NNI) is the ratio of the average observed distance to the average expected distance.

Average nearest neighbor index is calculated by the following formula:

$$NNI = \overline{D_O} / \overline{D_E}$$

where  $NNI$ ,  $\overline{D_O}$  and  $\overline{D_E}$  represent the nearest neighbor index, average observed distance, and average expected distance, respectively. The distribution trend of comprehensive parks could be obtained based on NNI.

**1.2.3 Standard deviation ellipse method.** Through the "grid calculator" in GIS, the heat value of selected samples was calculated, and then the values of forward and backward 18 days were averaged. Considering that it is not comprehensive to evaluate the performance of comprehensive park system by the number of visitors, this study introduced park service efficiency  $E$  for calculation.

$$E = \overline{R_G} / S$$

Here,  $E$ ,  $\overline{R_G}$  and  $S$  represent the service efficiency, average heat and area of each comprehensive park, respectively<sup>[12]</sup>.

The service efficiency of each park at two stages was calculated, and the directional distribution (standard deviation ellipse) tool was used to divide the park service efficiency into 7 levels by natural breakpoint method, in which the comprehensive parks of grade 6 and 7 were defined as service hotspots, and those of grade 4 and 5 were defined as service sub-hotspots. This research focused on the study of service hotspots and service sub-hotspots, and did not study the service hotspots of grades 1–3.

## 2 Data source and processing

The data of comprehensive parks in the central urban area of Beijing were derived from the Open Street Map, and corrected and supplemented by Landsat 8 satellite images.

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According to the information of comprehensive parks, such as name, type, administrative district, total area, water area, longitude and latitude coordinates, etc., the surface data of comprehensive parks were finally obtained in the ArcGIS platform (Fig.1).

The population heat map data in 2022 and 2023 used in this study were derived from Baidu heat map. On December 7, 2022, the comprehensive team of Joint Prevention and Control Mechanism of The State Council issued the latest notice on epidemic prevention and control measures, which means that Beijing would gradually lift the lockdown. In this study,

the population heat data in the central urban area of Beijing was tracked and extracted over 9 natural weeks from November 7, 2022 to January 7, 2023 (Table 2). Involving working days and rest days, the main tracking time periods were three representative moments of 9:00, 15:00 and 18:00 on Monday, Wednesday, Friday and Saturday to represent the visit situation of comprehensive parks at different instants of time. Finally, 108 groups of gdb point data from 36 valid days were obtained. The data contents included the acquisition time, latitude and longitude coordinates of sampling points (GCS\_WGS\_1984) and heat value.

### 3 Research results

#### 3.1 Distribution characteristics of comprehensive parks

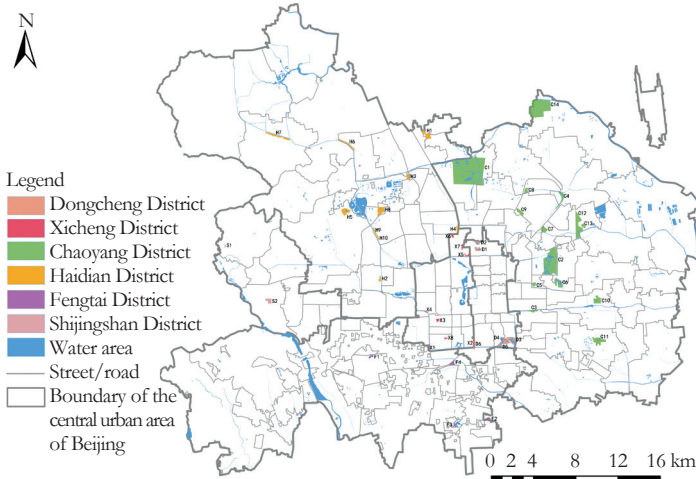
According to the kernel density analysis of 44 comprehensive parks in the central urban area of Beijing (Fig.2), the kernel density distribution showed the characteristics of high in the center and low around the periphery. The comprehensive parks were concentrated in Dongcheng District and Xicheng District, mainly gathered in Desheng Street, Hepingli Street, Taoranting Street and Longtan Street. The comprehensive parks in Chaoyang District were the most, accounting for 3.06% of the total administrative district, but were relatively scattered, mainly concentrated in Jiuxianqiao Street, Maizidian Street and Tuanjiehu Street. The comprehensive parks in Haidian District mainly distributed in Haidian Street, Wanliu District office and Shuguang Street. There were less comprehensive parks in Fengtai District and Shijingshan District. Overall, the western and eastern parts of the central urban area of Beijing were relatively short of comprehensive parks. The nearest neighbor index of comprehensive parks was calculated to be 1.089 117, the Z value was 1.130884, and the NNI value was greater than 1. Therefore, the comprehensive parks were in random spatial distribution pattern (Fig.3).

#### 3.2 Change characteristics of visits to comprehensive parks before and after the liberalization of epidemic policies

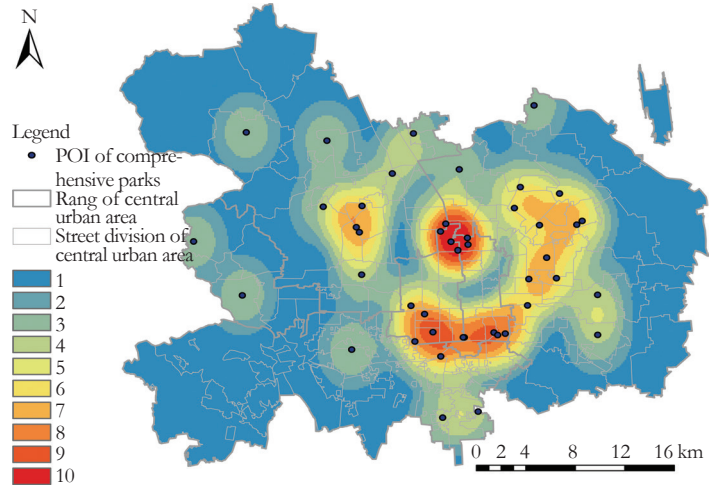
**3.2.1 Overall change characteristics of park visits.** Based on the heat map data of the central urban area of Beijing from November 7, 2022 to January 7, 2023, a line chart of the total number of visitors to comprehensive parks was obtained (Fig.4). As can be seen from Fig.4, the change trend in the number of visitors mainly had four stages. The first stage was from November 7 to November 26, 2022; the overall number of visitors to comprehensive parks showed a downward trend, and basically reached the lowest point on November 26, while the total number of visitors to 44 comprehensive parks was less than 3,000 during the three periods with high pedestrian flow rate on the same day. The second stage was from November 26, 2022 to December 7, 2022, and the overall number of visitors to comprehensive parks showed a gradual increase. The third stage was from December 7, 2022 to December 18, 2022, and the total number of visitors to 44 comprehensive parks slowly decreased. The final phase lasted till January 7, 2023, and the number of visitors grew rapidly; the maximum number of visitors to 44 comprehensive parks was nearly 6,000 during the

**Table 1 Comprehensive park database in the central urban area of Beijing**

Administrative district	No.	Park	Area//hm <sup>2</sup>
Dongcheng District	D <sub>1</sub>	Liuyin Park	17.47
	D <sub>2</sub>	Qingnianhu Park	17.00
	D <sub>3</sub>	Longtan Park	42.30
	D <sub>4</sub>	Longtan Xihu Park	10.02
	D <sub>5</sub>	Longtan Zhonghu Park	39.67
	D <sub>6</sub>	Yongdingmen Park (Dongcheng)	8.69
Xicheng District	X <sub>1</sub>	Jinzhongdu Park	6.62
	X <sub>2</sub>	Yongdingmen Park (Xicheng)	11.21
	X <sub>3</sub>	Xuanwu Garden	7.80
	X <sub>4</sub>	Baiyun Park	10.10
	X <sub>5</sub>	Beibinhe Park	5.69
	X <sub>6</sub>	Shuangxiu Park	6.20
	X <sub>7</sub>	Rendinghu Park	9.02
	X <sub>8</sub>	Wanshou Park	5.10
Chaoyang District	C <sub>1</sub>	Olympic Forest Park	581.88
	C <sub>2</sub>	Chaoyang Park	288.70
	C <sub>3</sub>	Qingfeng Park	26.70
	C <sub>4</sub>	Dawangjing Park	33.04
	C <sub>5</sub>	Tuanjiehu Park	12.30
	C <sub>6</sub>	Honglingjing Park	41.99
	C <sub>7</sub>	Side Park	17.00
	C <sub>8</sub>	Beixiaohe Park	19.59
	C <sub>9</sub>	Wanghe Park	38.60
	C <sub>10</sub>	Xinglong Park	45.70
	C <sub>11</sub>	Guta Park	55.70
	C <sub>12</sub>	Jangfu Park (Phase I-III)	215.00
	C <sub>13</sub>	Jangfu Park (Phase IV)	21.00
	C <sub>14</sub>	Wenyuhe Park (Chaoyang)	44.00
Haidian District	H <sub>1</sub>	Xixiaokou Park	26.54
	H <sub>2</sub>	Linglong Park	8.13
	H <sub>3</sub>	Heqingyuan Park	12.67
	H <sub>4</sub>	Madian Park	7.73
	H <sub>5</sub>	Beiwu Park	45.20
	H <sub>6</sub>	Baiwang Park	17.20
	H <sub>7</sub>	Hot Spring Park	27.97
	H <sub>8</sub>	Haidian Park	32.80
	H <sub>9</sub>	Bagou Landscape Garden	6.24
	H <sub>10</sub>	Changchun Fitness Park	7.12
Fengtai District	F <sub>1</sub>	Fengtai Garden	9.37
	F <sub>2</sub>	Donggaodi Park	7.20
	F <sub>3</sub>	Nanyuan Park	9.30
	F <sub>4</sub>	Wanfangting Park	10.60
Shijingshan District	S <sub>1</sub>	Xiaoqingshan Park	6.01
	S <sub>2</sub>	Xin'an Park	17.99



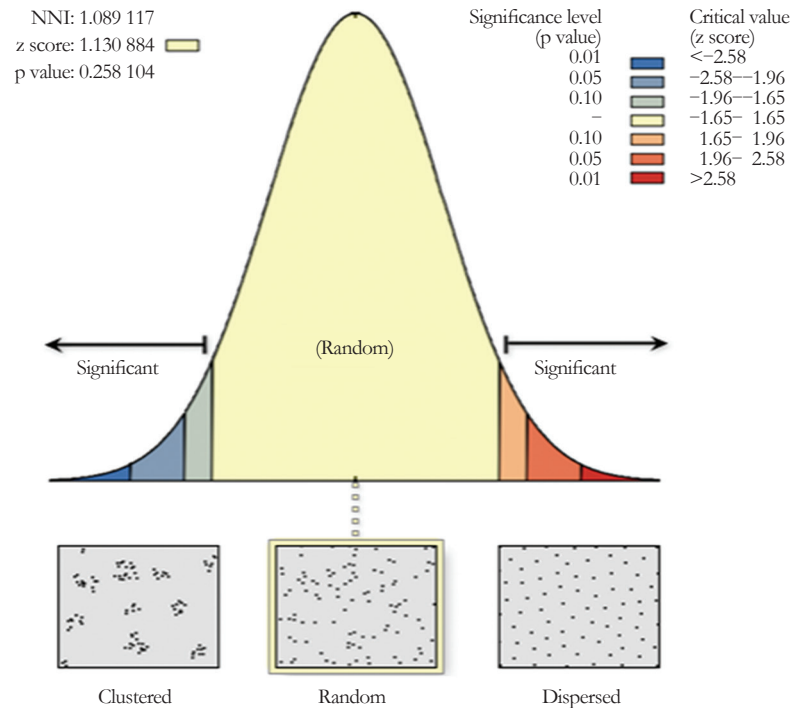
**Fig.1 Distribution of comprehensive parks in the central urban area of Beijing**



**Fig.2 Kernel density analysis of comprehensive parks**

three periods with high pedestrian flow rate on the same day.

In order to explore the impact of COVID-19 on the number of park visitors in Beijing, we obtained the number of newly confirmed COVID-19 cases in the central urban area of Beijing from January 1, 2020 to January 6, 2023 (Fig.5). Taking the liberalization of epidemic policy on December 7, 2022 as an important node, it can be seen that the number of confirmed COVID-19 cases was relatively small before November 15, and the overall visit of comprehensive parks was relatively normal; the number of new confirmed cases increased sharply from November 15 to December 7, reaching a peak around November 27, with an average daily increase of more than 1,000. Through comparison, it was found that the total number of visitors to comprehensive parks also showed a downward trend at this stage, and the number of newly confirmed COVID-19 cases was basically negatively correlated with the number of visitors to comprehensive parks. With the increase in the number of confirmed COVID-19 cases and the release of epidemic prevention and control policies, the demand of residents for going out was relatively limited, and the number of visitors to parks gradually decreased. After December 7, 2022, 10 days after the release of the “New Ten” of COVID-19 epidemic, the number of visitors to comprehensive parks showed a relatively stable upward trend. Around January 1, the number of confirmed COVID-19 cases fluctuated greatly, but the number of visitors to comprehensive parks was still on the rise. Considering that after the implementation of new policy, there was no mandatory requirement for nucleic acid testing, and there was a certain error in the statistics of newly confirmed cases.



The z score is 1.130 883 732 89, and there seems to be no significant difference between this pattern and random pattern.

**Fig.3 Nearest neighbor analysis**

**3.2.2 Change characteristics of working days and rest days.** This paper specifically analyzed the visit characteristics of comprehensive parks on working days and rest days of 9 natural weeks, calculated the average number of visitors on three working days per week, and obtained the change line chart of visits to comprehensive parks in the central urban area of Beijing on working days and rest days (Fig.6). From the perspective of overall change, working days and rest days showed basically consistent fluctuation characteristics, while rest days had

more significant change trend than working days. Visits to comprehensive parks were more affected by COVID-19 epidemic on rest days. Before the liberalization of epidemic policy on December 7, 2022, the number of visitors on working days was mostly higher than that on rest days. Affected by the epidemic policies and the opening of parks and other factors, both showed a downward trend, especially the number of visitors to comprehensive parks on rest days decreased significantly. After the liberalization of epidemic policy, the passenger flow volume

on rest days increased rapidly and formed a large fluctuation, reaching a peak value from December 25 to December 31, which may be due to the increased demand of urban residents for parks after the liberalization of the epidemic. Coupled with the New Year's Day holiday, residents had more leisure time to go to urban comprehensive parks for recreation.

**3.2.3 Change characteristics at different time points of a single day.** The variation of weekly average heat value of comprehensive parks in the central urban area of Beijing at different time points from November 7, 2022 to January 10, 2023 is shown in Fig.7. From the perspective of overall change, the variations of weekly average heat value at 9:00, 15:00 and 18:00 were relatively stable, showing basically consistent fluctuation characteristics. Among them, the overall change had the smallest fluctuation at 9:00, and the largest fluctuation frequency and amplitude at 15:00. Around November 28, 2022, when the number of new COVID-19 cases peaked, the number of park visitors reached the lowest value at 9:00, 15:00 and 18:00. During the New Year's Day holiday from January 1 to 3, 2023 after the liberalization of the epidemic, the number of park visitors peaked at 15:00 and remained stable, while the number of park visitors at 9:00 and 18:00 showed a slight decline and then an increase.

By comparing the change characteristics of average heat of comprehensive parks at the three time points, it was found that with the gradual liberalization of epidemic policy on December 7, 2022, the number of visitors to comprehensive parks at 15:00 gradually evolved to the highest value at the three time points. It might be because since November 2022, the epidemic situation in Beijing had been severe, and most residents were in a state of home isolation or work from home, and they were more inclined to conduct outdoor recreation activities in the evening. After the introduction of new policy

on December 7, 2022, the daily work and life of residents gradually returned to normal, and because Beijing has four distinct seasons and low temperatures in winter, most residents chose to carry out activities in the afternoon with plenty of sunshine.

**3.3 Changes in service hotspots before and after the epidemic**

The spatial distribution of single-day service hotspots and sub-hotspots in comprehensive parks in the central urban area of Beijing before and after the introduction of the latest COVID-19 policy on December 7, 2022 is shown in Figs.8-9. According to the results of standard deviation ellipse, the service hotspots and sub-hotspots tended to be centrally distributed and had centripetal characteristics. From the shape of the ellipse, before the liberalization of Beijing epidemic policy on December 7, 2022, the standard deviation ellipse of service hotspots had a large difference between the long and short axes, indicating that the distribution of service hotspots at this stage had obvious directionality and a high clustering degree, mainly distributed in Dongcheng District and Xicheng District, including Qingnianhu Park, Liuyin Park, Madian Park and other 9 parks. After the liberalization of Beijing epidemic policy on December 7, 2022, the standard deviation ellipse of service hotspots became larger, and the length of long axis increased significantly, indicating that service hotspots increased at this stage, with a total of 14 parks, and gradually spread to Chaoyang District. Before December 7, the standard deviation ellipse of service hotspots had a small difference between the long and short axes, showing a dispersed distribution and a large number, and a total of 14 comprehensive parks such as Beibinhe Park and Shuangxiu Park were service sub-hotspots. After December 7, 2022, the distribution of service hotspots gradually changed from circular to oval, indicating that the directionality was enhanced.

From the direction of the ellipse, before and after the introduction of epidemic policy on December 7, the distribution of service hotspots further spread and changed from the "southwest to northeast" direction, and the service scope became larger. With the liberalization of epidemic policy, the distribution of service sub-hotspots diffused from dispersed distribution to "northwest - southeast" direction.

**3.4 Optimization strategy of urban comprehensive park design**

At different stages of the COVID-19 epidemic, the issues and challenges that the comprehensive park service system needed to address had changed with the adjustment of the policy. During the outbreak of the epidemic, in order to prevent its further spread, some comprehensive parks would be closed, and some comprehensive parks would become places for nucleic acid testing and emergency isolation. At this time, the park had weakened function of recreation and became an important emergency place. In the post-epidemic era, it is necessary to speed up the overall recovery of parks' recreational functions to meet the needs of residents to go out and get in touch with nature. Based on the visit characteristics of comprehensive parks during the COVID-19 epidemic, this paper proposes optimization strategies from service network, park opening time and visits.

**3.4.1 Optimizing the service network of comprehensive parks.** According to the *Urban Green Space Planning Standard* (GB/T 51346-2019), the comprehensive parks with an area  $\geq 50 \text{ hm}^2$  can be used as the reserve space for makeshift hospitals to cope with emergency epidemic situations; for the comprehensive park with an area of 10-50  $\text{hm}^2$ , it can be used as a transfer station for isolated observation and material transportation; and for the comprehensive park with an area less than 10  $\text{hm}^2$ , it is mainly used to meet the needs of urban residents for recreational activities, so as to make full use of comprehensive park service network. In the post-epidemic era, the spatial pattern of comprehensive parks in the central urban area of Beijing should be improved to make comprehensive parks develop from random to clustered distribution. The construction of comprehensive parks can be appropriately increased on the east and west sides, so that residents of different ages in various regions, especially vulnerable groups such as children and the elderly, can carry out recreational activities more conveniently and diversely. In the face of health emergencies, a relatively perfect

**Table 2 Tracking date of heat map data**

No. of week	Date range	Date of working day	Date of rest day
1	November 7-12	November 7, November 9, November 11	November 12
2	November 13-19	November 14, November 16, November 18	November 19
3	November 20-26	November 21, November 23, November 25	November 26
4	November 27- December 3	November 28, November 30, December 2	December 3
5	December 4-10	December 6, December 7, December 8	December 10
6	December 11-17	December 12, December 14, December 16	December 17
7	December 18-24	December 19, December 21, December 23	December 24
8	December 25-31	December 26, December 28, December 30	December 31 (New Year's Day)
9	January 1-7	January 4, January 6	January 1, January 2 (New Year's Day)
Total		26 d	10 d

comprehensive park service network plays an important role in alleviating urban pressure.

**3.4.2 Arranging park opening time reasonably.** According to the analysis of the changes in tourist visit at different time points, the mana-

gement department can open the park in different periods according to the adjustment of epidemic policy. The time points 15:00 and 18:00 are the peaks of crowd visit, and should be treated seriously. In the face of public

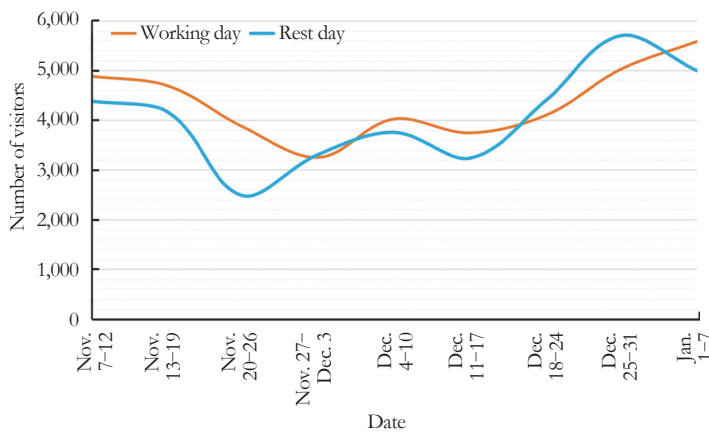
health emergencies, Dongcheng District and Xicheng district, in which comprehensive parks are relatively concentrated at present, should consider the way of park linkage and open as many comprehensive parks as possible



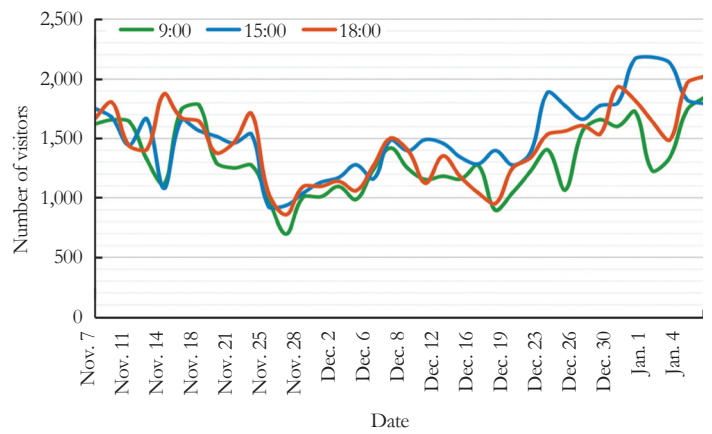
**Fig.4 Overall change line chart of park visits**



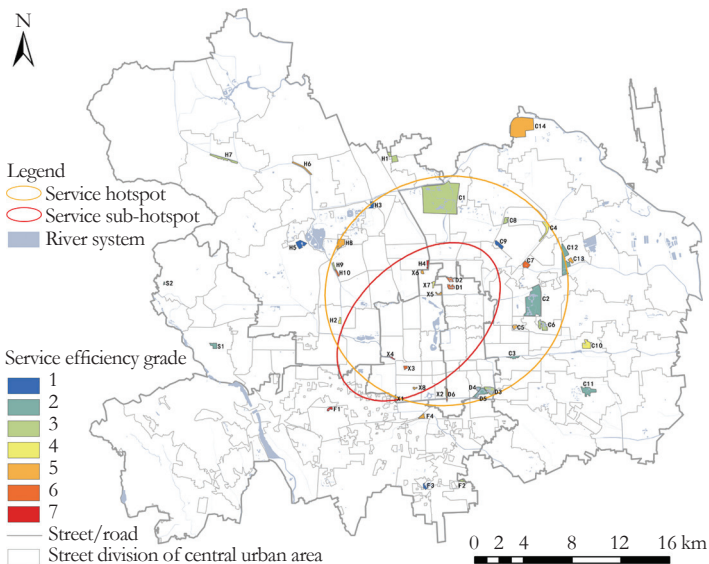
**Fig.5 Number of new COVID-19 cases in the first study phase**



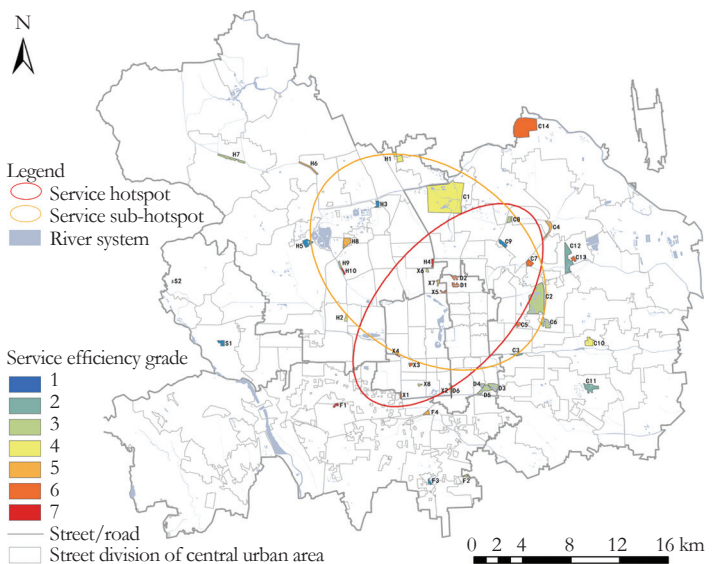
**Fig.6 Change line chart of park visits on working days and rest days**



**Fig.7 Variation chart of average heat at different time points**



**Fig.8 Service hotspot/sub-hotspot space before the liberalization of epidemic policy**



**Fig.9 Service hotspot/sub-hotspot space after the liberalization of epidemic policy**

during visit peak hours through coordination and cooperation among parks; the opening of parks can be staggered at ordinary hours to guide nearby residents to visit the park avoiding the peak hour, so as to avoid the situation of excessive pedestrian volume at a certain moment, and improve the recreation security for visitors and residents. It is also helpful for the staff to carry out disinfection, air purification and other epidemic prevention measures in the park.

**3.4.3** Steadily controlling the number of visitors. In the face of peak flow of people in comprehensive parks during public health emergencies, intelligent means should be actively used to predict and deploy in advance, and do a good job of crowd diversion and drainage. According to the changing characteristics of pedestrian flow rate on working days and rest days before and after the epidemic, it can be found that the flow rate on rest days is significantly affected by the epidemic. For parks with small areas but many visitors, the number of park visitors should be monitored and the law should be summarized to make plans in advance, which is conducive to alleviating the problem of large flow of people visiting comprehensive parks. This method also needs to release park opening and closing information and current limiting information in advance, open the appointment system, and guide tourists and residents to make reasonable travel planning by making full use of public accounts and network services. At the same time, the park can also conduct overall control and timely response to the visit situation.

## 4 Conclusions

By constructing a comprehensive park database in the central urban area of Beijing and extracting heat map data during the epidemic period and before and after the liberalization of epidemic policy, we analyzed the distribution characteristics of comprehensive parks, the change characteristics of visits to comprehensive parks before and after the liberalization of epidemic policy, and the change characteristics of service hotspots before and after the epidemic, and put forward the optimization strategy for comprehensive parks to cope with the epidemic

and gradually restore the recreation service function in the post-epidemic era.

(1) The comprehensive parks in Beijing were in random spatial distribution. Chaoyang District had the largest number of comprehensive parks, but with scattered distribution. Dongcheng District and Xicheng district had concentrated distribution of comprehensive parks, while the western and eastern parts of the central urban area lacked comprehensive parks, and the recreation service network needed to be improved.

(2) Before the liberalization of epidemic policy, the number of newly confirmed COVID-19 cases was basically negatively correlated with the number of visitors to comprehensive parks, and the total number of visitors to comprehensive parks was declined due to the epidemic. After the liberalization of epidemic policy, the number of park visitors fluctuated and showed an overall upward trend, with the largest number of visitors at 15:00; rest days were particularly affected by COVID-19.

(3) After the liberalization of epidemic policy, the number of service hotspots of comprehensive parks in the central urban area of Beijing increased in a larger scope, and the directionality of “southwest–northeast” was still obvious; the service sub-hotspots spread from dispersed distribution to “northwest–southeast” direction; Qingnianhu Park, Liuyin Park, Madian Park, Changchun Fitness Park, Fengtai Garden, Baiyun Park, Xuanwu Park, Side Park, Yongdingmen Park (Dongcheng) were the main service hotspots, while Rendinghu Park, Wanfangting Park, Wanshou Park, Linglong Park, Haidian Park, Baiwang Park, Dawangjing Park and Xinglong Park were the main service sub-hotspots.

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