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Research Paper

Effects of urban parks on residents' expressed happiness before and during the COVID-19 pandemic

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HIGHLIGHTS

- Access to high green quality parks tend to improve residents' expressed happiness.
- Living environment is associated with residents' expressed happiness.
- Different types of urban parks are likely to affect residents' expressed happiness.
- Links between parks and residents' happiness is more evident during the pandemic.

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ABSTRACT

The COVID-19 pandemic has impacted human health worldwide. In these unprecedented times, the benefits of urban parks for residents have gained attention. However, few studies have explored the effects of urban parks on residents' expressed happiness from the perspective of big data, and fewer have further deciphered the disparities between residents' expressed happiness before and during the pandemic. In this study, we explored the effects of urban parks on residents' happiness by including nine independent factors in baseline regression models, and chose 577 urban parks in Nanjing City, China, as study sites. Around 600,000 geotagged posts crawled on *Sina Weibo (Chinese Twitter)* were employed to obtain residents' expressed happiness. The results demonstrated that residents with access to urban parks with higher normalized differential vegetation index (NDVI) values are likely to be happier; and subdistrict-scale urban parks have the highest positive association with residents' expressed happiness. The presence of water, relatively dense populations, low land surface temperatures, and a low proportion of impervious land in the living environment were significantly associated with the higher expressed happiness of residents. The research period was divided into before and during the pandemic, and we identified that the positive association between NDVI of urban parks and residents' expressed happiness increased by one-half during the pandemic period compared to the overall results (0.372 vs. 0.255), indicating that the COVID-19 pandemic awakened Chinese residents' longing for high "green quality" urban parks. Our findings can provide guidance and recommendations for health-oriented urban park planning and design.

1. Introduction

The novel coronavirus disease (COVID-19) was first identified in Wuhan, China, in December 2019, immediately before the 2020 Chinese Spring Festival. It has substantially impacted global human health, security, and economic development. People throughout China were encouraged to stay at home and "self-quarantine" during the outbreak of the pandemic, while Wuhan City was required to be compulsorily quarantined. The lack of daily recreational and social activities has had a significant negative impact on people's moods (Brooks et al., 2020). Along with the emotional contagion[1] on social media, which has been confirmed to exist (Looi et al., 2020), people's negative emotions soared during the COVID-19 pandemic, making their subjective well-being and moods highly deserving of attention.

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[1] Here it refers to the phenomenon that reports and tweets on social media may lead to the spread of negativity/positivity among people, which might affect people's wellbeing.

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Studies on human health during the COVID-19 pandemic are rapidly accumulating, and many have explored the associations between urban green spaces (UGSs) and public health. Specifically, some of these studies have suggested that the pandemic has increased the frequency of visitation to UGSs and addressed the importance of UGSs around their homes (Kleinschroth et al., 2020; Yi et al., 2021). Others have argued that exposure to UGS could mitigate the negative effects of COVID-19 quarantine time (Brooks et al., 2020; Rousseau and Deschacht, 2020), such as relieving urban dwellers' stress, improving residents' physical, emotional, and mental health by providing places of solace and respite, and by offering amenities for exercising and relaxing while enabling social distancing (Corley et al., 2020; Pouso et al., 2020; Slater et al., 2020; Ugolini et al., 2020). A more recent empirical study suggested that UGS can mitigate the racial disparity of the pandemic infection (Lu et al., 2021). Researchers have reconsidered the relationship between UGSs and public health from a variety of perspectives since the outbreak of the pandemic; however, few studies have compared changes in the associations between UGSs and residents' health benefits before and during the pandemic.

Considerable evidence from previous studies already proves that exposure to UGS is beneficial for various dimensions of health (Bratman et al., 2019; Enssle and Kabisch, 2020; Zhang et al., 2020). UGSs, particularly urban parks, have environmental, aesthetic, and recreational functions that can contribute to people's health, including physical, mental, social health, academic and job performance, as well as happiness (Frumkin et al., 2017; Gascon et al., 2016; Richardson et al., 2010; Villeneuve et al., 2012; Zhang, Cheng, Li, Wan, & Zhao, 2021). Among these, the association between urban parks and happiness has received relatively less attention.

A variety of terms are used in the cross-disciplinary literature on happiness, including happiness, subjective well-being, life satisfaction, experienced utility, and quality of life (De Vries et al., 2021; MacKerron, 2012; MacKerron and Mourato, 2013). Various methods have been employed to obtain well-being and happiness data. Self-reported measures (e.g., self-reported well-being), questionnaires, and demographic surveys are most commonly used to explore the effects of urban parks on respondents' happiness (Grilli et al., 2020; Navarrete-Hernandez and Laffan, 2019; Thompson et al., 2012; White et al., 2013; Yuan et al., 2018). Recently, smartphone apps and wearable sensors combined with GPS location data have been used to obtain momentary happiness data. A recent experimental study by Benita et al. (2019) used wearable sensors to record momentary subjective well-being as people's happiness data. Participants were asked to record their momentary feelings of happiness in various daily life scenarios in Singapore using sensors. Similarly, a more recent study by De Vries et al. (2021) launched a smartphone app called *HappyHier* to send requests to complete a short questionnaire, starting with the participants' happiness in natural environments. Such data acquisition methods are, however, restricted to recording participants' happiness in specific situations and scenarios; they fail to explore changes in urban residents' happiness over time. To date, few studies have demonstrated the general impact of urban parks on happiness in large populations. There is scarce research into how different types and attributes of urban parks affect happiness in daily life.

In recent years, social media platforms, such as Twitter and Weibo, have become ubiquitous and important for social networking and content sharing (Hughes et al., 2012). They play a crucial role as a medium for information dissemination and communication, especially during the COVID-19 pandemic, when people are forced out of public spaces (Chen et al., 2020). The widespread use of these platforms, combined with developments in data crawling techniques and text analytics (e.g., sentiment analysis), has enabled us to obtain large-scale and long-term databases on residents' expressed happiness (Roberts et al., 2019).

To address the above-mentioned gaps, we conducted a sentiment analysis of a large number of microblogs (with location information) obtained from social media. Additionally, we aimed to explore the effects of urban parks on residents' expressed happiness and to decipher whether the COVID-19 pandemic has changed their relationship. Nanjing City, China, was selected as the study site to address the following scientific questions:

i) Do residents living within the service radius (buffers) of urban parks express higher happiness?
ii) Does higher "green quality" of a park (i.e., with higher green coverage) lead to happier residents who have access to it?
iii) Are there disparities in residents' expressed happiness among the different types of urban parks?
iv) Has the relationship between urban parks and residents' expressed happiness changed before and during the COVID-19 pandemic?

Addressing these scientific questions can provide planning guidance and design recommendations for urban parks. Thus, when a similar crisis occurs in the future, cities can respond effectively not only from a medical and epidemiologic perspective but also from an urban planning perspective, which promotes the use of green spaces for well-being and happiness.

2. Methodology

2.1. Study area

Nanjing, the capital city of Jiangsu Province, China, was chosen as the study site. A megacity with a population of approximately 8 million people and covering an area of approximately 6,600 km^2, it is one of the most important cities in the Yangtze River Delta (YRD), from an economic, cultural, and historical perspective. The YRD is the largest urban agglomeration in Asia and has undergone rapid economic growth. Nanjing has often been used as a model site for green space planning and landscape ecology, making it an appropriate city for studying urban parks and health (Zhang, Cheng, & Zhao, 2021). Specifically, 577 major urban parks, referred to as UGS with recreational amenities and facilities (e.g., public parks and recreational fields), across the city were selected and classified into four groups according to their areas (Fig. 2a). There are 176 community-scale urban parks (group 1), which have an area between 0.5 and 2 ha; 258 subdistrict-scale urban parks (group 2), with an area between 2 and 20 ha; 92 regional-scale urban parks (group 3), with an area between 20 and 100 ha; and 51 city-scale urban parks (group 4), with an area over 100 ha. Considering that the check-in data inside urban parks was insufficient and to better evaluate the potential influence of social activities in or around urban parks on residents' sentiment, we set a 300 m, 500 m, 1500 m, and 2000 m buffer distances for groups 1 to 4 separately, depending on the service radius of the different levels of urban parks. The buffer analysis tool of ArcGIS 10 (ESRI, 2011) was used to form a buffer surface for each urban park, as shown by the colored parts in Fig. 2. We defined buffer zones as the range of residents' social activities around urban parks; that is, the residents in these areas have access to urban parks and their services.

2.2. Variable selection and calculation

The normalized differential vegetation index (NDVI) has been widely used as an indicator to reflect and assess the vegetation quality in urban areas (Myeong, 2006; Sarkar et al., 2015; Wang et al., 2019), and has also been applied to study vegetation distribution (Pettorelli et al., 2005). Therefore, we consider it as a factor that can represent the green quality of urban parks; and thus, it was our main independent variable. The NDVI data of the whole city were derived from Landsat-8 Operational Land Imager (OLS) images, with a spatial resolution of 30 m, calculated using the Map algebra tool of ArcGIS 10. Four satellite images were acquired for each of the following time periods: August 2019 (period 1), November 2019 (period 2), February 2020 (period 3), and

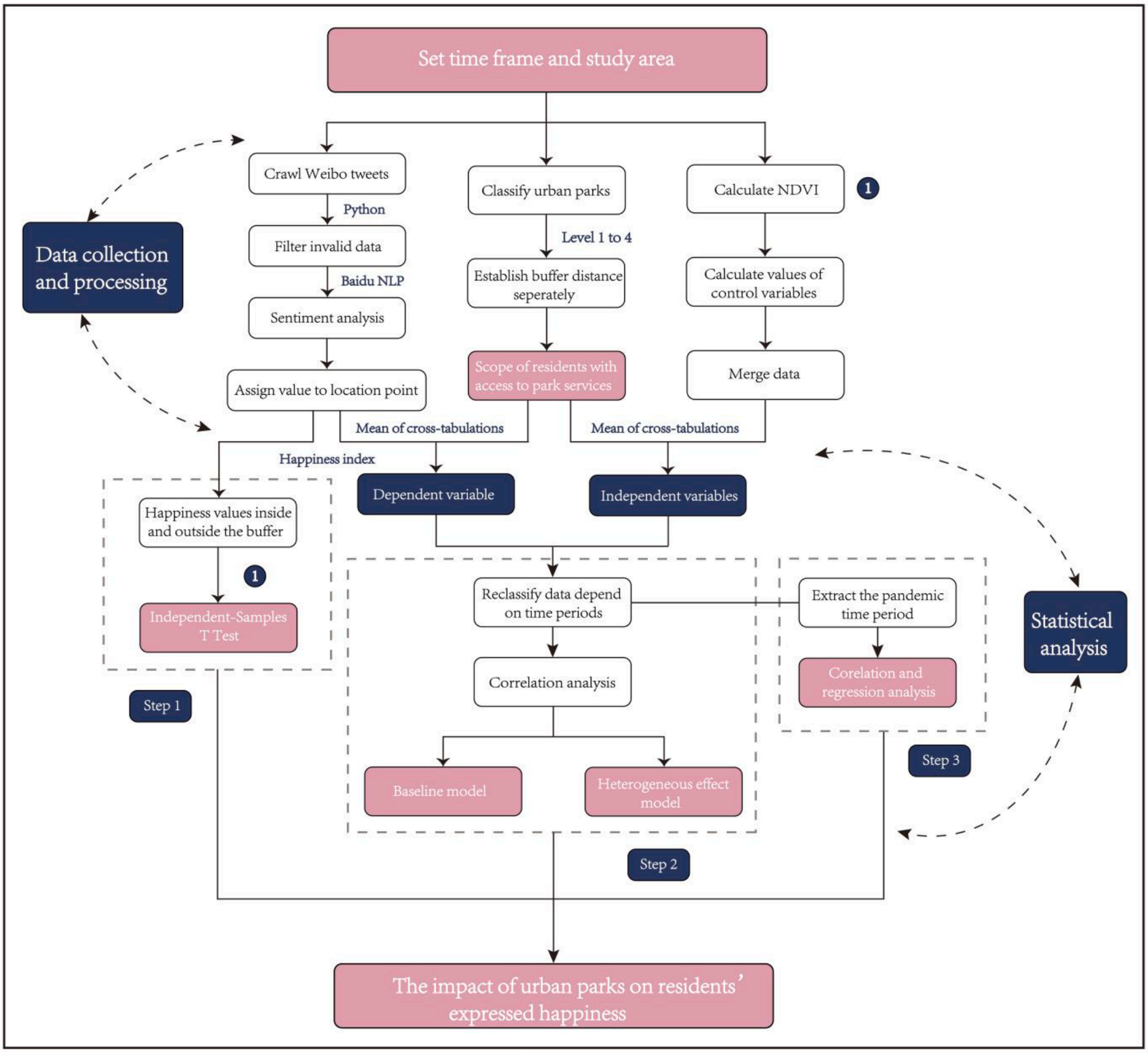

Fig. 1. The framework of methodology.

April 2020 (period 4). NDVI and urban park layers were merged to obtain the NDVI values for each park for each time period. We set the NDVI value of water to zero to remove the negative values from the database. Consequently, the NDVI values were all positive and ranged from 0 to 0.45.

People's emotions are affected by multiple factors when they engage in social activities (Sacharin et al., 2012); hence, we further selected eight control variables; that is, seven continuous variables—land surface temperature (LST), air quality index (AQI), urban park area (UPA), the proportion of water area (WP), the proportion of impervious land (ILP), the proportion of noise (NP), and population density (PD)—and one binary variable—the existence of water (WE, where 0 is "without water" and 1 is "with water"). All of them, except for UPA, are based on the scope of residents with access to urban park services (buffer zones). The PD, NP, ILP, and WP of Nanjing are displayed in Fig. 3. We obtained LST data by applying the radiative transfer equation to Landsat images in ENVI 5.3. AQI data were obtained from the National Climatic Data Center, which is part of the National Oceanic and Atmospheric Administration. The LST and AQI values are the mean values of the buffer areas. For the calculation of the NP, we set up 150 m, 100 m, and 50 m coverage areas for highways, expressways, and pedestrian paths, respectively, and intersected the noise layer and the urban park's buffer layer in ArcGIS 10 to obtain the NP data. The remaining factors were calculated using ArcGIS 10. All data were then collapsed to the urban park/period level. The sample number (n) was 1,305.

2.3. Weibo data collection and processing

Sina Weibo, often called "Chinese Twitter" (Twitter is blocked in China), is the largest open social media platform in China, having reached over 500 million users by May 2020 (Wang, Zhou et al. (2020)). It is a platform where people voluntarily publish messages and exchange information. All users' information is anonymous. Weibo data has been widely accepted and used in several studies. Zheng et al. (2019) used Weibo posts to explore the impact of air pollution on the happiness of urban dwellers. Wang, Wu et al. (2020) utilized Weibo data to explore the effects of residential lockdown on individuals' subjective well-being in China during the COVID-19 pandemic. Research has indicated that the Pearson correlation coefficient between the online check-in data and official visitor statistics reaches 0.712 (Shen et al., 2017), suggesting that the former can be representative of parks' real visits. The widespread use of social media data implies that people's real-time happiness derived from social media is highly efficient.

Our data are geotagged *Weibo* posts from July 2019 to June 2020,

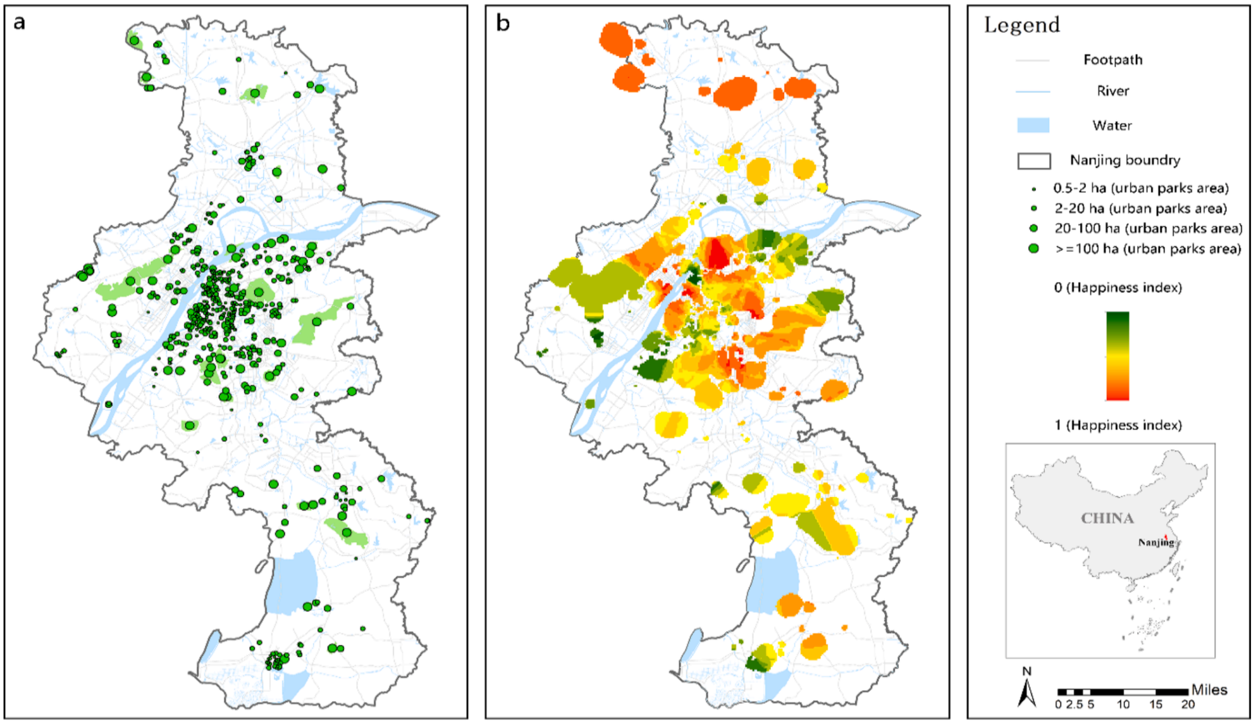

Fig. 2. a. The geographical spatial distribution of different levels of urban parks in Nanjing; 2b. The visualization of happiness index in urban parks' buffer zone. Kriging Method in ArcGIS 10 was used for Interpolation analysis of this figure.

which were collected using Python (web crawler) connected to the streaming application-programming interface (API). Data provided by the API are limited to a subsample of all Weibo data, where users voluntarily shared their location information. We obtained approximately 600,000 raw data and approximately 560,000 posts after screening invalid texts because of the randomness of data for duplicates, emojis, too-short phrases, and system-set advertising slogans, such as votes, play charts, super talk, check-in, and so on. They were excluded because they cannot express personal subjective thoughts and may lead to errors in subsequent data analysis.

Partial urban parks are inaccessible, more geographically isolated, or less attractive, resulting in very little check-in data obtained within their serviceable area, with <10, or even none, for a single time period. These urban parks were also excluded, and 330 urban parks with approximately 350,000 posts remained. Each post included release time, content, and location. To examine the disparities in the effect of urban parks on people's happiness over time, we divided our time frame into four periods: July to September 2019 (period 1), October to December 2019 (period 2), January to March 2020 (period 3), and April to June 2020 (period 4); all data were disaggregated by the time of release.

Text sentiment analysis was then performed based on the Baidu Natural Language Processing platform (https://ai.baidu.com/tech/nlp), which was one of the first four national new-generation AI open innovation platforms approved by the China Ministry of Science and Technology in 2017. For Weibo posts, sentiment analysis was performed by first extracting Chinese characters (excluding numbers, English characters, punctuation, URLs, tags, mentions, etc.) to construct Chinese word segments, and obtaining the sentiment scores of these segments from a Baidu dictionary containing the sentiment scores of Chinese words (https://cloud.baidu.com/doc/API/index.html). This technique automatically returns the text's emotional classification (positive, negative, neutral) and scores in the range of 0 to 1, along with the corresponding confidence. We used the positive sentiment value of the tweet as its happiness index, where 0 represented "extremely negative emotions" and 1 represented "extremely positive emotions." Then, we converted each location to geographic coordinates and assigned the happiness value of the corresponding tweet to it. The mean of all happiness values within each buffer zone was used as the happiness index for that region. We then visualized the expressed happiness of all urban park buffer areas by applying the Kriging interpolation analysis method in ArcGIS 10 (Fig. 2b). The color from green to red in this figure indicates the happiness value from low to high.

2.4. Statistical analysis

The research focused on the independent-samples *t*-test and two main statistical models: the baseline regression model and the heterogeneous effect regression model. First, Levene's test for equality of variances and *t*-test for equality of means were performed to monitor whether there were significant differences in residents' expressed happiness inside and outside the buffer (the urban parks' service area), and made comparisons.

Bivariate correlation analysis was performed on all variables to test the relationship between NDVI and residents' sentiment, and also to screen out other variables that could affect the dependent variable. Subsequently, a baseline regression model was used to explore the associations between the factors and residents' expressed happiness. Temporal dummy variables were included in the model (temporal fixed effects) to eliminate the bias brought to the results by different time periods. All statistics in this paper were presented with period 4 as the default; periods 1, 2, and 3 were added to the equation:

$$\text{Happiness}_{ij} = \alpha_0 + \alpha_1 X_{ij} + \alpha_2 C_{ij} + \alpha_3 T_{it} + \varepsilon_0 \quad (1)$$

where Happiness_{ij} is the happiness index of the urban park *i* in period *j*; X_{ij} is the NDVI of the urban park *i* in period *j*; C_{ij} includes all control variables associated with dependent variable after being tested (in this paper, they are ILP, LST, WP, WE and PD); T_{ij} is the product term of NDVI and time dummy variables, and is used for temporal fixed effects, and period 4 is the default season; α_0 is a constant, and ε_0 is an error term. α_1 is expected to be positive and is shown as the coefficient of NDVI in the tables.

As our NDVI values range from 0 to 0.45, we further reclassified

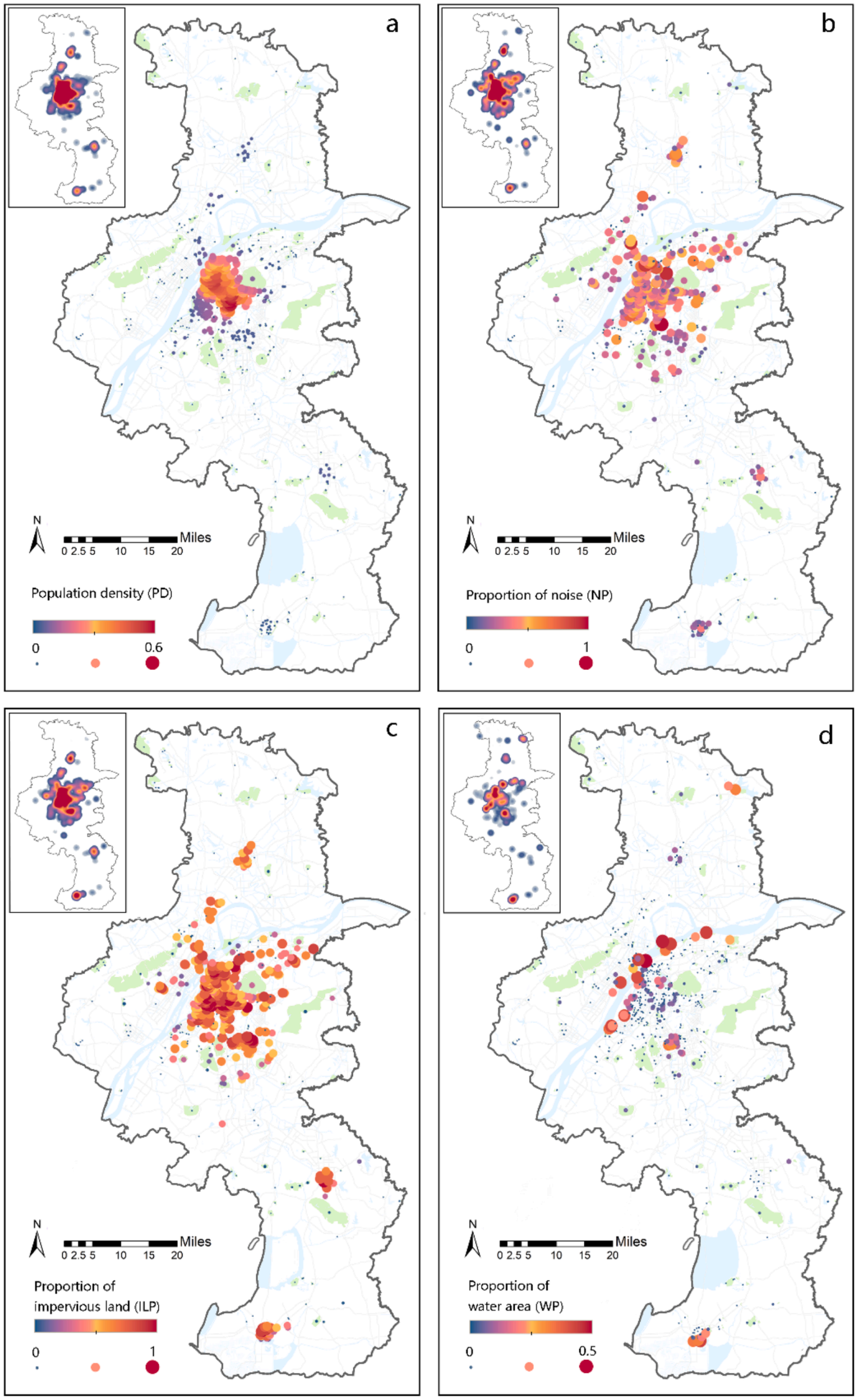

Fig. 3. The visualization of four control variables of Nanjing city. Graph in the upper left corner are the density graphs. Every circle in the figure represents an urban park.

them into five grades: a value between 0 and 0.05 was considered very low; between 0.05 and 0.15 was low; between 0.15 and 0.25 was medium; between 0.25 and 0.35 was high; and between 0.35 and 0.45 was considered very high. To intuitively observe how the impact of NDVI on expressed happiness varies with increasing rank, and to explore whether there were significant disparities within four urban park groups, we added NDVI grade variables and urban park group dummy variables (D_{it}) to Equation (1), and obtained Equation (2). The urban park group dummy variable was used to test the effect of different types of urban parks in the model, on residents' expressed happiness. The beta in Equation (2) has the same meaning as the alpha in Equation (1), and both represent the regression coefficient of the variable.

$$Happiness_{ij} = \beta_0 + \beta_1 X_{ij} + \beta_2 C_{ij} + \beta_3 T_{it} + \beta_4 D_{it} + \mathcal{E}_0 \quad (2)$$

Periods 3 and 4 (January to June 2020) in the study correspond to the time during the COVID-19 pandemic and full quarantine at home. Note that the precipitous decline in the outdoor activity population during the COVID-19 pandemic provided an excellent experimental setting for our study, controlling for many other influences. We extracted the data for this part and employed the baseline regression Equation (1) for periods before and during the pandemic separately. In this step, we expected to explore people's attitudes toward greenness during the pandemic period and detect the potential influence of the absence of greenness in daily life on people's sentiments.

In general, we proposed three steps for the statistical analysis. First, we examined the factors affecting residents' expressed happiness; second, we deciphered the heterogeneous effect within five NDVI levels and four urban park groups; finally, we compared the changes in residents' expressed happiness before and during the COVID-19 period, and attempted to interpret the phenomenon through the lens of greenness. All statistical analyses were performed using the Eviews 9 software. The framework of the methodology is illustrated in Fig. 1.

3. Results

3.1. Identification of factors associated with residents' expressed happiness

In Levene's test of the two groups of happiness data inside and outside the buffer area, $p = 0.000$; In the *t*-test, we found that $t = 4.623$ and $p = 0.000$, indicating a significant difference between the two groups. The median values of residents' happiness inside and outside the buffer were 0.713 and 0.706, respectively. Although the differences were small, the slightly higher happiness value of residents who have access to urban parks allowed us to conduct a follow-up study based on the premise that urban parks are positively correlated with the happiness of urban dwellers.

By testing all variables for the bivariate correlation, UPA and NP were excluded because their probability values exceeded 0.05; we selected six independent variables, including NDVI, and five control variables, ILP, LST, WP, WE, and PD. The results of the estimation of equation (1) are shown in Table 1; the R-square is 0.218. We can see that NDVI in urban parks was positively linked to residents' expressed happiness, and a one-standard-deviation increase in the NDVI caused a 0.255 standard growth in the happiness index. The associations of impervious land and LST with residents' happiness were opposite, and their coefficients were relatively low (−0.062 and −0.002, respectively). Both the presence and the area of the water surface within the sphere of social activity were positively related to people's happiness (0.065 and 0.064, respectively); their coefficients were quite similar. Moreover, places with a high PD (0.069) seemed to have happier residents. The relationship between residents' expressed happiness and the NDVI of urban parks in the four study periods is presented in Fig. 4. The dot plot indicates that NDVI in urban parks is significantly higher in spring and summer than in autumn and winter. Except for the WE, the coefficients of the five variables (NDVI of urban parks, ILP, LST, WP, and PD) are illustrated in Fig. 5a. As evident in Table 1 and Fig. 5a, the regression coefficient for NDVI was the highest and was almost four times higher than the others.

Table 1
Associations between the selected factors and expressed happiness.

Dependent Variable	Mean Happiness	
Variable	Coefficient	Probability
NDVI of urban parks	0.255***	0.000
Proportion of impervious land (ILP)	−0.062***	0.000
Land Surface Temperature (LST)	−0.002**	0.019
Proportion of water (WP)	0.064**	0.037
NDVI*the existence of water (WE)	0.065**	0.025
Population density (PD)	0.069***	0.000
Constant	0.799***	0.000

Note: This is the table showing the results of Equation (1), where the coefficient of "NDVI of urban parks" is α_1 value; the coefficients of "ILP," "LST," "WP," "WE" and "PD" are α_2 values; the constant is α_0 value in Equation (1). *p < 0.1, **p < 0.05, ***p < 0.01.

3.2. Potential heterogeneous effects of NDVI and urban parks on expressed happiness

In the regression employed on the graded NDVI, the "very low" grade was set to be the default; four classes from "low" to "very high" were included in the equation. The results are summarized in Table 2 and Fig. 5b; the R-square is 0.210. The coefficients of all four grades were significantly positive. The results indicate a monotonically increasing trend in the regression coefficients as the NDVI grade increases. Control variables were included, and their effects were consistent with those of the first regression.

We set each of the four urban park groups as the default term, adding the product terms of NDVI and other groups as dummy variables, and performed a regression (Table 3 and Fig. 5c). The results illustrate that the largest positive association between NDVI and residents' expressed happiness was found in subdistrict-scale urban parks (0.277), while the smallest was found in city-scale urban parks (0.212), although they comprised the largest areas. The coefficient for regional-scale urban parks was most similar to the overall coefficient in Table 1 (0.250 vs. 0.255). Residents' responses to NDVI did not exhibit a monotonous tendency with the changes in urban park groups, and the disparities between them were not so large.

3.3. Relationship between urban parks and residents' expressed happiness during the pandemic period

We reorganized our database into two parts: before the pandemic (including periods 1 and 2) and during the pandemic (including periods 3 and 4). By estimating the baseline regression separately, we observed that the effect of NDVI on expressed happiness was insignificant before the pandemic. Further, the regression coefficient during the pandemic period was highly significant (Table 4) and much larger than the result in Table 1 (0.372 vs. 0.255). All control variables were included in regression analysis.

In the heterogeneous effects test during the pandemic period, all four regression coefficients were significantly correlated, and the one for subdistrict-scale urban parks remained the largest, with the trends between groups being identical to those of full sample in Table 3 (Fig. 5d). It is noteworthy that all coefficients during the pandemic period increased substantially compared to the overall results presented in Section 3.2.

4. Discussion

4.1. Factor most associated with residents' expressed happiness in urban parks

We observed significant differences between inside and outside the buffer of urban parks, implying that people who have access to urban park services may have higher expressed happiness values. Our study primarily focused on residents who had access to urban parks and their services. This contributes to the literature because previous studies only considered green justice across age or ethnic groups and ignored the fact that not all people have access to green services (Enssle and Kabisch, 2020; Kabisch and Haase, 2014; Rigolon et al., 2018; Williams et al., 2020).

In exploring the factors associated with residents' expressed happiness, we observed that the estimates for both the overall NDVI and the

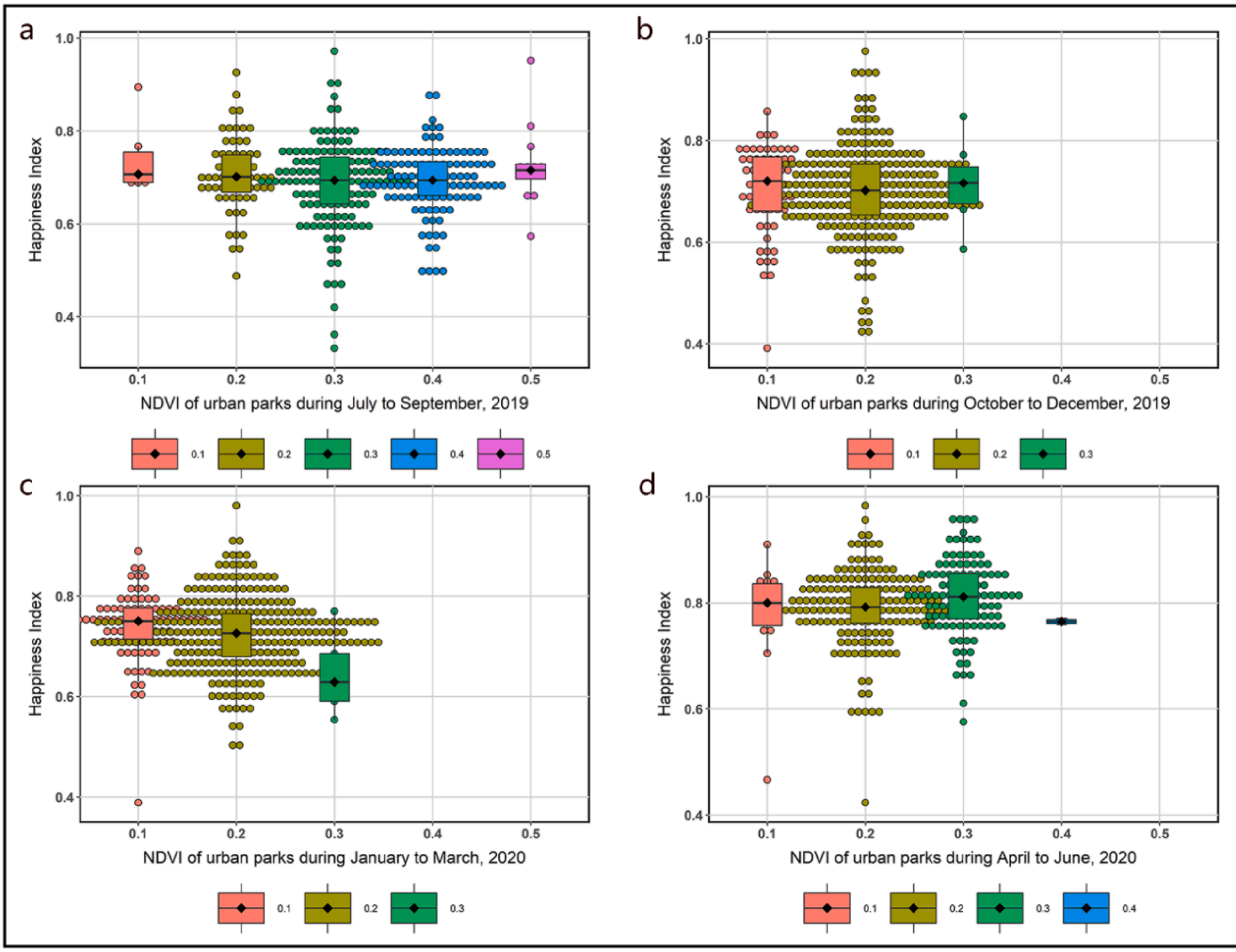

Fig. 4. The dot plots of the relationship between residents' expressed happiness and NDVI of urban parks in four study periods. Every dot in the figure represents an urban park.

graded NDVI in urban parks exhibited significant positive correlations with residents' expressed happiness, and their regression coefficients monotonically increased as the NDVI rating rose. In this study, the NDVI values are all positive because we identified that the raw water NDVI value was assigned negative values, while people's moods tended to be higher when they approached blue spaces (White et al., 2020); therefore, we considered the NDVI value of water as 0 to reduce the interference of this phenomenon. Our results demonstrate that the better the "green quality" (represented by the value of NDVI, with higher values indicating higher quality) of the urban park, the higher the associations between it and residents' expressed happiness. This may inspire residents' attention and care for green spaces. NDVI has already been used as an indicator of residential and surrounding greenness to explore its relationship with mental health in previous research (Amoly et al., 2014). Our results illustrate the extent of the potential impact of NDVI on people's happiness.

A recent study by Houlden et al. (2019) examined the relationship between the amount of green space within a certain radius of homes in London and the mental well-being of its residents. They observed a 0.52 unit increase in happiness for an increase of 1 ha of green space within a 300 m radius of people's homes. However, urban park areas did not have a significant effect on the happiness index in this study. These two contrasting results can be partly explained by the differences in the scope of the studies and their target populations: our study explored the impact of a single urban park on nearby residents, while the former focused on the general increase in the area of the surrounding green spaces. In addition, disparities in the impact of domestic and foreign urban parks on residents (Benita et al., 2019), caused by differences in the equality of green spaces, are also contributing factors.

The synergistic effects of water and urban parks on the buffer scale suggest that a high-quality living environment may be beneficial to people's happiness. Moreover, the coefficient of the proportion of water within the service range of the urban parks was very similar to that of the existence of water (0.064 vs. 0.065), which hints at the consideration of the impact of the amount of blue space on people's happiness in daily life. In the baseline regression, we found that both ILP and LST were negatively associated with people's expressed happiness, while PD had a positive association, although the value was small. It is generally accepted that the more urbanized the areas, the more noticeable the heat island effect (Rizwan et al., 2008). Given that the proportion of impervious land is an indicator of urbanization (Wang et al., 2001), and that land surface temperature is a reflection of the heat island effect (Imhoff et al., 2010; Yu et al., 2020), the collaborative effect of ILP and LST on people's expressed happiness is reasonable. Contrary to our expected result, the fact that people are relatively happier in densely populated areas can be partly explained by the diversity of recreational facilities. Places where people congregate tend to attract more commercial and entertainment venues, which can enrich people's social activities and, in turn, increase the attractiveness of the venue.

These findings suggest that there are different associations between different aspects of the living environment and residents' expressed happiness. They provide a basis for urban planning based on the residents' perspective and real "feedback," accessible through their social media posts. Specifically, the service area of an urban park needs to be

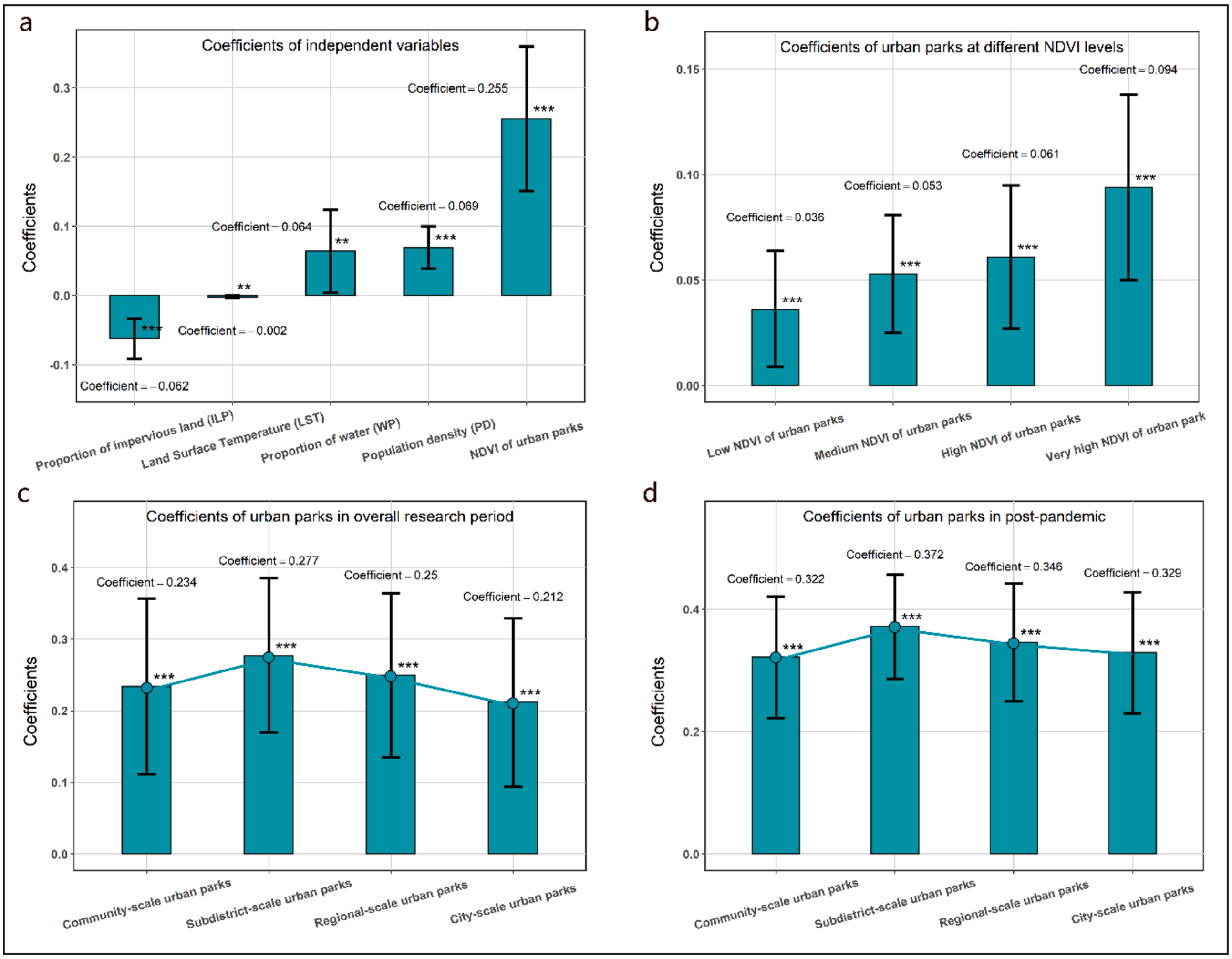

Fig. 5. The histograms of the coefficients of variables on residents' expressed happiness. *p < 0.1, **p < 0.05, ***p < 0.01.

Table 2
Sentiment dynamics at different NDVI levels.

Dependent Variable	Mean Happiness	
Variable (Default: very low)	Coefficient	Probability
Low	0.036^{***}	0.010
Medium	0.053^{***}	0.000
High	0.061^{***}	0.001
Very high	0.094^{***}	0.000
Proportion of impervious land (ILP)	-0.058^{***}	0.000
Land surface temperature (LST)	-0.002^{**}	0.041
Proportion of water (WP)	0.051*	0.098
Population density (PD)	0.062^{***}	0.000
Constant	0.795^{***}	0.000

Note: Temporal fixed effects are indicated by * p < 0.1, ** p < 0.05, *** p < 0.01.

considered when planning residential areas. This approach could contribute to ensuring green justice and bringing health benefits to residents.

4.2. People's green sensitivity to different grades of urban parks

By analyzing the potential heterogeneous effects of different grades of urban parks, we identified that people are most sensitive (in response to NDVI) to "green quality" (such sensitivity is hereafter referred to as "green sensitivity") in subdistrict-scale urban parks and least sensitive to those in city-scale urban parks, which have the largest areas and relatively more constituents. Subdistrict-scale urban parks are within people's daily life circle and have a high frequency of access (Feng et al., 2019), and inhabitants' green sensitivity reflects the important role of parks of suitable size in regulating people's daily moods. In contrast, city-scale urban parks have a larger range of services and poorer accessibility. In addition, people visit these parks for a variety of motivations, not just for the "green benefit," due to which they exhibit less green sensitivity.

Overall, to a certain extent, these findings can guide decision-makers and urban planners in the configuration and composition of different scales of urban parks. Concerning larger urban parks, more attention should be paid to the diversity of constituent elements to meet their ecosystem services and social service functions. However, that residents can enjoy sufficient green benefits to enhance their physical and mental health in relation to smaller urban parks should be guaranteed.

4.3. Residents' conversion in attitudes toward urban parks

The above discussion suggests that positive associations may exist between urban parks and people's expressed happiness. When the period of the study was split into before and during the pandemic on the basis of the unprecedented event, we observed an interesting phenomenon: the large increase in the NDVI coefficient (green sensitivity). This indicates that the pandemic has most likely contributed to a dramatic conversion in residents' attitudes toward "green quality." During the quarantine phase of the pandemic, the desire to go out had increased due to the sudden decrease in social activities. However, the threat from

Table 3
Sentiment dynamics in different scales of urban parks.

Dependent Variable	Mean Happiness			
Default	Community-scale urban parks	Subdistrict-scale urban parks	Regional-scale urban parks	City-scale urban parks
NDVI (Default group)	0.234***	0.277***	0.250***	0.212***
	(0.000)	(0.000)	(0.000)	(0.000)
NDVI* community-scale urban parks		−0.044	−0.016	0.022
		(0.184)	(0.719)	(0.652)
NDVI* subdistrict-scale urban parks	0.044		0.028	0.066*
	(0.184)		(0.405)	(0.088)
NDVI* regional-scale urban parks	0.016	−0.028		0.038
	(0.719)	(0.405)		(0.326)
NDVI* city-scale urban parks	−0.022	−0.066*	−0.038	
	(0.652)	(0.088)	(0.326)	
Constant	0.805***	0.805***	0.805***	0.805***
	(0.000)	(0.000)	(0.000)	(0.000)
Control variables	Yes	Yes	Yes	Yes
N	1,305	1,305	1,305	1,305
R^2	0.221	0.221	0.221	0.221

Note: Temporal fixed effects are included in the equation using time dummy variables, and period 4 is the default season. P-values are shown in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

COVID-19 prevented people from going to densely populated areas, making urban parks ideal visiting destinations. Consequently, urban parks have been given more attention and importance now than in the past. Furthermore, studies have shown that green spaces have a positive effect on relieving mental stress (Brooks et al., 2020); thus, at a particular time of high nervous tension, people's demand for greenness, and their motivations to visit green spaces increased.

During the separate testing of people's responses to different grades of urban parks during the pandemic, residents' performance was identical to the overall trend over the year, but with a one-third increase in green sensitivity. This phenomenon demonstrates that the pandemic did not alter the residents' preferences to visit urban parks, but significantly increased the positive influences of "green quality" on their expressed happiness. Similarly, the significant differences in residents' green sensitivity between the periods before and during the pandemic revealed that residents became aware of the importance of urban parks with high green quality in their daily lives after the pandemic and the ensuing restrictions, thus awakening their desire to visit urban parks.

4.4. Limitations and future studies

Our study has three main limitations. First, we assumed that residents within the urban parks' service area would visit the parks; however, this is uncertain and should be addressed in future studies.

Second, previous studies on environmental justice have pointed out that the elderly and children are vulnerable communities (Guo et al., 2019; Sikorska et al., 2020); thus, in studies on the correlations between NDVI of urban parks and happiness, perhaps these populations are more sensitive to "green quality." However, our raw data were derived from social media platforms, which are primarily used by younger generations. The narrowness of sample population groups leads to a major limitation in our data collection and should be considered by combining the traditional methods of investigation (similar to using questionnaires) and big data methods to ensure the balance of sampling. Given this drawback in obtaining data, future research should improve the data structure and expand the scope of the study to decipher the disparities and commonalities in residents' green sensitivity across cities to draw general conclusions.

Third, our study classified urban parks according to their size, and the fact that each park has a different composition, frequency of visitation, and urban dwellers' motivation to visit may have different effects on happiness (Giles-Corti et al., 2005). Future studies should consider park quality factors and use methods such as text analysis to explore the influence of parks on residents' mental health from different perspectives. In this study, we obtained residents' green sensitivity for each grade of the urban park. In future studies, the data provided by users (tweets in social media) can be applied to discover the most appropriate NDVI ranges for different grades of urban parks from the perspective of improving people's expressed happiness, thus providing guidance and recommendations for urban park planning.

It should be acknowledged that there are additional limitations, such as the fact that the data in this study measured the sentiment expressed on *Weibo* rather than people's actual happiness. Despite the increasing maturity of AI technology, discrepancies remain concerning measurements of true happiness. Moreover, as people experienced differing lifestyle and emotional changes during the pandemic and restrictions that cannot be attributed to greenspace alone, our results cannot entirely determine the factors influencing their happiness.

5. Conclusion

The COVID-19 pandemic may have had a significant negative impact on people's physical and mental health. Urban parks have stress-relieving benefits, and their association with people's mental health during the pandemic has been addressed in recent studies. However, few studies have applied big data obtained from social media (large populations) to explore the general impact of urban parks on happiness.

Consequently, in this study, nine independent variables were

Table 4
Sentiment dynamics before and during COVID-19 pandemic.

	Pre-pandemic	During the pandemic				
	Overall	Overall	Group 1	Group 2	Group 3	Group 4
NDVI of urban parks	−0.082	0.372***	0.322***	0.372***	0.346***	0.329***
	(0.081)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.695***	0.695***	0.695***	0.695***	0.695***	0.695***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
N	1,305	1,305	1,305	1,305	1,305	1,305
R^2	0.174	0.174	0.174	0.174	0.174	0.174

Note: Group 1, community-scale urban park; Group 2, subdistrict-scale urban park; Group 3, regional-scale urban park; and Group 4, city-scale urban park. Under the overall columns, individual fixed effects are included in the equation using group dummy variables, and group 2 is the default. P-values are shown in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

selected to identify the factors that are associated with residents' expressed happiness and observe whether there are differences in the relationship between urban parks and residents' expressed happiness before and during the pandemic. We also investigated the heterogeneous effects of different levels of urban parks on residents' happiness by dividing the parks into four groups. The results suggest that parks with higher NDVI values may lead to residents' higher happiness, and that subdistrict-scale urban parks have the greatest positive association between NDVI growth and residents' expressed happiness. In addition, the positive association between urban parks and residents' expressed happiness increased significantly after the outbreak of the COVID-19 pandemic.

In summary, our findings highlight the potential ability of urban parks to enhance residents' happiness, bridging the limitations of the study subjects and scope of previous studies. Planning guidance and recommendations for the humane design of parks can be expected from this study, which has significant implications for the development of nature and human health through urban planning.

CRediT authorship contribution statement

Yingyi Cheng: Conceptualization, Methodology, Data curation, Writing - original draft, Writing - review & editing. **Jinguang Zhang:** Conceptualization, Writing - original draft, Writing - review & editing. **Wei Wei:** Data curation, Writing - original draft, Writing - review & editing. **Bing Zhao:** Conceptualization, Writing - original draft, Writing - review & editing, Supervision.

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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