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Travel changes and equitable access to urban parks in the post COVID-19 pandemic period: Evidence from Wuhan, China

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**A R T I C L E   I N F O**

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**A B S T R A C T**

COVID-19 has spread worldwide, leading to a significant impact on daily life. Numerous studies have confirmed that people have changed their travel to urban green spaces during the COVID-19 pandemic. However, in China, where COVID-19 has been effectively controlled, how the travel behavior of visitors to urban parks has changed under different risk levels (RLs) of COVID-19 is unclear. Faced with these gaps, we took a highly developed city, Wuhan, as a case study and a questionnaire survey was conducted with 3276 respondents to analyze the changes in park visitors’ travel behaviors under different COVID-19 RLs. Using a stated preference (SP) survey method, four RLs were assigned: new cases in other provinces (RL1), Hubei province (RL2), Wuhan (RL3), and in the district of the park (RL4). The results indicated that visitors reduced their willingness to visit urban parks, with 78.39%, 37.97%, and 13.34% of visitors remaining under RL2, RL3, and RL4, respectively. Furthermore, the service radius of urban parks also shrunk from 4230 m under no new cases of COVID-19 to approximately 3000 m under RL3. A higher impact was found for visitors using public transport, those with a higher income and higher education, and female visitors. Based on the modified travel behaviors, the Gaussian-based two-step floating catchment area (2SFCA) method was used to evaluate the accessibility and the Gini coefficient was calculated to represent the equality of the urban parks. A higher RL led to lower accessibility and greater inequitable access. The results should help the government guide residents’ travel behaviors after COVID-19.

1. Introduction

Since the novel coronavirus disease (COVID-19) was first identified in December 2019 in Wuhan, China, the entire world has been adversely affected by the ensuing pandemic (Huang et al., 2021). According to the World Health Organization’s (WHO) COVID-19 dashboard (https://covid19.who.int/), there have been 236,599,025 confirmed cases of COVID-19, including 4,831,486 deaths globally as of 6:49pm CEST, 8 October 2021. Owing to its large scale and scope, COVID-19 has profoundly changed our lives, society and living environment (Elsaid et al., 2021; Mostafa et al., 2021). One important change is residents’ mobility, which is impacted by the worry of infection when traveling as well as the travel restrictions proposed by the government, such as social distancing, encouragement to stay home, and self-isolation during the outbreak of the pandemic (Cheng et al., 2021).

Among all mobility changes, changes in travel to urban green spaces caused by COVID-19 are a concern for the government and public because urban green spaces benefit residents’ mental and physical health Berdejo-Espinola et al. (2021); Grima et al. (2020); Russette et al. (2021); Ugolini et al. (2020). Many studies have confirmed that people have tended to increase their visits to urban green spaces during the pandemic under relaxed movement restrictions. Visitations to national parks increased in large cities in Asia during the pandemic (Hong Kong, Singapore, Seoul, and Tokyo) (Lu et al., 2021) and Italy have increased their demand for and usage of small local urban green spaces (Kleinschroth and Kowarik, 2020; Ugolini et al., 2020). Similar conclusions have been proposed by other studies that the pandemic has increased the frequency of visiting urban green spaces and addressed the importance

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of such spaces around their homes (Venter et al., 2020, 2021; Cheng et al., 2021). Meanwhile, some studies have clarified that the restrictions proposed by local governments vary residents’ visit behavior to urban green spaces. Restrictions on social gatherings, movement, and the closure of workplaces and indoor leisure facilities are correlated with more visits to parks. Strict movement restrictions such as stay-at-home orders are negatively associated with park visits globally (Geng et al., 2021). A national study of UK adults suggested that 63% of people have decreased the time spent visiting green spaces following movement restrictions (Burnett et al., 2021) and this finding was consistent with Natural England’s report (Natural England, 2020). A study carried out in Italian cities during the period of national lockdown in the spring of 2021 found that only one third of respondents reported visiting urban green space (UGS) (Ugolini et al., 2021). Also, a study using weekly panel data for 620 U.S. countries, showed that park visits decreased by 10% beginning March 15, and by 17–35% through May 9, 2020 (Curtis et al., 2020).

Moreover, some studies have found that in regions with strict movement restrictions, even though actual visits to urban green spaces have decreased, residents’ demand for visiting such spaces increased. During the COVID-19 pandemic in Italy (Larcher et al., 2021), when public green spaces were closed and people were forced to stay at home, the importance of having outdoor spaces increased and a rise in interest in urban green spaces was observed.

Existing studies have discussed changes in travel behaviors to urban green spaces from a holistic perspective, finding that the pandemic has increased people’s demand for and visits to urban green spaces when the local government has proposed relaxed restrictions, while strict restrictions have lowered visits to urban green spaces. These conclusions are meaningful for the government to formulate policies to control residents’ travel behaviors during the pandemic. However, few studies have focused on changes in travel behavior in the post-COVID-19 pandemic period when the scale and scope of COVID-19 has been relieved compared with the pandemic period. According to WHO’s weekly epidemiological update on COVID-19 (released on 5 October 2021, https://www.who.int/publications/m/item/weekly-epidemiological-update-on-covid-19—5-october-2021), the number of weekly COVID-19 cases and deaths continued to decline globally, with over 3.1 million new cases and just over 54,000 new deaths during the week of 27 September to 3 October 2021. Reported cases in the week decreased by 9% as compared to the previous week. In China, COVID-19 has been effectively controlled by the government. New daily cases of COVID-19 have reduced from the hundreds and thousands in January and February 2020 in Wuhan to zero for a long time (Wuhan Municipal Health Commission, http://wjw.wuhan.gov.cn/ztzl/28/fk/yqtb/202004/120200430_1198710.shtml). Since new COVID-19 cases occur on a small scale, residents in most areas of China have been living in a normal life. The government does not restrict residents’ travel in cities without new cases, but encourages them to wear a mask and avoid traveling to places with a high risk of COVID-19. In this study, we define current period in China, to examine the travel behavior changes in the post-COVID-19 pandemic period. Urban parks are different from other green spaces. Even if urban parks maintain functions of ecology, landscape, culture and education, the recreation is the main function of urban parks. While for national parks and protected areas, ecological function may be more important than that of urban parks. Meanwhile, according to the classification proposed by Ministry of Housing and Urban-Rural Construction of the People’s Republic of China, urban parks are located in urban areas, while these green spaces including national parks and protected areas are usually located outside urban areas. In this study, a questionnaire survey and analysis was carried out for urban parks in Wuhan, China, to examine the travel behavior changes in the post-COVID-19 pandemic period. A stated preference (SP) survey method was used by assuming four RLs of being infected by COVID-19 in the post-pandemic period. RLs were assumed to be associated with the distance from new cases of COVID-19 based on the theory of psychological distance, which considers that the RL felt by a person is associated with psychological distance, including the spatial distance, time distance, and hypothetical distance (Liberman and Trope, 2014). Four RLs were proposed according to the spatial distance: new cases occurred in other provinces (RL1), new cases occurred in Wuhan (RL2), new cases occurred in Wuhan city (RL3), and new cases occurred in the districts in which the urban park is located (RL4). The time distance and hypothetical distance were assumed to be related to the spatial distance because of the rapid speed of information dissemination and few new cases in the post-COVID-19 pandemic period. Based on this assumption, travel preferences under RLs were surveyed for 3276 urban park visitors in Wuhan during March and June 2021. The modifications of their travel behaviors during the post-COVID-19 period remains unclear. And under the different risk levels (RLs) of infection, how have residents changed their travel behaviors to urban green spaces?

Existing studies have been conducted for the periods before or after the pandemic period. In this study, we define current period as the post-COVID-19 pandemic period. The risk of COVID-19 infection is consequently classified as no risk or absolute risk. However, in China, with dispersed new cases, it is hard to define it as a pandemic period with absolute risk or a period with no risk. In the post-COVID-19 pandemic period, it is necessary to clarify the RLs of COVID-19 that residents have felt and, consequently, examine how their travel behavior has changed. These changes would ultimately change human well-being and quality of life as well as the objectives of urban planning for sustainable cities.

The use of geotagged big data makes it possible to trace people’s travel behaviors and locations. Most studies of how visits to urban green spaces have changed have been conducted based on big data such as Instagram posts (Lu et al., 2021), posts on the Sina microblog (Chinese Twitter) (Cheng et al., 2021; Zhu and Xu, 2021), Google’s Community Mobility Reports, and the Oxford Coronavirus Government Response Tracker (Geng et al., 2021). The data need to be collected during the pandemic and before or after the pandemic to reflect changes in people’s travel behavior during the pandemic. In the post-COVID-19 period, it is difficult to find and define periods with different RLs of COVID-19 and then compare the changes in travel behaviors during these periods.

In this context, it is necessary to examine travel behavior changes in the post-COVID-19 pandemic period, including travel preference and travel threshold to urban green spaces. According to standard for planning of urban green space (Ministry of Housing and Urban-Rural Construction of the People’s Republic of China, 2019) and the standard for classification of urban green space (Ministry of Housing and Urban-Rural Construction of the People’s Republic of China, 2017) in China, urban parks are defined as an important type of UGS located in urban area that open to the public with certain recreation and service facilities. Urban parks are different from other green spaces, such as national parks, protected areas. Referring to International Union for Conservation of Nature (IUCN)’s categories (Dudley, 2008), national parks and protected areas usually maintain lager size than those of urban parks. Additionally, the functions are different between urban parks and other green spaces. Even if urban parks maintain functions of ecology, landscape, culture and education, the recreation is the main function of urban parks. While for national parks and protected areas, which also maintain recreation functions, such as ecotourism (Buckley, 1994; Lindberg and McKercher, 1997), ecological function may be more important than that of urban parks. Meanwhile, according to the classification proposed by Ministry of Housing and Urban-Rural Construction of the People’s Republic of China, urban parks are located in urban areas, while these green spaces including national parks and protected areas are usually located outside urban areas. In this study, a questionnaire survey and analysis was carried out for urban parks in Wuhan, China, to examine the travel behavior changes in the post-COVID-19 pandemic period. A stated preference (SP) survey method was used by assuming four RLs of being infected by COVID-19 in the post-pandemic period. RLs were assumed to be associated with the distance from new cases of COVID-19 based on the theory of psychological distance, which considers that the RL felt by a person is associated with psychological distance, including the spatial distance, time distance, and hypothetical distance (Liberman and Trope, 2014). Four RLs were proposed according to the spatial distance: new cases occurred in other provinces (RL1), new cases occurred in Wuhan (RL2), new cases occurred in Wuhan city (RL3), and new cases occurred in the districts in which the urban park is located (RL4).
2. Description of study area

Wuhan is the capital of Hubei province (113°41'E–115°05'E, 29°58'–31°22'N) and the largest mega-city in central China (Cheng and Masser, 2003) covering approximately 8569 km² (Wuhan Municipal Statistics Bureau, 2020) (Fig. 1 (a)). Wuhan is a highly developed city with a registered population of 90.64 million in 2019; GDP reached 1.62 trillion yuan (~251604.55 million U.S. dollar) in that year (Wuhan Municipal Statistics Bureau, 2020). According to Wuhan Municipal Statistics Bureau’s report, the life expectancy in Wuhan is 80.57 years (http://tjj.wuhan.gov.cn/tjfw/tjgb/202104/t20210425_1675623.shtml) and over 33% of the permanent resident population has achieved a higher education (http://tjj.wuhan.gov.cn/tjfw/tjgb/202105/t20210528_1707420.shtml). With such a dense population, highly economic and human development, public and local governments have paid much attention to public facilities to improve residents’ quality of life. According to the 14th Five-Year Plan of Wuhan proposed by the Wuhan Municipal Development and Reform Commission (http://fgw.wuhan.gov.cn/xwzx/tpxw/202104/t20210430_1679318.html), building convenient and accessible public facilities is crucial to improving residents’ feeling of happiness.

Meanwhile, Wuhan city suffered from COVID-19 and lockdown from January 23, 2020 to April 8, 2020, with 50,008 cases in that time (data sourced from the Wuhan Municipal Health Commission, http://wjw.wuhan.gov.cn/ztzl_28/fk/yqtb/202004/t20200430_1197428.shtml). In this context, it is sensible to take urban parks in Wuhan as a case study to clarify the extent to which residents acted differently during the post-COVID-19 pandemic period when visiting urban parks with a lower RL of COVID-19 than that during the pandemic.

According to the List of Built Open Urban Parks in Wuhan City released by the Wuhan Municipal Bureau of Landscape and Forestry (updated December 2018) (http://ylj.wuhan.gov.cn/xwdt/tzgg/202004/20200406_989805.shtml), there are 81 urban parks in Wuhan, 79 of which are free; 54 of these free urban parks are located in our study area (see Fig. 1 (b)). This study was limited to urban parks in the central area of Wuhan, including Qiaokou, Jianghan, Jiang’an, Hanyang, Wuchang, Hongshan, Qingshan, and Jiangxia districts (see the marked places in Fig. 1(a)) because the population of urban residents is concentrated in central Wuhan. Second, parks in central Wuhan usually play a similar role for visitors and their surrounding built environment is also similar. Fig. 1 (a) and (b) depict the location of our study area along with the distribution of parks within it, and Fig. 1 (c) presents the spatial distribution of the surveyed visitors.

3. Methods

3.1. Questionnaire design

A questionnaire survey was conducted in 21 urban parks out of 54 free urban parks released by Wuhan Municipal Bureau of Landscape and Forestry on the weekends and holidays during the period of March and June 2021 (Table 1). The survey conducted on the days without rainfall, to reduce the impact of weather on respondent’s selection. These 21 urban parks were randomly selected by considering their sizes and...

![Fig. 1. Map of spatial distribution of (a) the sampled parks and all urban parks in Wuhan city, (b) the sampled parks and urban parks in our study area, and (c) the surveyed visitors.](image-url)
locations.

To analyze changes of travel behavior for urban park visitors in post-COVID-19 pandemic period, a stated preference survey method were used. SP surveys are used to measure individuals’ preferences toward hypothetical scenarios (Adamowicz et al., 1994; Mahmoud et al., 2015). SP surveys are increasingly used in different fields such as transport (Yamada and Thill, 2003), health (Lim et al., 2020), and environmental issues (Cherchi and Hensher, 2015; Schwappach and Strassman, 2006) due to its capability to assess preferences (Louvierie et al., 2008).

In our study, the SP survey was conducted by asking visitors which RLs of COVID-19 would change their visiting behaviors, if at all. They chose from four hypothetical RLs: new cases of COVID-19 being found in provinces rather than Hubei province (RL1), new cases of COVID-19 being found in Hubei province but not in Wuhan (RL2), new cases of COVID-19 being found in Wuhan but not in the district in which the surveyed park is located (RL3), and new cases of COVID-19 being found in the district in which the surveyed park is located (RL4). RL0 was also proposed to indicate no new cases of COVID-19 domestically.

During the survey, research assistants asked park visitors (aged >14 years) to answer questionnaires. In total, 3387 questionnaires were submitted. Following analyses were conducted based on the data collected from these 3376 questionnaires.

3.2. Evaluating travel behavior changes under COVID-19 RLs

To evaluate the travel behavior changes when visitors visit urban parks under the different RLs of COVID-19 infection, two indices were used. The first is the travel behavior modification (TBM) index:

\[ \text{TBM}_{\text{risklevel}} = \frac{N_{\text{risklevel}}}{N} \]  

where \( \text{TBM}_{\text{risklevel}} \) is the TBM index at a specific RL of COVID-19. \( N_{\text{risklevel}} \) is the number of respondents who prefer to maintain their visits to parks under the RL and \( N \) is the number of all respondents. \( \text{TBM}_{\text{risklevel}} \) ranges from 0 to 1, and a higher value suggests a lower modification of travel behaviors during the specific RL of COVID-19.

Meanwhile, the threshold travel distance (TTD) under the different RLs of COVID-19 was calculated as the second index to reflect travel behavior changes. TTD is a widely used index to reflect the service radius for facilities such as urban parks and health care facilities. The TTD can be calculated as the third quartile of the travel distance for all visitors (Xie et al., 2018; Guo et al., 2019; Lin et al., 2021). In this study, the TTD under the different RLs, \( \text{TTD}_{\text{risklevel}} \), was extracted from visitors to urban parks to reflect the modification of their travel behaviors. \( \text{TTD}_{\text{risklevel}} \) in this study is defined as the third quartile of the travel distance under the RL for respondents who still prefer to visit parks, but not all the respondents. In addition, the TTD here can be considered as the service radius of urban parks.

To calculate TTD, the travel distances for all respondents are required. The travel distance of all the respondents from their homes to the park they visited was calculated based on the road network and their travel mode. First, the coordinates of the respondent’s home and nearest park entrance were extracted from http://api.map.baidu.com/lbsapi/getpoint/index.html. Then, the minimum travel distance from the respondent’s home and nearest park entrance was calculated for each respondent using Baidu Maps. Moreover, we also calculated the spatial distribution of the travel distances to all the parks to calculate accessibility. The study area was divided into grids with a 3 arc (approximately 100 m) resolution. For one park, the coordinates for each grid were extracted to calculate the minimum travel distance from the center of the grid to the nearest park entrance. The calculated travel distance was assigned to a specific grid, which was presented as the spatial distribution of the travel distance to one park.

Additionally, to find out whether built environment and characteristics of parks are associated with travel behavior to urban parks, the Pearson correlation between the TBMs and factors, as well as between the TTDs and factors for the 21 sampled urban parks were calculated. Fifteen factors were selected, including park size, park capacity, population density with in a 2 km buffer, population density within a 5 km buffer, density of public stations within a 2 km buffer, density of public stations within a 5 km buffer, density of shops within a 2 km buffer, density of shops within a 5 km buffer, density of restaurants within a 2 km buffer, density of workplaces within a 2 km buffer, density of workplaces within a 5 km buffer, density of toilets in the park, density of restaurants in the park, and density of shops in the park.

Specifically, park size and park capacity were sourced from Wuhan Municipal Bureau of Landscape and Forestry. Population density was calculated based on the spatial distribution of population. The spatial distribution of the population in our case study area was downloaded from WorldPop (www.worldpop.org) at a 3 arc resolution, as shown in Fig. 2 (b). The other densities were calculated based on the points of interest (POIs), which were retrieved from Amap (https://www.amap.com/) in June and July 2021 for our study area. The spatial distribution of the POIs density in our study is presented in Fig. 2 (a).

3.3. Assessment of urban park accessibility under the different RLs of COVID-19

In this study, the Gaussian-based two-step floating catchment area (2SFCA) method was used to evaluate the accessibility of urban parks by referring to existing studies (Guo et al., 2019). The 2SFCA method has been extensively employed to compute the park accessibility (Xiao et al., 2019; Lin et al., 2021) and has been proved to achieved better outcomes (Polzin et al., 2014) and capture the complexities of real world (Chen and Jia, 2019). In 2SFCA method, numerous different forms of the distance decay can be used, such as the negative linear function (Schuurman et al., 2010), the Gaussian function (Wan et al., 2012), the exponential function (Jamtsho et al., 2015), the inverse power function (Schuurman et al., 2010), and the kernel density function (Dai and Wang, 2011). Among all these decay function, Gaussian function is the most popular one and Silverman (1986) argued that the different functional forms for determining distance decay weight will not significantly impact the spatial pattern of the estimates. Therefore, in our case, Gaussian decay function was used in the 2SFCA method.

An area with a higher value of accessibility indicates a higher potential for reaching spatially distributed facilities (Wang and Mu, 2018). In our case, this indicates a higher potential to reach spatially distributed urban parks. To calculate accessibility, first, for each park j, we searched all the population locations (k), within a threshold distance (d_k) from park j, which formulated as the catchment area or service radius for park j. Populations at k were weighted by a Gaussian function (G). The sum of the weighted populations was regarded as the potential demand of park j. Therefore, the park-to-population ratio, \( R_j \), was computed as

\[ R_j = \frac{\sum_{k \in \text{Pois}} S_k G(d_k, d_j) P_k}{\sum_{k \in \text{Pois}} P_k} \]  

where \( P_k \) is the population at location k whose centroid is within the threshold distance \( d_k \) to park j; \( d_j \) is the travel time between the centroid of location k and nearest entrance of park j; \( S_k \) is the size of the j-th park, in km²; and G is the friction-of-distance function and in this study it is a Gaussian function. The population at location k was extracted from spatial population dataset downloaded from WorldPop (www.worldpop.org). 

\( d_k \) in Eq. (2) is the most important coefficient to calculate
accessibility. However, there is no consensus on how to determine $d_o$. According to the American Society of Planning Officials, the service radius of a neighborhood park should be 0.5 miles (i.e., about 805 m). Khaza et al. (2020) assigned 500 and 1000 m buffer distances to calculate the service radius of the parks in Khulna city. Vilcea and Sosea (2020) considered 700 m as the average distance that a person would be willing to walk to the nearest park. In studies in Chinese cities, Lin et al. (2017) determined 2 km as the distance threshold of each park in Fuzhou, while Shen et al. (2017) set a 1.2 km buffer distance covering approximately 97% of all the residents in the study area as the service radius for parks in central Shanghai. In the study by Fan et al. (2017), the authors designated the $d_o$ as 300 m for green spaces between 0.02 and 0.20 km$^2$, 2 km for green spaces of 0.20–1.00 km$^2$, and 5 km for green spaces of greater than 1.00 km$^2$.

In this context, we calculated the third quartile of the travel distance for all the respondents for the 21 urban parks following existing studies as well as the standard for planning of urban green space (Ministry of Housing and Urban-Rural Construction of the People’s Republic of China, 2019), and then assigned the service radius for urban parks in Wuhan according to their size (see Table 2). The service radius is considered to be $d_o$ in this study and is used in Eq. (2) to calculate $R_l$.

In addition, for the different COVID-19 RLs, the service radius, $d_{o\text{-RLlevel}}$, differs. $d_{o\text{-RLlevel}}$ was determined according to our surveyed data to reflect the service radius changes during COVID-19:

$$d_{o\text{-RLlevel}} = d_o + \frac{TTD_{RLlevel}}{TTD} \times (d_o - 300)$$ (3)

The TTD that services three-quarters of all visitors was calculated first. Similarly, the travel distance under the different COVID-19 RLs was calculated as $TTD_{RLlevel}$. Finally, the ratio between $TTD_{RLlevel}$ and TTD was defined, which, along with the service radius in Table 2, was used to define the service radius under the different COVID-19 RLs.

Second, for each population location $i$, we searched all parks $l$ within the threshold distance $d_o$ to location $i$, to form the catchment area for $i$. Using the same $G$ as in Eq. (2) to weight and sum the $R_l$ within catchment area $i$, park accessibility at location $i$ ($A_i$) can be measured as follows:

$$A_i = \sum_{l \in [d_o, d_o]} [G(d_o, d_o) \times R_l]$$ (4)

where $l$ indicates the parks within the threshold distance $d_o$ of population location $i$. Here, $A_i$ represents the availability of the park (size of parks in km$^2$/population in number of 100,000 people) for each population location $i$. The study area was divided into 3 arc grid units, as in the population dataset. Then, $PR_{o\text{-RLlevel}}$ was added into Eq. (4) to reflect the preference of visitors to urban parks under the different COVID-19 RLs as follows:

$$A_{i\text{-RLlevel}} = \sum_{l \in [d_o, d_o]} [G(d_o, d_o) \times R_l \times TBM_{RLlevel}]$$ (5)

The value of $TBM_{RLlevel}$ denotes the probability of visitors going to urban parks, which ranges from 0 to 1, where 1 indicates that the probability of visitors going to urban parks is the same as that under no COVID-19 RL and 0 indicates that no visitor wants to visit urban parks under this COVID-19 RL. $TBM_{RLlevel}$ can be calculated using Eq. (1).

### 3.4. Measurement of equitable access to urban parks under the COVID-19 RLs

The Gini coefficient (Bendel et al., 1989) is a single, simple mathematical metric that represents the overall degree of inequality (Zhang et al., 2020) which was first used to measuring income disparities (Dorfman, 1979; Hahn-Holbrook et al., 2018a,b), and recently has been commonly used to detect inequality in accessibility to urban green spaces (Wang et al., 2019; Wu and Kim, 2020). The Gini coefficient for accessibility can be calculated by Eq. (6).

$$G = \frac{1}{2n^2} \sum_{j=1}^{n} \sum_{i=1}^{n} |A_i - A_j|$$ (6)

where $G$ is the Gini coefficient of accessibility for the entire study area, $n$ is the sample size (in our case, $n$ is the grid with the population in the case study area), $u$ is the average accessibility in the study area, and $A_i$ and $A_j$ are accessibility at location $i$ and location $j$, respectively. The Gini coefficients of accessibility for districts and the entire case study were calculated. These ranged from 0 to 1, where 0 indicates perfect equality and 1 indicates perfect inequality (Wagstaff et al., 1991; Wustemann et al., 2017).

### Table 2

| Size (km$^2$) | Service radius (m) |
|--------------|--------------------|
| ≤ 0.20       | 1600               |
| 0.20 ~ 0.50  | 3000               |
| ≥ 0.50       | 5000               |
4. Results

4.1. Travel behavior changes

According to our survey, the risk of COVID-19 reduced visitors’ willingness to visit an urban park. Among the 3276 respondents, under RL1, 108 visitors (3.30%) would not visit a park, with a TBM index of 96.70%. When the risk increased to RL2, an additional 600 visitors would not visit a park, and 2568 respondents remained. Similarly, as the COVID-19 RLs increased to RL3 and RL4, the TBM index decreased to only 37.97% (1244 respondents) and 13.34% (437 respondents), respectively (see Fig. 3). The kernel densities of remaining visitors under the different RLs of COVID-19 are presented in Fig. 3, which represents the density of point features around each output raster cell by using quadratic kernel function described in Silverman (1986) and Duong (2007)’s study. Clearly, the risk of COVID-19 reduced visitors’ willingness to visit urban parks with a lower space density. The results show the huge impact of COVID-19 on visitors’ travel willingness in RL3 and RL4.

Meanwhile, the TTD for visitors to visit a park was 4230 m when there were no cases of COVID-19 nationally. As the RLs of COVID-19 increased, travel distance shrank to 3875 m under RL2. Additionally, when the RL increased to RL3, travel distance decreased to 3028 m. This suggests that the risk of COVID-19 clearly reduces the TTD when residents visit an urban park. However, the TTD at RL4 was 3284 m, higher than that (3028 m) at RL3. This is probably because the visitors willing to visit an urban park under RL4 are less worried and a relatively high travel distance is acceptable. The TTDs under the five COVID-19 RLs are listed in Fig. 3 along with the number of respondents.

The visitors were grouped by age to examine their different travel behaviors (see Table 3). Among the 3276 respondents, 466 visitors were aged 60 or above and 2810 were aged 14–59 years. As Table 3 shows, elderly visitors were less worried than the other visitors, with 22.39% of elderly visitors remaining at RL4. However, only 11.67% of the other visitors remained under RL4.

In addition, the impacts of the COVID-19 RLs on the TTDs of elderly and other visitors were compared (see Table 3). First, it was found that the elderly preferred shorter TTDs than the other visitors under any RL. It is probably due to their physical limitations, and most of elderly visit urban parks by walking which also leads to a shorter travel distance. This is consistent with existing studies showing that elderly visitors have shorter TTDs than other visitors (Xie et al., 2018; Guo et al., 2019).

Second, a decreasing trend was found from RL0 to RL3, from 1907 m to 1492 m for elderly visitors and from 4773 m to 3419 m for the other visitors. On the contrary, the TTDs in RL4 were higher than those in RL3, which did not reduce along with the RLs of COVID-19.

Visitors with different travel modes also responded differently under the RLs of COVID-19 (see Table 4). Among the 3276 surveyed visitors, over 50% walked to parks, while about 20% drove or took a taxi. About 10% and 15% of visitors visited parks by cycling and public transport, respectively. The results show that the risk of COVID-19 reduced the
number of visitors to urban parks using public transport to a large degree. Under RL4 and RL3, the TBM indices were 11.65% and 30.31%, respectively. This means that fewer visitors remained if they visited a park using public transport. On the contrary, the risk of COVID-19 had a minor impact on visitors who visited parks by cycling, with TBM indices of 17.69% and 39.95% under RL4 and RL3, respectively. The results are reasonable and make sense. The process of traveling by public transport would increase the risk of infection of COVID-19, as visitors come into contact with a large number of people. Traveling to parks by cycling suffers a low risk of coming into contact with a large number of people.

On the contrary, the TTDs for these travel modes differed under the RLs of COVID-19. The TTD for driving cars was over 10 km, while for walking, it was only about 1 km with no COVID-19 risk. With COVID-19 risk, the decline was the most obvious for visitors taking public transport. The TTDs dropped from approximately 1.6 km–1.4 km from RL0 to RL3 for visitors taking public transport. While the TTDs for cycling and driving cars almost did not change from RL0 to RL3.

There were 3275 respondents provided their gender information, and they were grouped by sex: 1275 respondents were men and 2000 respondents were women (see Table 5). The performance of male and female visitors was different under the different RLs of COVID-19. Female visitors were more conservative and cancelled their travel to urban parks. As Table 5 shows, only 35.30% of female visitors remained under RL3, while 42.12% of male visitors remained. Similar conditions were observed for RL4, RL2, and RL1.

Meanwhile, the TTDs changed differently between men and women. As Table 5 shows, men experienced about 400 m longer TTD than women when visiting urban parks under no COVID-19 risk. From RL0 to RL3, the TTDs for men dropped from about 4.5 km to about 3.8 km and the TTDs for women dropped from about 4.1 km to about 2.9 km.

Out of the 3276 respondents, only 1414 provided their income. We analyzed these 1414 respondents to clarify the relationship between travel behavior changes and income. The 1414 respondents were classified into four groups according to their monthly income: 200–3000 (31.02 U.S. dollar–465.27 U.S. dollar), 3000–6000 (465.27 U.S. dollar–930.54 U.S. dollar), 6000–10000 (930.54 U.S. dollar–1550.89 U.S. dollar), and > 10,000 yuan (1550.89 U.S. dollar). The number of respondents in each group was 193, 630, 476, and 142, respectively. As shown in Table 6, visitors with higher income changed their travel behavior under COVID-19 much more than visitors with lower income. Only 9.15% of visitors with a monthly income larger than 10,000 yuan remained under RL4, and the value was higher for the other three income groups. Similar conditions were observed for the other RLs of COVID-19.

The TTDs were longer for visitors with the highest monthly income (larger than 10,000 yuan or 1550.89 U.S. dollar), which was about 6 km, while the TTDs for the other visitors were only about 3.2–3.7 km. Under the COVID-19 RLs, visitors with the highest income drastically reduced their TTDs to no more than 2 km from RL0 to RL4. Visitors with a moderate income reduced their TTDs from about 3.6 km to about 2.3 km from RL0 to RL4. While COVID-19 had less impact on visitors with a low income, with their TTDs did not reduce obviously.

In total, 3239 respondents provided their education levels. We analyzed these 3239 respondents to clarify how visitors with different education levels modify their travel behaviors under the RLs of COVID-19 (see Table 7). Similar to the results grouped by income, visitors with higher education levels canceled their travel to urban parks more often than the other visitors. Only 8.99% of visitors with postgraduate and above education remained under RL4, while the TBM index was up to 21.21% and 16.92% for visitors with a junior and senior education, respectively.

Meanwhile, visitors with the highest education level tended to experience longer TTDs under RL0, also similar to the result that visitors with a higher income experienced longer TTDs than the other visitors. The risk of COVID-19 had a huge impact on their behaviors, with TTDs dropping from 5.6 km to 1.9 km from RL0 to RL4. A reduction in TTDs was also found for visitors with an undergraduate education level, from about 5.3 km to 3.8 km. However, no obvious drop in TTDs was found for visitors with a low education level as the risk of COVID-19 increased.

In sum, the risk of COVID-19 impacts visitors’ travel behavior by reducing their willingness to visit urban parks and shrinking the service radius urban parks. Huge impacts were found for elderly visitors, visitors using public transport, visitors with a higher income and higher education, and female visitors.

The travel behaviors of visitors changed under the different COVID-19 RLs, while the facilities surrounding and in parks and characteristics of parks were also associated with this change. Therefore, 15 factors were selected to reflect the built environment, facilities surrounding parks, and characteristics of parks. The Pearson correlation between the TBM indices and selected factors as well as between the TTDs and selected factors for the 21 sampled urban parks were then calculated (see Table 8).

The TBM index was negatively correlated with the density of public stations (X5), shops (X7), restaurants (X9), and workplaces (X11 and X12). This suggests that parks with convenient public transport and located in places with flourishing commerce experience a lower TBM index, which means that they suffer a higher impact of COVID-19 and that visits to these parks reduce much more than those to other parks. This is probably because these parks usually maintain a large service radius and service population. Visitors feel a high density in the parks and higher risk when visiting (usually with long travel distances), meaning that respondents preferred to visit near urban parks in their neighborhood under the post-COVID-19 period. On the contrary, parks with larger shops (X7) and restaurants (X9) experience higher TTDs under the risk of COVID-19.

| Table 4 |
| Changes in travel behaviors for visitors under the different travel modes under the different COVID-19 RLs. |

| Scenarios | Walking |  | Cycling |  | Bus and subway |  | Car |  |
|-----------|---------|-----|---------|-----|----------------|-----|-----|-----|
|           | TTD (m) | N/TBM(%) | TTD (m) | N/TBM(%) | TTD (m) | N/TBM(%) | TTD (m) | N/TBM(%) |
| RL4       | 1115    | 242/13.96 | 3624    | 66/17.69 | 15,992   | 63/11.65 | 12,276   | 66/10.51 |
| RL3       | 1115    | 736/42.56 | 2796    | 149/39.95 | 14,226   | 164/30.31 | 10,643   | 193/30.73 |
| RL2       | 1129    | 1393/80.33 | 2720    | 282/75.60 | 15,317   | 399/73.75 | 10,597   | 494/78.66 |
| RL1       | 1138    | 1676/96.66 | 2672    | 360/96.51 | 15,624   | 524/96.86 | 10,643   | 608/96.82 |
| RL0       | 1138    | 1734/100.00 | 2687    | 373/100.00 | 16,106   | 541/100.00 | 10,643   | 628/100.00 |

| Table 5 |
| Changes in travel behaviors for male and female visitors under the different COVID-19 RLs. |

| Scenarios | Male |  | Female |  |
|-----------|------|-----|--------|-----|
|           | TTD(m) | N/TBM(%) | TTD(m) | N/TBM(%) |
| RL4       | 3833   | 202/15.84 | 2939    | 235/11.75 |
| RL3       | 3287   | 537/42.12 | 2856    | 706/35.30 |
| RL2       | 4149   | 1027/80.55 | 3802    | 1540/77.00 |
| RL1       | 4523   | 1242/97.41 | 4118    | 1925/96.25 |
| RL0       | 4474   | 1275/100.00 | 4087    | 2000/100.00 |
Table 6
Changes in travel behaviors for visitors with different monthly incomes (1000 yuan) under the different COVID-19 RLs.

| Scenarios | 0.2–3 | 3–6 | 6–10 | >10 |
|-----------|-------|-----|------|-----|
|           | TTD(m) | N/TBM(%) | TTD(m) | N/TBM(%) | TTD(m) | N/TBM(%) | TTD(m) | N/TBM(%) |
| RL4       | 3647 | 34/17.62 | 2290 | 88/14.59 | 2363 | 49/10.29 | 1984 | 13/9.05 |
| RL3       | 3247 | 69/35.75 | 3028 | 236/39.47 | 2448 | 153/32.14 | 5811 | 37/26.06 |
| RL2       | 2972 | 141/73.06 | 3533 | 475/78.77 | 3545 | 366/76.89 | 6909 | 103/72.54 |
| RL1       | 3330 | 177/91.71 | 3833 | 589/97.68 | 3810 | 466/97.90 | 6909 | 136/95.77 |
| RL0       | 3289 | 193/100.00 | 3715 | 603/100.00 | 3636 | 476/100.00 | 6217 | 142/100.00 |

4.2. Spatially equitable access to urban parks under COVID-19

4.2.1. Spatial distribution and accessibility changes

Accessibility under the different COVID-19 RLs was calculated (see Fig. 4). As shown, the scale of places accessible to urban parks shrank as the RL increased from RL0 to RL3, especially RL2 and RL3. Place with the accessibility larger than 0 is the service area of urban accessibility for residents to urban parks.

As Fig. 4 (a) to Fig. 4 (e) show, the service area shrunk from RL0 to RL4. The total service area of urban parks in our study area was 1261.80 km² under RL0, which shrank to 695.27 km² under RL3, which was approximately 50% of that under RL0 (see Fig. 5 (a)). The decline in service scale for urban parks consequently reduced the service population, with 18,997,000 people under RL0 and 10,246,000 people under RL3 (see Fig. 5 (b)). The risk of COVID-19 also reduced the willingness of visitors to visit. The value of accessibility dropped as the RL of COVID-19 increased. As the results show, the maximum accessibility under RL0 was 65.51 (km² per 100,000 people), while the maximum accessibility in RL3 and RL4 was only 25.75 (km² per 100,000 people) and 3.52 (km² per 100,000 people), respectively. This suggests that even under RL4, the TTDs of visitors did not fall clearly, which led to a relatively large service radius of urban parks under RL4; the number of visitors willing to visit a park dropped sharply, and consequently led to a drop in accessibility for residents to urban parks.

4.2.2. Equitable accessibility changes

The travel behavior changes of visitors to urban parks also led to increases in inequitable access to urban parks. The Gini coefficient of accessibility for urban parks in the districts was calculated and analyzed. As the results show (see Fig. 5 (c)), the Gini coefficients in Qiaokou, Jianghan, and Wuchang were relatively low in RL0, no more than 0.5. This suggested moderate inequality in these districts. For Hongshan, Qingshan, and Jiangxia, the Gini coefficients were up to 0.9, which indicated more inequitable accessibility in these districts. The results indicate more inequitable accessibility in these districts. The results make sense since in Qiaokou, Jianghan, and Wuchang, the area of these districts is small (40.06 km², 28.29 km², and 64.58 km², respectively (Wuhan Municipal Statistics Bureau, 2020)) with concentrated and dense populations: 21,689 people/ km² and 2018.31 people/ km², respectively (Wuhan Municipal Statistics Bureau, 2020). Consequently, the Gini coefficients in these three districts were much lower than those in the other districts. On the contrary, the areas of Hongshan and Jiangxia were large (573.28 km² and 2018.31 km²) with scattered populations (population densities of 2988 people/ km² and 489 people/ km², respectively) (Wuhan Municipal Statistics Bureau, 2020). Many places and people lack urban parks. Therefore, Hongshan and Jiangxia suffered the most inequitable access to urban parks. As the COVID-19 RLs increased, the Gini coefficient increased. For Qiaokou, the coefficient increased from 0.40 to 0.60 from RL0 to RL4. Similar conditions were observed in the other districts.
5. Discussion

In this study, 3276 questionnaires in 21 urban parks in Wuhan city were answered and different RLs of COVID-19 were assigned to examine changes in the travel behavior of visitors under the post-pandemic period. The travel behavior included the willingness to visit an urban park and the TTD to an urban park. Since travel behavior changes the urban park’s service radius and accessibility, many studies have focused on the travel behavior changes caused by COVID-19 in urban parks or other urban green spaces (Cheng et al., 2021; Kleinschroth and Kowarik, 2020; Lu et al., 2021; Russette et al., 2021; Ugolini et al., 2021; Venter et al., 2021). Nearly all these studies have focused on the changes between the COVID-19 pandemic and non-pandemic periods. It was found that during the pandemic, residents increased their visits to urban green spaces, especially those near their homes, such as tree-lined streets; however, these increases only existed under relaxed mobility restrictions. How do residents change their travel behaviors when the risk of infection COVID-19 is different? Few studies have addressed this issue because it is difficult to quantify RLs, and even if the RL has been quantified, it is still difficult to obtain information on travel behaviors during specific periods. Properly answering this question is important and meaningful for the government to formulate policy to guide the use of urban green spaces.
residents’ travel behavior in the post-COVID-19 pandemic period. The pandemic has halted or reversed processes to achieve sustainable development by challenging the goal of ‘Ensure healthy lives and promote well-being for all at all ages’ proposed by the United Nations (https://sdgs.un.org/goals/goal3). Understanding usages of urban parks during the post-COVID-19 pandemic period would benefit future urban planning to achieve sustainable development.

Within this context and under the condition that new cases of COVID-19 in China have been few and had a scattered distribution since April 8, 2020, when Wuhan was no longer locked down, a SP survey was carried out by assigning RLs of COVID-19 based on the administrative distance between the study area and location with new cases of COVID-19. The results showed that the travel behavior of visitors to urban parks did not obviously change under RL1. With development of the RL, respondents have gradually reduced their willingness and travel distance to go to urban parks so as to protect themselves against COVID-19. Consistent findings have been found in studies in UK (Burnett et al., 2021), U.S. (Curtis et al., 2020), Italy (Ugolini et al., 2021) and other regions (Ugolini et al., 2020) that under a severe situation, visitations to urban green spaces were decreased. In this study, under higher RL, the respondents who go to urban parks reduced to 37.97% (under RL3) and 13.43% (under RL4), respectively. Meanwhile, some different findings also have been concluded in other studies. In Lu et al. (2021)’s study, the visitations to urban green spaces increased under soft social distancing restrictions in four Asian cities. This contradiction may be caused by the fact that in Lu et al. (2021)’s study all types of green spaces in the central city and outside the city have been considered, while in our study we just considered the urban parks in the central city of Wuhan. Moreover, varied cultural, urban contexts and economic developments also would lead to this difference.

Furthermore, it was found that the risks of being infected by COVID-19 had a larger impact on the travel willingness of visitors using public transport, visitors with a higher education and higher income, and female visitors. These findings proposed by our study are consistent with existing studies. Ugolini et al. (2020)’s online survey study suggested that the even if the total visitation reduced, the visitation by walking and by car were increased. It confirmed that the pandemic would largely depress the visitation by public transport and is consistent with our results. Also many studies have found a largely reduced visitation of female visitor during the pandemic (Burnett et al., 2021; Huerta and Cafagna, 2021; Ugolini et al., 2020).

However, some of our findings were different from existing studies. According to our questionnaire survey, a slight travel willingness change of elderly visitors has been detected, with 23.39% of elderly visitor still willing to go to urban parks under RL4, while only 11.67% of other visitors willing to go to urban parks under RL4. Existing studies tended to find out that the pandemic led to a larger reduce on the visitation of elderly visitors. In a national study for UK adults, Burnett et al. (2021) suggested that older (65+- years) respondents were less likely than middle-aged (25–64 years) respondents to have visited all types of green spaces following the restrictions during the pandemic. Also according to the UNWTO’s report (UNWTO, 2021), travel recovery on tourism including long distance travel such as international travel has been stronger among younger segments, and on the other side retirees were the most impacted segments. The differences may be explained by the fact that our study focused on the urban parks in central city, with a highly accessibility. Under this context, elderly people can go to urban parks with a high distance, and the impact of the pandemic on their visitation would be different from when they go to green space outside urban areas. Meanwhile, for elderly people who are retired, their demands on going to urban parks for daily recreations, social contacts, and physical exercise are stronger than that of other residents. It may lead to a higher willingness for elderly visitors under RLs of COVID-19.

The survey data also suggested that the travel distances of respondents were declined which meant people prefer to neighboring urban parks under the risks of COVID-19. This finding complements existing studies. Existing studies have confirmed in the pandemic, people prefer to green space in neighborhood (Kleinschroth and Kowarik, 2020; Ugolini et al., 2020). Similar, the UNWTO’s report (UNWTO, 2021) suggested that in turns of tourism, travellers trended to go for staycations or vacations close to home during the pandemic. Due to the fact that the travel distance and willingness to urban parks declined under RLs, the accessibility of urban parks in Wuhan reduced, followed by a more inequitable spatial distribution of accessibility.

This study has some limitations. In this study, the risks of being infected with COVID-19 were assigned simply by administrative region, with four classes based on the theory of psychological distance (Liberman and Trope, 2014). In our case, only the spatial distance was considered, as reflected by the administrative distance. In fact, the distance between the location with new cases and the study area can be accurately evaluated by their real distance, traffic flow, and population flow. In future studies, the careful determination of the distance between locations with new cases and study area may be the most important issue. Meanwhile, the time and hypotheticality distances were not considered in this study. The length of the period in which new cases have been detected and the distance from the last new cases to the study time would reflect the time distance, and the number of newly detected cases should be considered to reflect the hypotheticality distance. Concerning the spatial distance, time distance, and hypotheticality distance, the RLs of COVID-19 can be accurately evaluated. Furthermore, our study only considered one type of UGS: urban parks. Different types of parks and green space have different functions. For example, national parks usually service a larger area than urban parks and attract visitors from a longer distance. In future work, an in-depth study of different types of urban green space should be conducted.

6. Conclusion

This study is the first to demonstrate visitors’ individual travel behavior changes to urban parks under different severity of COVID-19 in a highly developed Chinese city, Wuhan, by using data collected from a SP survey. The results suggested that visitors reduced their willingness and shrunk travel distance to go to urban parks as the RL of COVID-19 increased. The findings are consistent with some of existing studies that using questionnaire data and big data. Furthermore, according to the Gaussian-based 2SFCA method and Gini coefficient, our results show that in the post-COVID-19 pandemic period, it is a challenge of maintaining or promoting accessibility and equality of urban parks. Being aware of changes in the accessibility and equality of urban parks for visitors is important for sensible urban planning as well as for the government to control or guide visitors’ travel behaviors in the post-COVID-19 pandemic period.

Credit author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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