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# Social inequality of urban park use during the COVID-19 pandemic

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Although many studies have examined social inequalities related to urban parks, there is limited knowledge about the social inequalities of urban park use during crises. By integrating a large amount of mobile phone data and e-commerce user data, this study tracked 81,350 anonymized individuals' urban park use behavior in Shenzhen, China, from 2019 to 2021, covering a period before and after the start of the COVID-19 pandemic. Results reveal that while most of the parks saw a reduction of over 50% in the number of visitors, some parks, especially relatively small and remote parks, had more visitors after the pandemic began than before. In addition, COVID-19 has caused residents' urban parks use time to decrease and such impacts are more severe in vulnerable groups (e.g., females, the elderly, juveniles, and low-income groups). Moreover, there are significant inequalities in urban park use between rich and poor communities, and COVID-19 has slightly exacerbated these inequalities. The study highlighted that integrating mobile phone data with e-commerce data is an effective way to unveil the complex social inequalities behind human behavior. Findings could help to improve social equality in urban park use as well as providing insights for evidence-informed decision-making in post-pandemic recovery and future crises.

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## Introduction

Social inequality, as one of the notable features of contemporary society (Carmo 2021), can be found in various sectors, such as the economy, education, health, well-being, and so on (Mpungose 2020; Cantante 2020). In residents' daily activities, urban parks, as the essentially public facilities that are often freely available to a wide range of people. Nevertheless, many studies have demonstrated that urban parks do not benefit residents equally (Jennings et al. 2016), but, rather, have contributed to urban inequalities. The inequality of urban park uses leads to disparities in residents' physical and mental well-being, decreasing urban equality and adding to the concerns of urban scholars and policymakers (Rigolon 2016). Although many studies have examined the inequalities related to urban parks (Rigolon et al. 2018; Xiao et al. 2017), the issue of the social inequality of urban park use during crises has been little relevant research. Understanding the social inequalities of urban park use during the pandemic is a key topic for providing targeted strategies to assist residents who are greatly impacted by COVID-19. It is important for reducing social inequalities caused by the pandemic and improving social adaptability in the post-pandemic era (Larson et al. 2021; Huang et al. 2022).

Some studies have attempted to understand the differences or changes in urban park use before and after the COVID-19 pandemic (Geng et al. 2021). However, typically, these studies are either relied on conducting questionnaire surveys (Zhang et al. 2022) or are based on big data that is constrained by a relatively short time span. Studies based on questionnaire surveys usually face two key issues. One is that a representative sample is usually not included, particularly, those in an elite class and vulnerable groups tend to be under-sampled. The other is that a large geographical scale is hardly fully covered (Rao and Wilson 2022). Mobile phone data has merits for tracing residents' movement in large volumes at a large geographical scale, and thus has been widely used in park use behavior studies (Ren et al. 2022). Undeniably, it has introduced challenges in identifying park users' sociodemographic information (Huang et al. 2018). But the sociodemographic information is crucial to explore social segregation and inequality related to park visitation (Moro et al. 2021; Parolin and Lee 2021).

This study aims to fill the current research gaps and find fresh evidence for the differences and changes in residents' urban park use behavior before and after the start of the COVID-19 pandemic, and thus uncover the related social inequalities. We use residents' travel behavior panel data with sociodemographic attributes which are extracted from the mobile phone dataset and the e-commerce user dataset. By linking individual trajectory data from mobile phones with e-commerce user data based on telephone numbers, we traced 81,350 residents and recorded 289,945 visits to urban parks in the densely populated megacity Shenzhen, China, covering the same time window over 3 years, in March 2019 (1 year before the pandemic), in March 2020 (during the first year of the pandemic), and in March 2021 (during the second year of the pandemic). Three main research questions:

- RQ1: How did the overall urban park use change before and after the COVID-19 pandemic?
- RQ2: How did such disparities vary among different sociodemographic groups?
- RQ3: How did it relate to social inequalities between wealthy and poor communities?

The main innovations of this study relative to the existing literature are as follows. First, by integrating mobile phone data with e-commerce user data, this study provides a new understanding of residents' practical urban park use behaviors based on the people-oriented investigation. Second, the study quantitatively assesses

the social inequalities of urban park use during the pandemic, which are not only based on objective disparities in urban park use between population groups but also related to the different degree losses in urban park use during the pandemic. Third, findings could provide valuable and targeted insights for park management during this crisis, as well as offering practical implications for setting policies beyond recovery to help reduce social inequalities and guide cities toward becoming more livable, equitable, resilient, and sustainable in the post-pandemic period.

## Background

**Crisis-induced social inequalities.** Social inequalities have been defined as follows: "inequalities are differences that we consider unjust. Inequality is a negation of equality. Behind a perception of inequality there is a notion of injustice, a violation of some equality" (Carmo 2021). In recent years, because various populations are affected disproportionately by crises (Jamal and Higham 2021), social inequalities caused by crises have given rise to intense debates in society and academia. For example, women and youths are the most vulnerable to climate change crises, particularly in low-income countries (Lau et al. 2021); the economic crisis has increased the loss of family income, resulting in inequalities in educational opportunities (Torche 2010); the refugee crisis has left millions of children homeless (Erucar et al. 2018); and the racial inequalities have deepened in US prisons during COVID-19 (Klein et al. 2023).

These studies have explored many dimensions of social inequalities (Therborn 2013), including, for example, vital inequalities, referring to biological differences between populations (e.g., life, health, death); resource inequalities, referring to unequally distributed resources (e.g., income and wealth, educational opportunity); and existential inequalities, referring to unequal recognition of human individuals (e.g., racial discrimination).

**The pandemic-induced urban park uses inequalities.** Previous studies suggest that the impact of COVID-19 has not been equal for different social groups (Yu et al. 2023; Salon et al. 2021; Geng et al. 2021), leading to the worsening of existing inequalities and the creation of new social inequalities (Rydland et al. 2022). There are numerous examples of social inequalities that have deepened during the COVID-19 period. For example, poor communities with crowded living spaces and homeless families face a higher risk of virus transmission (Abrams and Szeffler 2020), and the rich have better access to COVID-19 tests and treatments than the poor (Sutarsa et al. 2020). In this vein, there is a growing awareness that the COVID-19 pandemic is not only a global health crisis that needs to be solved but also a social equality issue. Addressing social inequalities in adaptation and recovery during the COVID-19 period has become a priority for governments and multilateral organizations (Editorial in Nature Sustainability 2022).

In this study, we use the term "social inequality" for the following two dimensions of inequality in urban park use during the pandemic. One dimension is the unequal distribution of urban park use, which highlights that all social groups should be able to use or access urban parks equally. Here, we analyze the evolution of the uneven distribution of individuals' urban park use behavior before and after the pandemic. Another dimension of social inequality is the different degrees of reduction in urban park use during the pandemic, highlighting the disproportionate effects of crises on various social groups. Although the urban parks are generally freely available to a wide range of people and everyone experienced the same COVID-19 pandemic, there are

still disparities in the changes in urban park use across sociodemographic subgroups and residential communities. In other words, the inequalities caused by the pandemic are not evaluated based on absolute statistics but in comparison with pre-pandemic behavior. Here, we conduct a comparative analysis of the disproportionate effect of the COVID-19 pandemic on various groups of residents.

## Materials and methods

**Data description.** The data obtained for our study are anonymized mobile phone data, anonymized e-commerce user data, urban park data, and housing price data:

- (1) The anonymized mobile phone data, which were used for generating the panel data of individual urban park use behavior, were provided by a third party. We have a really strict mutual agreement signed with the data provider, and the ethical approval was done beforehand between the data provider and users. In this study, we collected mobile phone data from three time windows, covering before and after the start of the COVID-19 pandemic period: March 2019 (before the pandemic), March 2020 (during the first year of the pandemic), and March 2021 (during the second year of the pandemic).
- (2) The anonymized e-commerce user data, which were used for linking the individual urban park use behavior with their socioeconomic attributes, were provided by JD.com company, which is a large-scale e-commerce company in China, with a market share of 27% in 2021 in China. In this study, we obtained e-commerce user data in 2019, before the COVID-19 pandemic, and five variables of socio-demographic attributes, including gender, age, income level, education degree, and occupation. Among these, occupation and income level are predicted based on the residents' consumer habits.
- (3) The urban park data were collected from the official inventory list of parks in Shenzhen in 2021, which was provided by the Shenzhen City Administration and Comprehensive Law Enforcement Bureau (2022). In this study, we selected 161 municipal urban parks as our research area (see Supplementary Table S2).
- (4) The residential communities serve as the fundamental unit of living in Chinese cities. Due to the housing price of residential communities are highly influenced by their location and availability of surrounding public service facilities, (e.g., parks, rail transit, education, and medical resources), especially in Chinese cities (Liang et al. 2018), housing prices have been considered as an indicator to reflect the wealth levels and living conditions of different residential communities to a certain extent (Kim et al. 2019). In this study, the housing price data of residential communities were provided by the Shenzhen Housing and Construction Bureau's guidance price on February 8, 2020.

**Integrating mobile phone data and e-commerce user data.** In the age of big data, integrating multisource datasets enables us to generate new understanding from various perspectives (Fukaya et al. 2020). In this study, a novel method to obtain residents' behavior panel data with sociodemographic attributes was proposed by combing the smartphone tracking dataset and the e-commerce platform user dataset. Although the mobile phone dataset and e-commerce dataset cannot cover all residents, the focus of our study is not to capture all residents' urban park behavior but to track individual-level urban park behavior

differences before and after COVID-19. The pseudocode of the data treatment process is shown in Supplementary Table S3.

*First, recording individual urban park use behavior based on mobile phone data.* we first filtered out the panel data from anonymized observations of whoever visited urban parks during March 2019, 2020, and 2022 and between 5 a.m. to midnight (12 a.m.), and traced their urban park behavior, including who (person-oriented exploration), where (location of the urban park), and when (the date, and time of their arrival and departure). Based on the premise that the more use time residents spent at urban parks, the more beneficial it is for residents' health (Cindrich et al. 2021), we examined two indicators of urban park use behavior: the time spent in urban parks, and the travel distance to the urban park.

*Next, generating the panel data for individual urban park use behavior with socioeconomic attributes.* Given that e-commerce users' data can predict individuals' socioeconomic features (e.g., occupation, income level) and that this data is registered in connection with telephone numbers, merging the mobile phone tracking data and e-commerce data allows the generation of new data by enriching the description of individuals' socioeconomic features. Each record in the dataset includes indicators about the following: (1) urban park behavior, including the arrival time, departure time, and park visited; (2) sociodemographic indicators, including gender, age, income level, education, and occupation; (3) the residential location grid code. The unit of grid analysis is 500 m.

*Finally, data cleaning and preprocessing.* Because our research objective focuses on residents, we screened out observations who did not live in Shenzhen during the research time window. According to the "time-constrained home detection" method, which has been used in many previous studies (Vanhoof et al. 2018; Luo et al. 2016), the residential location of each individual was defined as the location where they spent the most time at night. Additionally, to eliminate occasional visits to parks, we removed each visit of less than 30 min. Ultimately, for our analysis, we obtained 81,350 individuals' panel data for urban park use behavior with sociodemographic attributes from 2019 to 2021. To ensure the anonymity of the data, before being transferred to the researchers, it was processed and each user was assigned a randomly generated pseudonymous identification code.

**Measuring methods of social inequalities in urban park use.** In this study, we attempt to measure the social inequalities in urban park use during the pandemic in the following ways:

- (1) We depicted the complementary cumulative density function (CCDF) to measure the overall distribution of the group's urban park use (Fan et al. 2022). We mainly examined the distribution of individuals' time spent in urban parks and the travel costs of visiting urban parks (distance from home to urban parks) before and after the start of the pandemic. The slopes of the CCDFs are examined by using a linear formula.
- (2) To measure the change rate before and after the pandemic, the change ratio of use time in urban parks (CRT) was constructed as an indicator to measure the annual change percentage of an individual's spending time in urban parks. For each indicator, we carry out averages of the individual-level indicator separately over all subgroups, such as males and females. To eliminate occasional visitors during the observation time windows, we selected the individuals who visited urban parks

throughout the study's period of three time windows. CRT was calculated using the following Eq. (1):

$$CRT_y = \frac{\sum_{d=1}^n (T_{y,d}) - \sum_{d=1}^n (T_{y-1,d})}{\sum_{d=1}^n (T_{y-1,d})} \times 100\% \quad (1)$$

where  $y$  is the year;  $d$  is the date;  $T$  is the spending time in an urban park each visit. When  $CRT = 0$ , the use time to urban parks is the same as the previous year; when  $CRT > 0$ , the use time to urban parks is higher than the previous year; when  $CRT < 0$ , the use time to urban parks is lower than the previous year.

- (3) The Gini coefficient applies to the size distribution of non-negative datasets, such as length, count, area, volume, duration, and energy (Eliazar 2018). It has been widely used for measuring inequalities in various disciplines (Sitthiyot and Holasut 2020), for example, measuring income and wealth inequality in socioeconomics (Scheffer et al. 2017) and measuring differences and inequality in accessing public facilities among various groups in human geography (Cromley 2019; Delbosc and Currie 2011). In this study, to quantify the inequality of urban park use among different housing price communities, we depicted the Lorenz curves and calculated the Gini coefficient as Eq. (2). The Lorenz curve plots the Cartesian coordinates (see Fig. 4), where the horizontal axis is the cumulative share of housing prices from lowest to highest, and the vertical axis is the cumulative proportion of staying time in urban parks (use time in urban parks) or the cumulative share of travel distance to urban parks (travel cost). The line at 45 degrees represents perfect equality in Lorenz curves, and the Gini coefficient is calculated according to the ratio of the area that lies between the line of perfect equality and the Lorenz curve over the total area under the line of perfect equality. The Gini coefficient ranges from 0 to 1, with a larger Gini coefficient representing greater inequality (Lorenz 1905). The Gini coefficient was calculated using the following Eq. (2):

$$Gini_y = 1 - \sum_{i=1}^n (X_i - X_{i-1})(Y_i + Y_{i-1}) \quad (2)$$

where  $y$  is the year,  $X$  represents the value of the horizontal axis in the Lorenz curve, and  $Y$  represents the value of the vertical axis in the Lorenz curve.

## Results

**Urban park use changed before and after the COVID-19 pandemic.** As shown in Fig. 1a–c, while most of the parks had a reduction of over 50% in the number of visitors, there were some parks, especially relatively small and remote parks, that gained visitors, surpassing the pre-pandemic level after the start of the pandemic. Compared with 149,389 visitors to urban parks in 2019, before the pandemic, the number of visitors showed a drastic drop (to 39.86% of pre-pandemic numbers) in 2020, then recovered slightly in 2021 to 54.23% of pre-pandemic numbers (see Fig. 1d). The drastic decline in urban parks visitation might have been a result of the government's restrictions on mobility and social gatherings. According to the lockdown policies, residents were supposed to stay at home during the early stage of the pandemic in 2020. As the lockdown policies have been eased, there has been a gradual recovery in the use of urban parks (Nundy et al. 2021). However, the number of visitors to urban parks was still lower than pre-pandemic levels due to ongoing concerns about the risks posed by the pandemic.

Besides the number of visits suffering a steep decline, large changes took place in urban park behavior per visit. Figure 1e revealed that residents' stay time per visit declined after the

epidemic, and the decrement is relatively greater in 2020 (on average 85 min less) than in 2021 (on average 72 min less). Figure 1f shows that in comparison to the pre-pandemic levels (in 2019), residents visited closer parks (an average of 1.24 km less) during the early stage of the pandemic in 2020, whereas they went to relatively farther parks (an average of 1.19 km more distant) 1 year later, in 2021. The preference for visiting closer parks during the early stage of the pandemic in 2020 might have been partially a result of social distancing measures, which limited the range of residents' activities (Ugolini et al. 2021). In addition, Fig. 1g shows that after the pandemic, residents preferred to go to smaller parks, on average about 200 ha smaller.

Figure 1h presents weekends were less affected than weekdays in 2020 and also recovered better in 2021, almost reaching the pre-pandemic level, as well as a larger impact on the number of visits in the morning than afternoon. It could potentially be because the usual visitors to parks in the morning and on working days are mainly retired elderly people, and women with children, and they are more affected by the pandemic than other groups (as shown in Fig. 3a, d). We also observed that the daily peak time for visits hardly changed before and after the pandemic.

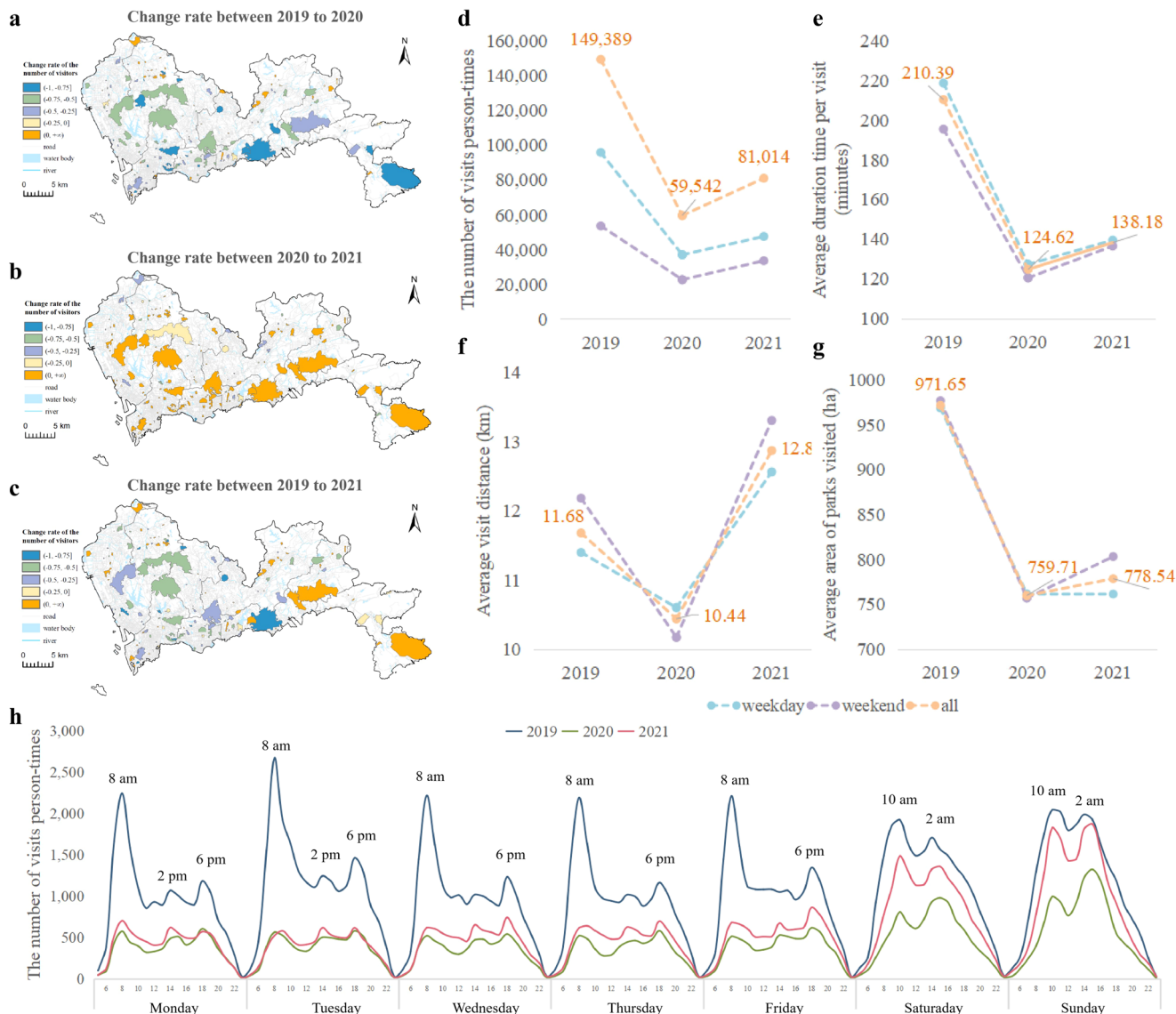
Figure 2 depicts the distribution of residents' average daily stay time in urban parks (use time in urban parks) and visit distance (travel cost) before and after COVID-19. Sharp slopes of CCDFs are shown in Fig. 2a, indicating that there are inequalities among residents' use time in urban parks. For example, some residents spend more than 100 min a day on average in urban parks, but other people stay less than 10 min on the average daily duration time in urban parks. Compared to the distribution of average daily time in parks from 2019 to 2021 based on the CCDFs, the slopes of the CCDFs before the pandemic are sharper than after the pandemic, indicating that COVID-19 might exacerbate the inequalities in urban park stay time.

Furthermore, the steep slopes of CCDFs in Fig. 2b indicate that there are also significant inequalities among different individuals' travel costs for urban parks, such as some residents who travel more than 10 kilometers to urban parks and other residents who are likely to visit closer parks. Unlike what is demonstrated in Fig. 2a, Fig. 2b shows that COVID-19 might not exacerbate the inequalities in urban park travel costs, which can be proven by the observation that the distribution of the CCDFs did not change from 2019 to 2021. Additionally, comparing the slopes of CCDFs in Fig. 2a, b, we observe that the slopes of CCDFs for travel costs are sharper than the CCDFs for use time to urban parks, indicating that the inequalities of residents' travel costs are more serious than use time to urban parks.

**Differences among sociodemographic groups.** Figure 3 shows that, on average, residents of different sociodemographic sub-groups have great differences in their responses to urban park use during COVID-19. Findings suggest that vulnerable people (e.g., elderly, below 18 years old, female, and low-income groups) have been severely impacted, which might be explained by the vulnerability, perceived risk, and fear can significantly increase participation in risk-aversion and preventive behaviors during COVID-19 (Yildirim et al. 2021).

Specifically, for the gender gaps, Fig. 3a shows that in the first year of the pandemic, greater drops in females happened than in males in terms of the number of visitors and use time of urban parks, but in the second year of the pandemic, recovery was faster for females than for males. We also observed that, on average, females visited closer parks than males. For the age disparities, Fig. 3d indicates that the tails of the age distribution (i.e., those aged below 18 years old and those aged over 60 years old) dropped the most in use time to urban parks in the first year of the





**Fig. 1** Changes in urban park behavior before and after the pandemic. Maps of the change rate of the number of visitors between 2019 to 2020 (a), between 2020 to 2021 (b), and between 2019 to 2021 (c). d-g Change in the number of visitors, average stay time per visit, average visit distance, and average area of parks visited. h Temporal patterns of visits.

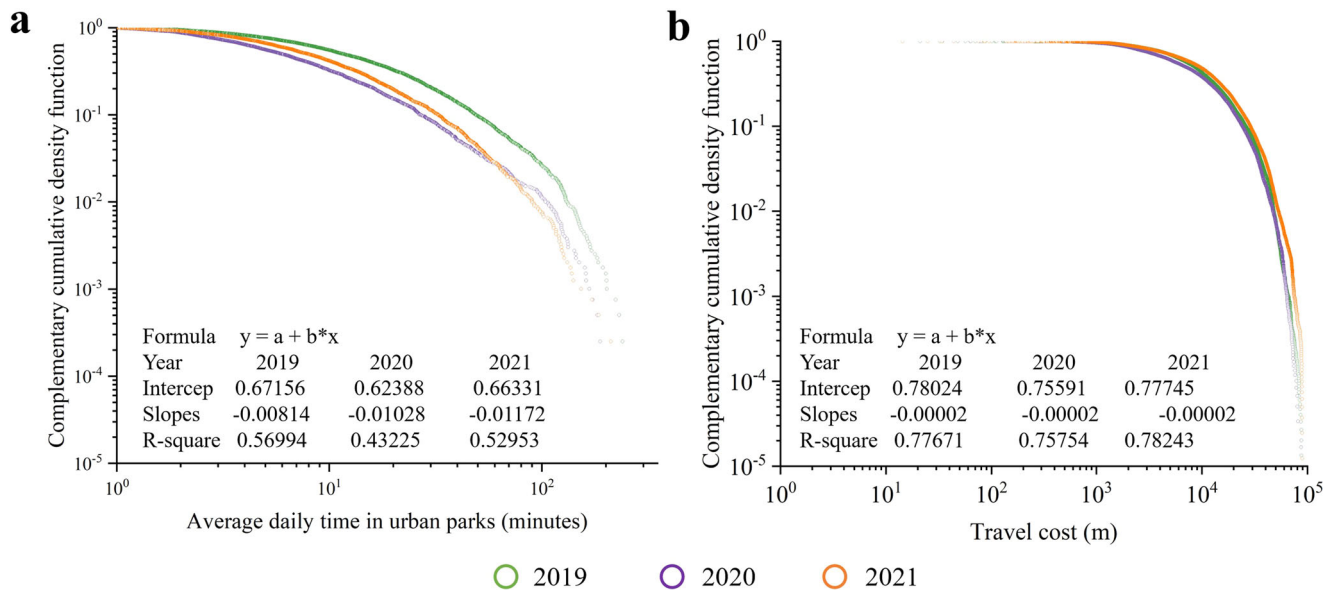
pandemic. Notably, entering into the second year of the pandemic, while most of the groups were starting to recover their use time to urban parks, the use time of residents below 18 years old decreased further. This might be due to the fact that children and adolescents stayed at home for a long time to study remotely and kept a more social distance from society during the pandemic (Dong et al. 2020). As well, the concerns about risk and “COVID-19 vaccine hesitancy” from parents (Bell et al. 2020), limit the opportunities to visit parks for younger groups under the age of 18 years old.

For the income level differences, Fig. 3b shows that the upper-income class always has more use time in urban parks. Lower-income class decreases most but recovers fastest in the use time to urban parks. For the difference between residents with and without a college degree, Fig. 3c result shows that counterintuitively, the residents with a college degree decrease more in their use time in urban parks, but they recover faster than people without a college degree, indicating people with a college degree are more sensitive to the crisis compared with people without a college degree. It is potentially because the

cognitive gaps between different educational levels may impact people’s risk perception and attitudes toward the pandemic (Santamaría-García et al. 2022).

For the occupational disparities, we find that individuals’ daily routines (e.g., working hours, commuting, suitability to work at home) among different occupations ultimately affect their needs to access urban parks. As shown in Fig. 3e, compared with people in other occupations, medical staff had the largest decline in use time in parks but recovered faster entering the second year of the pandemic. This can be explained by their being busy with their work during the pandemic period. Moreover, we see that people working in public institutions (e.g., public civil servants, teachers) had the smallest change rate both for the decline phase and the recovery phase, indicating they have the greatest anti-disturbance ability.

**Inequalities between wealthy and poor communities.** As shown in Fig. 4a, the Gini coefficients reflecting the differences between residents’ use time in urban parks from 2019 to 2021 are 0.57, 0.60, and 0.57 perspectives. Results demonstrated that there are



**Fig. 2 The distribution of residents' urban park use behavior before and after the pandemic.** The complementary cumulative density function (CCDF) of average daily time in urban parks (**a**) and visit distance to urban parks (**b**) from 2019 to 2021. The numerical values of the slopes of CCDFs are shown in the figures.

significant inequities between wealthy and poor communities both before and after the pandemic. Interestingly, we found a reversal in the use time to urban park inequities by housing price; that is, compared with the pre-pandemic behavior, the epidemic exacerbated the inequities in the first year of the pandemic, whereas they returned to the pre-pandemic level in the second year of the pandemic. Figure 4b shows that the Gini coefficient of travel costs to urban parks increased after the pandemic, indicating that the pandemic has expanded the inequalities of residents' travel costs to urban parks. While the Gini coefficient (0.44 in 2021) shows a little decrease in the second year of the pandemic compared with the first year level (0.47 in 2020), it did not return to the pre-pandemic level (0.42 in 2019).

As shown in Fig. 4c, our findings indicate that the disparity in average time spent in parks between groups living in the richest and poorest communities was larger in 2019 (before the pandemic) than that in 2020 and 2021 (after the start of the pandemic) and that the richest communities experienced the highest decline rate in urban park usage. These observations might be explained by the fact that wealthy communities have better community gardens and outdoor activity spaces within their own communities, which implies that they potentially have more alternatives whether to visit urban parks than poor communities do (Zhang et al. 2020).

Moreover, we have found the wealthier the residential communities are, the more the residents visited closer and smaller parks (Fig. 4d), and the relationship didn't change before and after the pandemic. The potential reason is that the distance to urban parks has a negative impact on housing prices (Kim et al. 2019), and wealthy communities are more likely to be located close to urban parks.

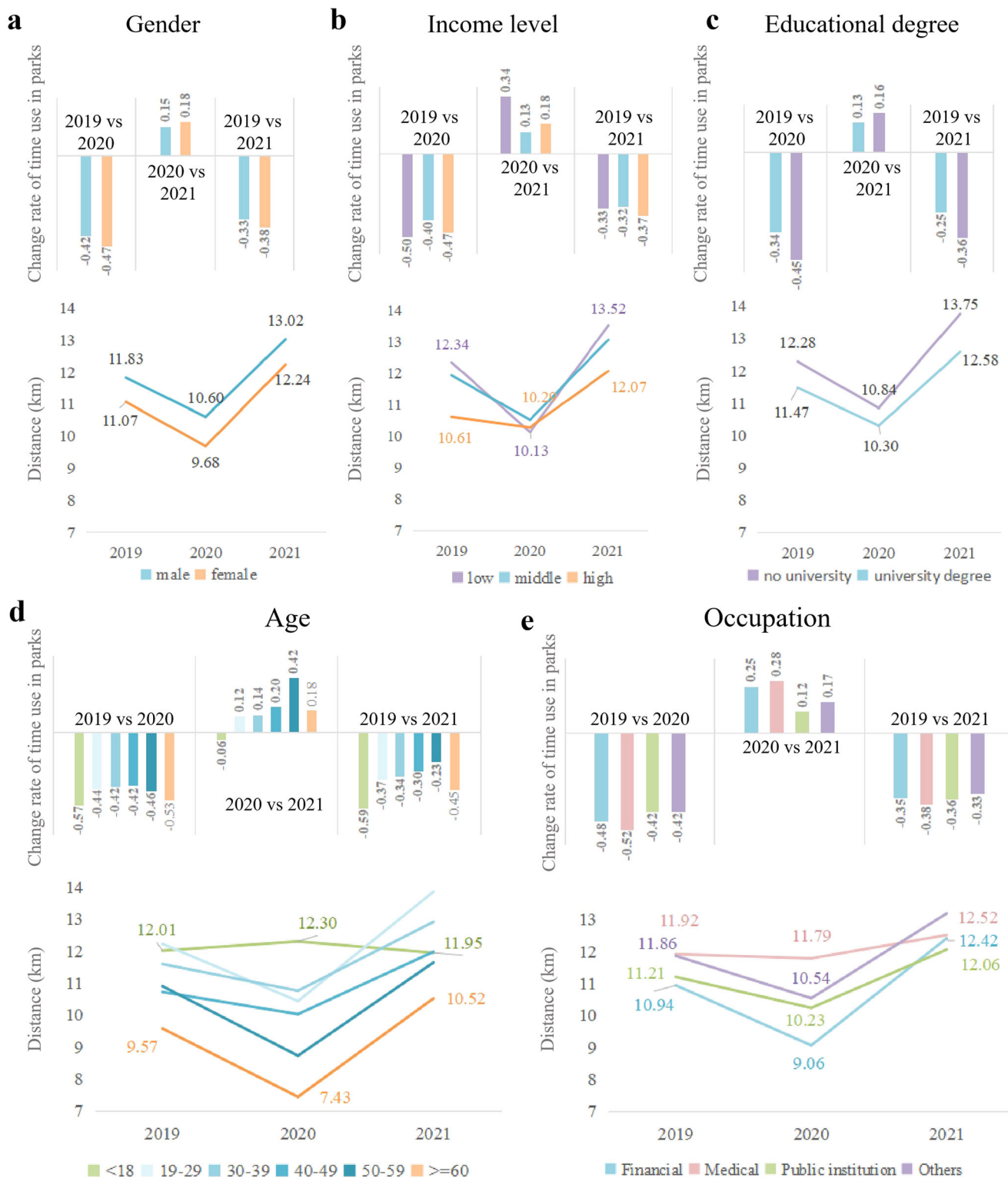
## Discussion and conclusion

We find new evidence for the changes and differences in urban park use behavior before and after the pandemic, and thus reveal the related social inequalities through data-driven exploratory analyses. Results demonstrated that compared with 149,389 visitors to urban parks in 2019 before the pandemic, the number of visitors showed a dramatic decrease (60.14%) in 2020, then recovered in 2021 to

54.23% of pre-pandemic numbers. We also revealed that COVID-19 has decreased residents' use time in urban parks and that such impacts are more severe in vulnerable groups (e.g., females, elderly, below 18 years old, and low-income groups). Moreover, we quantitatively confirmed that there are distinct inequalities in urban park use among different housing-price communities both before and after the pandemic—the Gini coefficients of residents' use time in urban parks and travel distance to urban parks are greater than 0.4 both before and after the pandemic.

The findings of our study have been discussed in the following aspects. Firstly, there would be a high risk of health and well-being losses for park-based activities after the pandemic. Previous studies have demonstrated that the emergence of COVID-19 has caused a significant decrease in residents' health and well-being (Zacher and Rudolph 2021; Xiang et al. 2020). Before the pandemic, in 2019, the social and economic costs caused by poor health and low well-being accounted for about 10% of the global gross national product (GNP) (McDaid et al. 2019; Patel et al. 2018), and those costs are growing after the outbreak of COVID-19 (Brooks et al. 2020). Urban parks use activities have been recognized as critical ways for citizens to maintain or promote their health and well-being, especially during times of COVID-19 restrictions (Jackson et al. 2021; Geng et al. 2021).

Many studies have investigated urban park use behavior change around the world since the outbreak of the COVID-19 pandemic, but their results are inconsistent and trend reversal (Jay et al. 2022; Ugolini et al. 2021; Day 2020). Due to the various local cultures and social and policy environmental features as well as the virus situation of the countries during different periods (Cortinez-O' Ryan et al. 2020), urban park use trends are substantially varied among global countries and regions. For most countries, the number of visitors to urban parks significantly decreased at the beginning of the outbreak and experienced a long and slow recovery process (Ritchie et al. 2022). For some countries, partly as a result of many indoor public recreational spaces being closed or having restricted access (Kleinschroth and Kowarik 2020), the number of visitors to urban parks has increased to some extent. In our analysis based on Shenzhen, China, we revealed that COVID-19 has created significant pressure on residents' urban park use behaviors and such changes

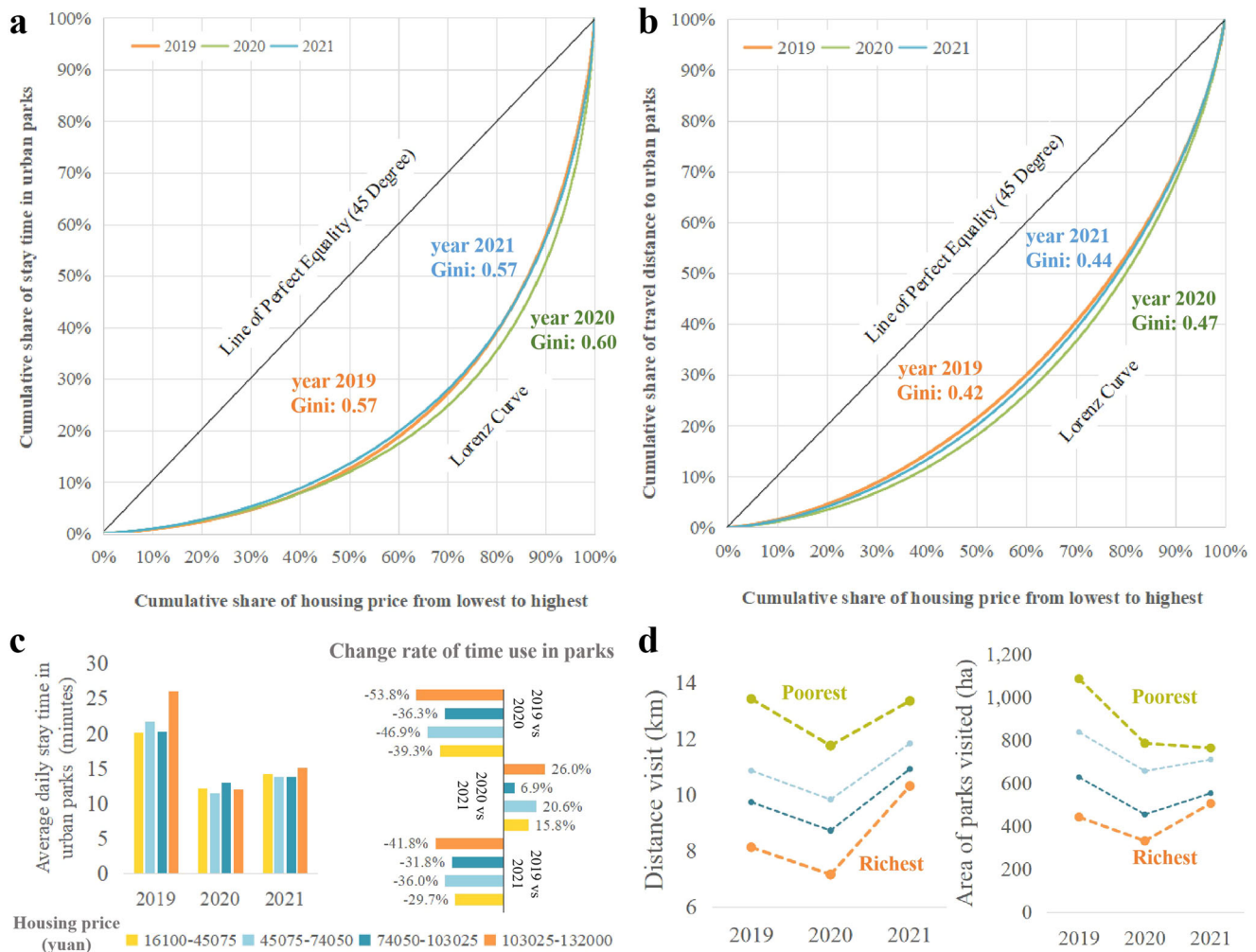


**Fig. 3 Social-demographic disparities in urban park use behavior.** **a** The gender gap between females and males. **b** Differences among residents with different income levels. **c** Differences in behavior changes between people with and without a college degree. **d** Ages differences in urban park behavior changes. **e** Occupational differences in urban park behavior changes.

might be lasting in the long term. For example, our study revealed that, like the majority of regions, the number of visitors to parks decreased in 2020 compared to the pre-pandemic level in 2019, and even when we entered the second year of the pandemic in 2021, there was a 45.77% decrease rate relative to the pre-pandemic equivalent. It may highlight the consequent risks in the

residents' loss of use time to urban parks may further threaten the health and livability of a city, resulting in increased social and economic costs caused by poor health and well-being.

Secondly, there are obvious environmental injustices and green gentrification in urban park use. A growing number of studies demonstrate that environmental injustice and green gentrification



**Fig. 4 The differences in urban park use between low-priced and high-priced communities.** **a** The Lorenz curve and Gini coefficient in use time to urban parks between different housing price communities. **b** The Lorenz curve and Gini coefficient of travel cost to urban parks between different housing price communities. **c** Average daily duration time and the change rate of the time in urban parks by housing price. Each bar-colored legend presents the quartiles of housing prices. **d** Distance to parks and area of parks, by poor and rich communities.

are two interrelated negative effects that often result from the process of the “green turn” of global cities. In the context of urban parks, environmental injustice and green gentrification can manifest in the unequal distribution of urban parks and disparities in park access between different residential communities or groups (Zhang et al. 2021; Kronenberg et al. 2020; Rigolon and Németh 2020; Rigolon et al. 2018). There are many mechanisms of environmental injustice and green gentrification in urban parks. Historical factors such as racism and “redlining” in American real estate may lead to deeper environmental injustice among different classes and ethnic communities (Anguelovski et al. 2022; Nardone et al. 2020). In Chinese cities, especially first-tier cities (e.g., Beijing, Shanghai, Shenzhen), housing prices in residential communities are closely related to the accessibility of parks (Wu et al. 2017). Many urban parks are located in areas that have undergone or are undergoing rapid gentrification. As more affluent residents move into these areas, property values and rental costs can increase. Ultimately, this can lead to the relocation of low-income residents, thus reducing their opportunities to enter urban parks and further aggravating the existing environmental injustice and green gentrification (Wolch et al. 2014).

Our results offer evidence that both before and after the start of the COVID-19 pandemic, high-income groups and wealthier communities have greater use time in urban parks, which reflects the

issue of persisting green gentrification in modern societies to some extent (Anguelovski et al. 2019). Additionally, our analysis demonstrates that disadvantaged groups are facing larger loss rates of use time in urban parks during the pandemic, indicating that the environmental injustice in urban parks shows characteristics of a vicious circle during crises (Berardi et al. 2022; Bambra et al. 2020). These findings warn us that if we do not take appropriate and targeted measures to help disadvantaged groups first, the adverse effects of environmental injustice and green gentrification in urban parks might continue to increase during the pandemic.

Thirdly, there are long-term behavior changes in park visitation. Beyond disparities and changes in urban park use before and after the pandemic, the pandemic provides a “stress test” to explore residents’ dependence on urban parks (Raymond et al. 2020). Our findings revealed that high-income residents and wealthy communities have had a greater loss of use time in urban parks after the pandemic, indicating they have more alternative recreational behaviors and substitute activities for spending their spare time than other groups. It also could reflect that the residents’ visit elasticity of demand for urban parks is quite different for different people (Bakhsh et al. 2020), the greater influence of the pandemic implied a lower elasticity of demand for urban park visits. Although human behavior is difficult to change (Salon et al. 2021), disruption of unnecessary recreational behavior may lead to long-



term changes in behavior that will be harder to recover to the pre-pandemic level. Meanwhile, it also could be a reflection of the fact that while residents' daily commuting behavior appears to have returned to some semblance of normalcy after the pandemic restrictions were eased, residents' recreational behavior has not recovered to the previous level and is forming a new normal.

For further policy-making, our findings offer insights into how to achieve the UN Sustainable Development Goals (e.g., Goal 3: good health and well-being; Goal 10: reduced inequalities; and Goal 11: sustainable cities and communities). The following policy recommendations are proposed specifically to improve social equality in public green park management and planning in the post-pandemic era. First, our analysis found that on average residents preferred to visit further and remote parks after entering the second year of the pandemic, which means the demand from residents for remote and large parks has increased after the COVID-19 pandemic. Governments are supposed to improve the infrastructure of remote parks to meet the needs of visitors and at the same time implement measures to ensure that the remote parks are safe and comfortable for all users, for instance, by constructing more restrooms and benches, improving access roads and parking lots, and increasing security personnel to regulate order and safety in these remote parks.

Second, findings indicate that there are significant social inequalities between poor and wealthy communities. Given that the residential communities are relatively independent and usually private in Chinese cities—that is, only for the use of residents of these communities and wealthy communities have “internal advantages” with better community gardens and green spaces, we suggest that sharing green spaces in wealthy communities to other people for a limited amount of time would be a way to reduce the inequalities of urban park use between poor and wealthy communities. However, this is a challenging solution that would require comprehensive consideration of cultural and social disparities between different communities. It also would require establishing effective regulation mechanisms and strengthening community cooperation.

Third, our findings imply that, partly due to parents' concern about the risk, the younger groups, aged below 18 years old, have experienced a substantial decrease in use time in urban parks, thus endangering the health and well-being of future generations. Park management is supposed to take more children-friendly measures to help parents feel that the parks are safe, for example, increasing the frequency and intensity of park cleaning and disinfection, especially in playgrounds, and offering more outdoor, family-friendly amenities in the parks, such as camping areas and sunshade facilities.

Future research should consider the effects of park characteristics on park use. It is widely believed that residents' urban park use behavior can be affected by park characteristics, particularly admission fees (Zhang and Zhou 2018); however, in China, almost all urban parks in cities are free, except a few tourism-oriented parks. Therefore, we did not examine the effects of admission fees on park usage. But we believe an examination of the effects of other park characteristics, such as operation time and park facilities, would update our understanding of the relationships between emerging events, for instance, COVID-19, and people's park use behavior.

We acknowledge three limitations in our paper. One is that social inequalities are a complicated social phenomenon. Our paper discusses the phenomenon from the perspective of urban park use. A multiple-perspective analysis, which could include more aspects of social inequality, should be explored in future studies. Another limitation is that our paper only examined municipal urban parks. Parks that are located inside gated communities and on-street green spaces are the main alternatives to green park use for many residents. The effects of these two types of parks on social inequalities in urban park use should be included in future studies. The other limitation is that our paper takes Shenzhen city as the case study.

Although it is a typical large city in China, more case cities need to be explored in order to achieve a more general knowledge of social inequalities in park use.

### Data availability

The data used for generating anonymized mobile phone data with sociodemographic attributes in this study (see Supplementary Table S1) are provided by China Unicom and JD.com company.

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## Author contributions

LY: design and perform of the work; PZ: revising the work and acquisition of funding; JT: revising the work; LP: data preprocessing; ZG: comments. They have all approved the version to be published.

## Competing interests

The authors declare no competing interests.

## Ethical approval

Not applicable.

## Informed consent

Not applicable.

## Additional information

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