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Park Characteristics and Changes in Park Visitation before, during, and after COVID-19 Shelter-in-Place Order

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Abstract: The COVID-19 pandemic has limited people's visitation to public places because of social distancing and shelter-in-place orders. According to Google's community mobility reports, some countries showed a decrease in park visitation during the pandemic, while others showed an increase. Although government responses played a significant role in this variation, little is known about park visitation changes and the park attributes that are associated with these changes. Therefore, we aimed to examine the associations between park characteristics and percent changes in park visitation in Harris County, TX, for three time periods: before, during, and after the shelter-in-place order of Harris County. We utilized SafeGraph's point-of-interest data to extract weekly park visitation counts for the Harris County area. This dataset included the size of each park and its weekly number of visits from 2 March to 31 May 2020. In addition, we measured park characteristics, including greenness density, using the normalized difference vegetation index; park type (mini, neighborhood, community, regional/metropolitan); presence of sidewalks and bikeways; sidewalk and bikeway quantity; and bikeway quality. Results showed that park visitation decreased after issuing the shelter-in-place order and increased after this order was lifted. Results from linear regression models indicated that the higher the greenness density of the park, the smaller the decrease in park visitation during the shelter-in-place period compared to before the shelter-in-place order. This relationship also appeared after the shelter-in-place order. The presence of more sidewalks was related to less visitation increase after the shelter-in-place order. These findings can guide planners and designers to implement parks that promote public visitation during pandemics and potentially benefit people's physical and mental health.

Keywords: COVID-19; park visitation; park characteristics; behavior; SafeGraph

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1. Introduction

The COVID-19 pandemic has been the most critical global public health crisis during the past two years. On 11 March 2020, the World Health Organization (WHO) officially declared a global pandemic and urged all countries to take immediate action to halt the spread of the virus [1] suggesting maintaining physical distance from others as a way of controlling the pandemic [2]. In response to this global public health crisis, the majority of state and local governments in the United States (U.S.) issued policies aimed at slowing down the transmission, such as working from home, restricting gatherings, and closing restaurants and retail stores [3]. Harris County, encompassing Houston, Texas, and the surrounding communities, imposed a strict shelter-in-place (SIP) order called "Stay Home, Work Safe" on 24 March 2020; the order was to be effective until 30 April 2020 [4]. To ensure compliance with the order, Harris County temporarily shut down the majority of businesses and restricted access to recreational facilities such as shopping malls, restaurants, movie theaters, and gathering places for social activities [4]. The COVID-19 pandemic, along with the SIP policy, have had far-reaching influences on people's behavioral patterns and health outcomes.

1.1. Adverse Health Impacts of COVID-19 and Shelter-in-Place Policy

Studies have reported that because of home confinement, people's physical activity time reduced. For example, a descriptive study looking at pedometer data showed that staying at home during the COVID-19 lockdown period entailed a remarkable decrease in the level of physical activity in most countries [5]. A longitudinal study from China also indicated that the COVID-19 outbreak has been associated with prolonged sleeping time and decreased physical activity among groups of young people [6]. Another study in Spain found that young individuals and very active males decreased daily self-reported physical activity and increased inactive time during COVID-19 confinement [7]. In an international survey across 49 U.S. states and 14 countries, researchers found that the frequency of outdoor recreation participation for adults in urban areas declined sharply throughout the first few months of the pandemic [8]. The lack of physical activity during the pandemic should be a concern because inactivity is associated with a variety of health risks, such as all-cause mortality [9,10], cardiovascular disease [11], and type 2 diabetes [12]. Besides physical health risks, maintaining mental health has also become a challenge. Various COVID-19 related stressors, such as economic uncertainties and job insecurity [13], concern for personal or family members' health [14], and social isolation [15], contribute to an increased risk of mental health problems. Indeed, a recent study from the U.S. found that approximately four times more adults in the U.S. reported anxiety and depression symptoms compared to before the pandemic [16]. Thus, the potential health risks brought by the pandemic should raise concerns for policymakers and public health professionals looking to minimize the overall adverse impacts of COVID-19.

1.2. Health Benefits of Visiting Parks during the COVID-19 Pandemic

Parks are among the most common places for urban residents to receive various health benefits at low cost [17,18]. Parks provide ample spaces for physical activity [19], contribute to restoration and stress relief [20], promote life satisfaction [21], and enable recovery from hazard-related, stressful life events [22]. Previous studies have shown that the health benefits of parks can be explained and achieved through a variety of pathways, including promoting physical activity [23–27], social coherence [28–32], and psychological well-being [33–35]. The contribution of parks to health varies based on park characteristics. For example, parks that are larger or of higher quality and have greenness and nature views showed strong associations with people's well-being [36,37]. Thus, parks are vital to human health, and park characteristics play an important role in the ultimate health benefits of park visits. The COVID-19 pandemic and prolonged inactivity at home raised public awareness of the critical need for contact with parks in cities. The need for having parks to maintain physical and mental health became apparent. In an international exploratory study conducted in six European countries—Croatia, Israel, Italy, Lithuania, Slovenia, and Spain—individuals expressed a great need for spending time in urban green spaces during the pandemic, seeing them as places of relief from stress and locations for exercise and relaxation [38]. People in Australia have also noted the importance of green space in improving personal well-being during COVID-19 [39]. In fact, simply having a window facing green space has been shown to increase life satisfaction and self-reported happiness during the pandemic [40]. Thus, given all the physical and mental health benefits provided by parks during such a widespread public health emergency, understanding how park features influence visiting behaviors may provide guidance to park management or programming and offer insights into future urban policy and planning practices.

1.3. Park Visits during COVID-19

Has park visitation changed during the COVID-19 pandemic? Although there have been restrictions on visiting public places and big gatherings, park visits during the pandemic increased for some countries compared to the pre–COVID-19 period, according to Google mobility data [41,42]. A study conducted in New Jersey, US, revealed that park visits surged by 63.4 percent after the outbreak of the pandemic [43]. This could be indicative of people's physical and psychological needs during the lockdown period. Thus, we wonder what are the predictors of visitation dynamics? A study conducted in the U.S. found that although daily mobility decreased during the early stage of the pandemic, the reduction rate was significantly lower in areas with state parks in Maryland and areas with local-scale parks in California [44]. Moreover, in Oslo, Norway, outdoor physical activity levels increased after lockdown, with increases highest on trails that were greener and in more remote areas [45]. The question then becomes, which specific park features are associated with changes in visitation?

1.4. Methods for Examining Park Visitation

Studies have evaluated the variables correlated with the frequency of park usage, such as park greenness, size, accessibility, and proximity to home [46–48]. However, some studies on how park features play a role in attracting visitors have relied on cross-sectional surveys with self-reported park usage data [46]. Other studies have used observational methods, requiring researchers to count visitor numbers at the point of interest (POI) [49]. However, observational study can sometimes be time-consuming and is unable to cover a large number of parks. Thus, a more time-efficient method is encouraged, covering a variety of parks in an area during the same timeframe to allow comparisons among parks and offer objective park visitor counts. Some recent studies used data from mobile phones or social-networking platforms to highlight mobility patterns during the pandemic. For example, one study measured how the greenness or presence of parks at a civil or county level contributes to mobility [44]. Other studies have examined mobility pattern changes at parks and changes in demand for parks during the COVID-19 pandemic [41,45,50,51]. Unfortunately, these studies were not focused on how the park characteristics may be related to these changes. To fill this gap, this study utilized the open mobility data source SafeGraph, which supplies weekly visit data of POI locations such as parks. With this dataset, we were able to calculate the changes in visitation before, during, and after the Harris County COVID-19 SIP order. Based on the visitation changes, combined with the park characteristics, we aimed to test the following research hypotheses:

1. Changes occurred in park visitation in Harris County when comparing three time periods: before, during, and after the SIP order.
2. The variations seen in park visitation for the time periods before, during, and after SIP are associated with park characteristics.

The results from comparing the visitation changes in these three time periods and their relationship with park characteristics will assist park managers in making informed administration and maintenance decisions. In the long term, these findings can be used by landscape designers, planners, and public health authorities as they determine and create park features and programs that will best benefit people's health and encourage park visits during times of crisis.

2. Materials and Methods

The research procedures are shown in Figure 1, with Harris County, Texas, selected as the study site. It ranked first in the state of Texas for total confirmed COVID-19 cases and in the top five nationwide as of 17 February 2022, according to John Hopkins University's COVID-19 U.S. county-level tracking map [52] (Figure 2). SafeGraph's weekly park visitation POI data were used to calculate the percent change in park visitation before, during, and after Harris County's SIP order. The data dates ranged from the weeks encompassing 2 March to 31 May 2020. We then calculated park greenness and park type as our primary park characteristics, with sidewalk and bikeway as control variables, to examine how park characteristics are related to the percent change in park visits around the COVID-19 pandemic.

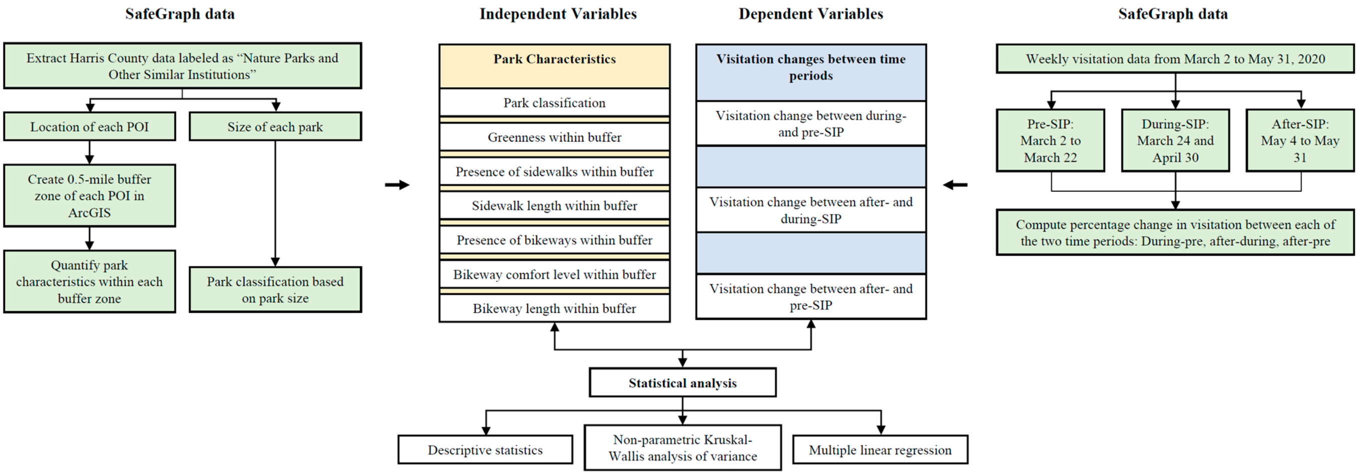

Figure 1. Harris County, Texas, research procedures diagram.

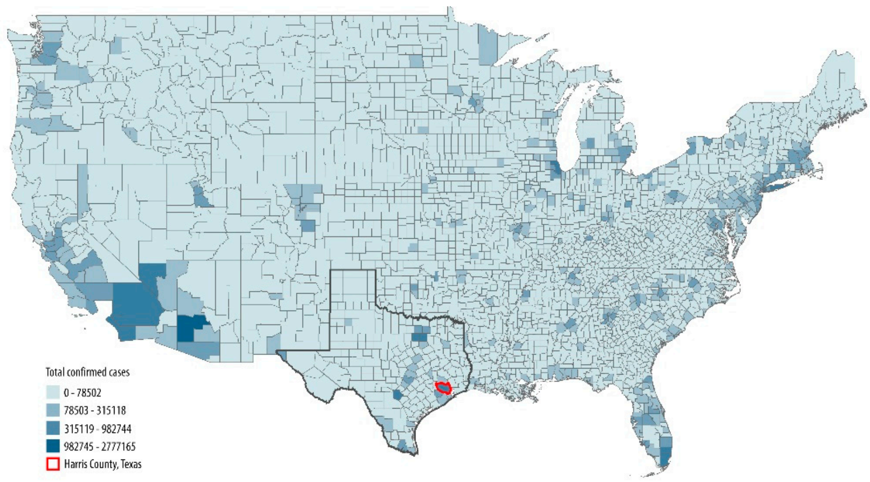

Figure 2. John Hopkins University U.S. COVID-19 confirmed cases tracking map at the county level on 17 February 2022, and the location of the study site, Harris County, Texas.

2.1. Visitation Change before, during, and after Shelter-in-Place Order

Visitation measures were extracted using SafeGraph data. The data on visit counts from anonymized mobile phone records contained 4.4 million POIs across the U.S. through location-enabled applications. A POI is a point that represents the geographical location of a place that a person may find interesting [53] POIs were classified based on the North American Industry Classification System, with those labeled as "Nature Parks and Other Similar Institutions" extracted. For larger parks with multiple attractions, the data may log multiple POIs. According to SafeGraph, the number of visits for each POI is recorded. In order to count as a visit to a given POI, a user must spend at least 4 min at the site [54].

Thus, our data included the weekly visit count for each POI and its geographical location from 2 March to 31 May 2020. In addition to POI location and weekly visits, the dataset also included the size of each park. The split points of weekly data for before, during, and after SIP was based on the official SIP order of Harris County [4]. The SIP order was in effect between 24 March and 30 April. In the dataset, we used park visitation data from four complete weeks from 30 March 30 to 26 April, a total of 28 days. The weeks beforehand were combined to represent the pre-SIP period and the weeks afterward were set as the post-SIP period—making the pre-SIP period from 2 March to 22 March, a total of 21 days, and the post-SIP period from 4 May to 31 May, a total of 28 days.

The percent change in the number of visits among the three times of comparison (before vs. during, during vs. after, and before vs. after SIP) was calculated as the dependent variables.

$$\%\text{ change between during SIP and pre SIP} = \frac{(\text{mean \# of visits during SIP} - \text{mean \# of visits pre SIP})}{\text{mean \# of visits pre SIP}}$$

$$\%\text{ change between post SIP and during SIP} = \frac{(\text{mean \# of visits post SIP} - \text{mean \# of visits during SIP})}{\text{mean \# of visits during SIP}}$$

$$\%\text{ change between post SIP and pre SIP} = \frac{(\text{mean \# of visits post SIP} - \text{mean \# of visits pre SIP})}{\text{mean \# of visits pre SIP}}$$

2.2. Park Assessment Method

This study considered park size and greenness density as the main park characteristics. In previous studies, park greenness and park size were two of the most important indicators associated with visitation [55,56]. We also controlled for park amenities as the covariate, such as the presence and length of sidewalks and the presence, length, and quality of bikeways. Because sidewalks are important park design elements, they have been explored in prior studies on the availability of sidewalks and bike lanes associated with visitation to greenspace among U.S. adults [57]. As the POI data were point-based, which represent the centroids of park attractions and do not match one-to-one to municipal park boundary data, we used a 0.5-mile buffer zone around each POI to calculate park characteristics (Figure 3). A 0.5-mile buffer is large enough to cover the vast majority of the parks in our study area. Moreover, a 0.5-mile buffer is a proper active radius for walking, according to nationally representative data from the 2009 National Household Travel Survey (NHTS), which showed the median value of desired walking distance for all age groups to be 0.5 miles [58]. Thus, park characteristics were calculated within each park's buffer zone.

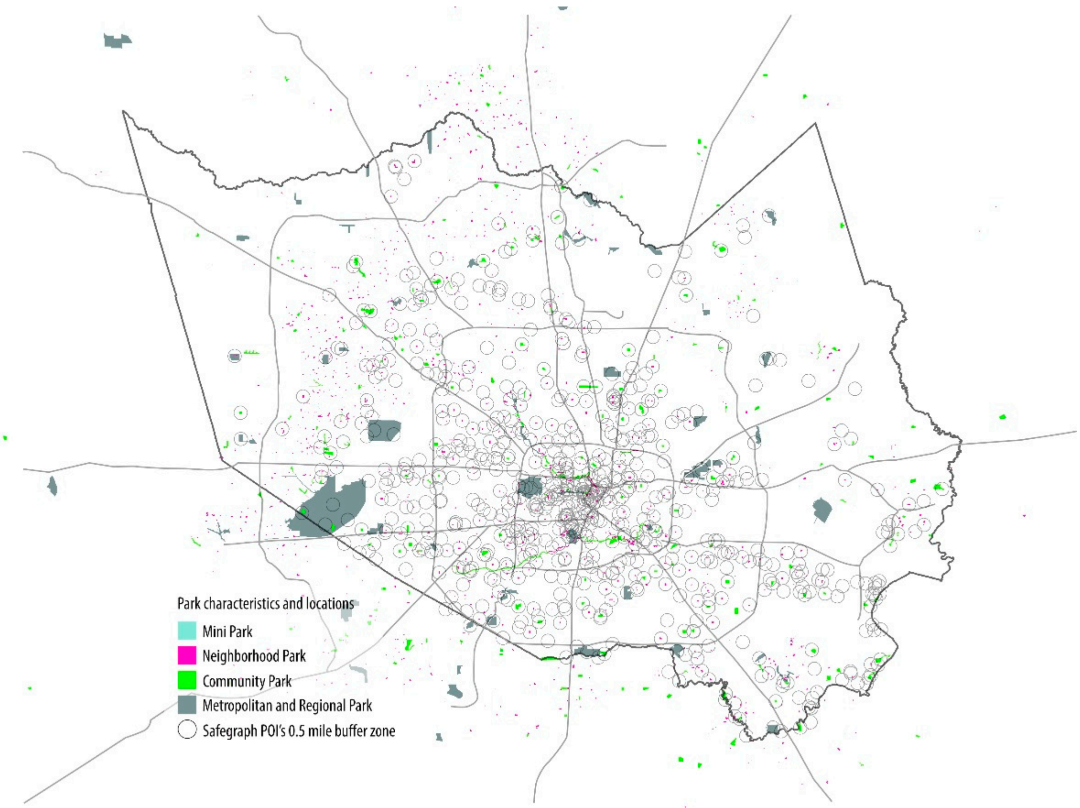

Figure 3. Park types and 0.5-mile buffer zone of each POI in Harris County, Houston, Texas.

2.2.1. Park Size Classification

Each park was classified as a mini park, neighborhood park, community park, or metropolitan/regional park based on its size according to National Recreation and Park Association (NRPA) guidelines [59]. According to the guidelines, mini parks are generally designed for dense population areas, sized between 2500 square feet and 1 acre, and serve people living within a 0.25-mile radius. Neighborhood parks vary between 1 and 15 acres and serve a broader population living within a 0.25 to a 0.5-mile radius. Community parks are between 16 and 99 acres and serve a number of neighborhoods within a 1 to 2-mile radius. Metropolitan/regional parks are larger than 100 acres and serve multiple communities; those larger than 500 acres are regional parks, which are multifunctional and can serve several towns within a one-hour drive.

2.2.2. Greenness Density

To assess the greenness within the 0.5-mile buffer zone of each POI, we calculated the normalized difference vegetation index (NDVI) using Landsat 8 imagery. NDVI is a sensitive indicator of tree canopy in which land surface reflects near-infrared (NIR) and visible (VIS) parts of the spectrum [60], which is calculated with the following equation [61]

$$\text{NDVI} = \frac{\text{NIR} + \text{VIS}}{\text{NIR} - \text{VIS}}$$

The calculated NDVI value ranges between -1 and 1, with lower values (≤ 0) indicating water bodies, snow, and barren areas of rock and sand, and higher values (>0) indicating photosynthetically active vegetation [61]. Landsat 8 imagery at 30 $\times$ 30 m resolution was obtained from the Global Visualization Viewer (GloVis) of the U.S. Geological Survey (USGS). The image taken between 27 March and 7 April 2020, was selected, as it had less than 10 percent cloud cover over our study site. Calculations were conducted in ArcGIS Pro, with negative values set to zero to avoid introducing bias in the greenness measurement. We calculated the mean NDVI within the 0.5-mile buffer zone of each POI (Figure 4).

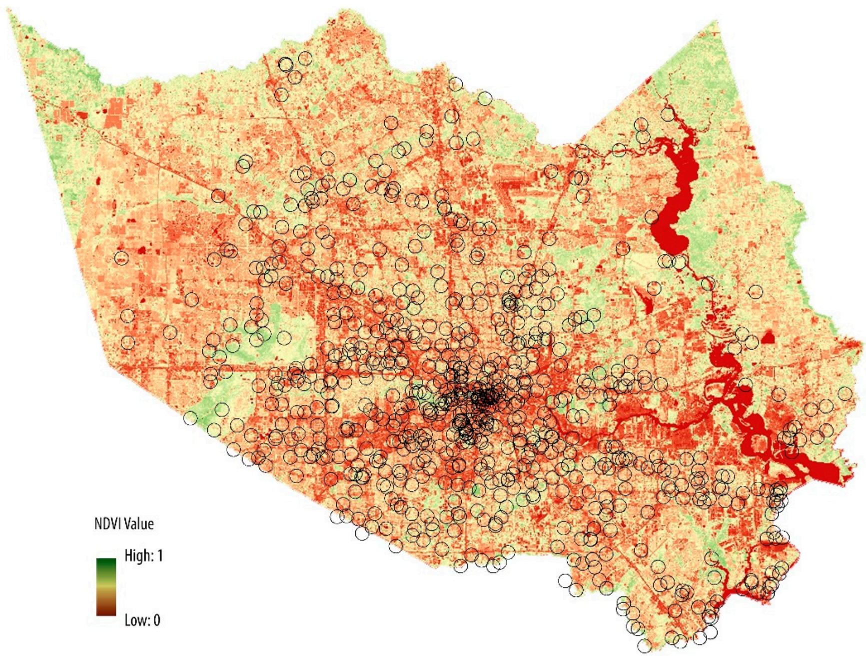

Figure 4. Mean NDVI value within each POI's 0.5-mile buffer zone in Harris County, Houston, Texas.

2.2.3. Sidewalks

For sidewalks, we prepared two variables: presence and length of sidewalks. Sidewalk data were obtained from the City of Houston Geographic Information System (COHGIS) data hub. This dataset was created based upon Houston's capital improvement projects and included sidewalks in various stages of improvement, including those programmed, under construction, and completed. The data were last updated on 12 July 2019. We created a subset of the sidewalk data that were labeled "completed". We then calculated the total length of sidewalks within the 0.5-mile buffer zone of each POI to determine the sidewalk density using ArcGIS Pro. No sidewalk quality data were available.

2.2.4. Bikeways

For bikeways, we prepared three variables: presence, length, and quality of bikeways. Bikeway data were obtained from the COHGIS data hub. The data were collected by the Houston Bikeways program, which contained each bikeway segment's length and its quality [62]. The quality was evaluated by the Houston Bike Plan study team based on comfort level for different population groups and abilities, and the evaluation criteria involved factors such as roadway width, travel lanes, travel speed, and traffic volume [63]. For the present study analysis, 1 represents "uncomfortable for most", 2 is "comfortable for confident bicyclists", 3 is "comfortable for most adults", and 4 is "comfortable for all ages and abilities". We calculated the total bikeway quality score by taking the value of each segment within the buffer area weighted by its length.

2.3. Statistical Analysis

We used R packages to perform statistical analyses of the visitation changes between pre-, during-, and post-SIP periods and the patterns associated with park features (Figure 4). We first tested for outliers and applied log transformation to those continuous variables not meeting the normality test. We then calculated descriptive statistics such as the mean, minimum, and maximum values of quantitative variables to observe the variables' distribution. Pearson's correlation coefficient was calculated for bivariate relationships. Next, to test for differences in visitation among pre-, during-, and post-SIP periods, we performed a nonparametric Kruskal–Wallis analysis of variance, which is typically used to compare three or more groups. Multiple linear regression (MLR) models were then fitted with vegetation level (NDVI) and park classification as our primary independent variables. Visitation percent changes between the compared time periods served as the dependent variables. MLR was used because we involved multiple parks features as our predictors of visitation change patterns. The control variables included in the regression models were the presence and quantity of sidewalks, and the presence, quantity, and quality of bikeways.

3. Results

3.1. Park Characteristics

Descriptive statistics of the POIs are presented in Table 1. A total of 727 parks' POIs were studied within Harris County (Houston, TX, USA). The NDVI values ranged from 0.0003 to 0.418, with the values normally distributed. Mini parks, with sizes ranging from 693 to 43,044 square feet (mean of 15,136 square feet), had 257 POIs. Neighborhood parks, with sizes ranging from 44,174 to 434,634 square feet (mean of 181,981 square feet), had 338 POIs. Community parks, with sizes ranging from 656,737 to 4,288,013 square feet (mean of 900,712 square feet), had 107 POIs. Metropolitan/regional parks, ranging in size from 4,455,555 to 350,428,815 square feet (mean of 33,923,892), had 25 POIs. Sidewalks were found to exist within the buffer zones of 367 POIs, with 255 POIs shown to have bikeways in their buffer zones. The weighted bikeway comfort level of each buffer zone ranged from least comfortable to most comfortable. Of the POI buffer zones, 128 had bike trails that were uncomfortable for most people, 88 were comfortable for confident bicyclists, 29 were comfortable for most adults, and only 1 had comfortable bikeways for all ages and abilities.

Table 1. Descriptive statistics for Harris County, Texas, POI variables.

	Frequency	Min	Max	Mean
Total POI	727	-	-	-
NDVI within 0.5-mile buffer zone	-	0.0003	0.418	0.242
Park size (sq ft)	-	693	350,428,815	1,514,657
Park size classification	-	-	-	-
Mini (sq ft)	257 (35%)	693	43,044	15,136
Neighborhood (sq ft)	338 (46%)	44,174	434,634	181,981
Community (sq ft)	107 (15%)	656,737	4,288,013	1,573,023
Metropolitan/regional (sq ft)	25 (4%)	4,455,555	350,428,815	33,923,892
Presence of sidewalks	365 (50%)	-	-	-
Sidewalk length (mile)	-	0.004	12.296	1.243
Presence of bikeways	255 (35%)	-	-	-
Bikeway length (miles)	-	0.054	5.185	1.42
Bikeway comfort level	-	-	-	-
S1 (uncomfortable for most)	128 (18%)	-	-	-
S2 (comfortable for confident bicyclists)	88 (12%)	-	-	-
S3 (comfortable for most adults)	29 (4%)	-	-	-
S4 (comfortable for all ages and abilities)	1 (0.01%)	-	-	-

3.2. Mean Visitation Differences before, during, and after SIP

In the present research, we hypothesized that the visitation to parks differs among the before, during, and after SIP order time periods. The differences in the visitation to parks between the three time periods were supported by using the Kruskal–Wallis nonparametric analysis of variance, with the results shown in Table 2 (all types of parks together, Kruskal–Wallis χ^2 = 89.662, df = 2, p < 0.001). The pairwise comparisons using Wilcoxon rank indicated mean visitation decreased significantly from pre- to during-SIP periods (Bonferroni adjusted p < 0.001), increased from during- to post-SIP periods (Bonferroni adjusted p < 0.001), and decreased from pre- to post-SIP periods (Bonferroni adjusted p < 0.001). We conducted subgroup analysis based on park size classification. The significant difference among pre-, during- and post-SIP periods remained for mini (Kruskal–Wallis χ^2 = 60.21, df = 2, p < 0.001), neighborhood (Kruskal–Wallis χ^2 = 62.418, df = 2, p < 0.001), and community parks (Kruskal–Wallis χ^2 = 13.905, df = 2, p < 0.001), but not for the metropolitan/regional parks (Kruskal–Wallis χ^2 = 2.515, df = 2, p > 0.05). This was likely due to the small sample size. These results suggest that, overall, visitation significantly declined after the issuance of the SIP order. Although visitation increased after the SIP was lifted, it did not return to pre-SIP levels in the following month.

Table 2. Analysis of the Kruskal–Wallis test for the means.

	Pre	During	Post	Kruskal–Wallis
All	15.178	8.367	11.217	89.662 ***
Mini	7.568	3.911	5.135	60.21 ***
Neighborhood	12.421	7.057	9.070	62.418 ***
Community	22.929	13.716	19.252	13.905 ***
Metropolitan/regional	97.526	48.997	68.383	2.515

p < 0.001 ***.

3.3. Pearson's Correlation

Table 3 presents the correlation matrix among variables. We found that the percent change between the during-SIP and pre-SIP periods' visitation was positively correlated with NDVI within the 0.5-mile buffer zone (r(725) = 0.12), meaning that greener parks had a smaller visitation decrease during-SIP when compared to pre-SIP. However, a negative correlation was observed between bikeway quantity and visitation change between during- and pre-SIP (r(253) = −0.191), indicating that bikeway quantity did not guarantee visitation in the during-SIP period. Buffer zones with higher bikeway quantity had a higher reduction rate compared to the pre-SIP period. Park size was not correlated with percent change between during- and pre-SIP periods but had a marginally negative correlation with percent change for post- and during-SIP periods (r(725) = −0.067) at a level of p < 0.1; bigger parks likely had smaller growth in visitation numbers after the SIP order ended.

For percent changes between post- and pre-SIP visitation, NDVI was positively correlated (r(725) = 0.135), confirming that greener parks had a lower reduction rate in visitation, while bikeway quantity was negatively correlated (r(253) = −0.192).

Table 3. Pearson's correlation of continuous variables.

	Park Size	NDVI	Sidewalk Quantity	Bikeway Quantity	During- vs. Pre-SIP % Change	Post- vs. during-SIP % Change	Post- vs. Pre-SIP % Change
Park size	-	-	-	-	-	-	-
NDVI	0.279 ***	-	-	-	-	-	-
Sidewalk quantity	–0.035	–0.058	-	-	-	-	-
Bikeway quantity	–0.133 *	–0.336 ***	–0.03	-	-	-	-
During- vs. pre-SIP % change	0.018	0.12 **	–0.031	−0.191 **	-	-	-
Post- vs. during-SIP % change	–0.067 +	–0.03	–0.05	0.007	–0.297 ***	-	-
Post- vs. pre-SIP % change	0.029	0.135 ***	–0.048	–0.192 **	0.724 ***	0.195 ***	-

$p < 0.001$ ***, $p < 0.01$ **, $p < 0.05$ *, $p < 0.1$ +.

3.4. Percent Changes Associations with Park Characteristics

We fitted a multiple linear regression with percent changes between pre-, during-SIP periods, and park characteristics, with the results shown in Table 4. It is significant that NDVI within the 0.5-mile buffer zone is positively related to the visitation changes between the during- and pre-SIP periods, both in the unadjusted and adjusted models. That is, parks with higher NDVIs were associated with less visitation decline in the during-SIP period relative to before the SIP, and the relationship remained significant after adjusting for the presence of sidewalks and bikeways in Model 2. In addition, Model 2 indicates that parks with the presence of sidewalks had a higher decrease in visitation in the during-SIP period compared to those without sidewalks. In Model 3, after adjusting for sidewalk quantity, bikeway quantity, and bikeway quality, the relationship of higher NDVI and lower visitation decrease remained significant. In conclusion, although park visitation decreased overall during-SIP compared to pre-SIP, the level of decrease varied; parks with higher NDVI had lower reduction rates and those with sidewalks had higher reduction rates.

Table 5 shows the results of the relationship between post- vs. during-SIP percent changes and park characteristics. There was no correlation between NDVI, park classification, and change in visitation between the post- and during-SIP periods in the unadjusted model. However, in Model 2, after adjusting for the presence of sidewalks and bikeways, NDVI showed a negative relationship with visitation changes, indicating that greener parks had less decline in visitation after the SIP order. In Model 3, the relationship with NDVI disappeared after adjusting for sidewalk quantity, bikeway quantity, and comfort level. In the meantime, the percent change in visitation between after SIP and during SIP are greater in neighborhood parks than mini parks, meaning neighborhood parks witnessed a higher reduction rate compared to mini parks.

Table 6 shows the relationship between post- and pre-SIP visitation change and park characteristics. Higher NDVI again showed a significant positive relationship with visitation change in both the unadjusted and adjusted models. It demonstrated that greener parks had lower variation in visitation between the post- and pre-SIP order. That is, although visitation to parks reduced post-SIP relative to pre-SIP, greener parks had lower reduction rates. In addition, in Model 2, after adjusting for the presence of sidewalks and bikeways, parks with sidewalks compared to those without sidewalks had a higher reduction rate in visitation change between post-SIP and pre-SIP. Moreover, Model 3, which was adjusted for sidewalk quantity, bikeway quantity, and bikeway comfort level, showed that the buffer zone with the most comfortable bikeways was associated with less decline in visitation after the SIP order than before the SIP order. However, this result may not be robust due to the small number of POIs falling within this category.

Table 4. Multiple linear regression analysis for during- vs. pre-SIP visitation changes.

	Model 1: Park Greenness + Park Classification (Unadjusted)					Model 2: Park Greenness + Park Classification (Adjusted)					Model 3: Park Greenness + Park Classification (Adjusted)				
				95% CI					95% CI					95% CI	
	B	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**
(Intercept)	−82.285	8.769	−9.384 ***	−99.556	−65.013	−41.58	8.809	−4.72 ***	−58.873	−24.286	−78.331	13.093	−5.983 ***	−104.133	−52.528
NDVI	172.436	33.815	5.099 ***	105.832	239.041	70.949	28.188	2.517 *	15.609	126.289	163.452	44.172	3.7 ***	76.4	250.504
Park classification (Mini as reference)															
Neighborhood	5.59	4.064	1.375	−2.415	13.595	−0.155	3.635	−0.043	−7.292	6.982	4.747	4.376	1.085	−3.876	13.371
Community	0.172	8.812	0.02	−17.184	17.529	−0.787	5.203	−0.151	−11.001	9.427	−0.223	9.407	−0.024	−18.762	18.316
Metropolitan/regional	−12.833	15.917	−0.806	−44.184	18.518	−7.397	9.353	−0.791	−25.759	10.966	−6.251	18.955	−0.33	−43.607	31.105
Presence of sidewalks						−7.864	4.124	−1.907 +	−15.959	0.232					
Presence of bikeways						−5.483	4.48	−1.219	−14.317	3.351					
Sidewalk quantity											0.675	1.434	0.471	−2.15	3.501
Bikeway quantity											−0.8	2.467	−0.324	−5.661	4.061
Bikeway comfort level (S1 less comfortable as reference)															
S2											−5.597	4.9	−1.142	−15.254	4.061
S3											2.807	7.31	0.384	−11.598	17.212
S4 (More comfortable)											38.406	32.14	1.195	−24.934	101.745

$p < 0.001$ ***, $p < 0.05$ *, $p < 0.1$ +. Model 2: adjusted for the presence of sidewalks and presence of bikeways. Model 3: adjusted for sidewalk quantity, bikeway quantity, and bikeway comfort level.

Table 5. Multiple linear regression analysis for post- vs. during-SIP visitation changes.

	Model 1: Park Greenness + Park Classification (Unadjusted)					Model 2: Park Greenness + Park Classification (Adjusted)					Model 3: Park Greenness + Park Classification (Adjusted)				
				95% CI					95% CI					95% CI	
	B	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**
(Intercept)	95.093	24.892	3.82 ***	46.063	144.123	85.411	18.545	4.606 *	49.002	121.819	128.915	37.263	3.46 ***	55.479	202.351
NDVI	−148.988	95.994	−1.552	−338.066	40.091	−107.511	59.344	−1.812 *	−224.020	8.998	−187.796	125.716	−1.494	−435.552	59.959
Park classification (Mini as reference)															
Neighborhood	−25.716	11.537	−2.229	−48.441	−2.992	−10.973	7.654	−1.434	−25.999	4.053	−26.349	12.454	−2.116 *	−50.892	−1.806
Community	−21.445	25.015	−0.857	−70.717	27.827	−3.81	10.953	−0.348	−25.313	17.693	−21.674	26.773	−0.81	−74.437	31.088
Metropolitan/regional	−2.815	45.184	−0.062	−91.814	86.184	−3.76	19.691	−0.191	−42.419	34.899	−6.551	53.948	−0.121	−112.869	99.766
Presence of sidewalks						−1.585	8.681	−0.183	−18.629	15.459					
Presence of bikeways						−7.481	9.473	−0.79	−26.079	11.117					
Sidewalk quantity											−1.432	4.08	−0.351	−9.474	6.609
Bikeway quantity											−8.404	7.02	−1.197	−22.239	5.431
Bikeway comfort level (S1 less comfortable as reference)															

Table 5. *Cont.*

	Model 1: Park Greenness + Park Classification (Unadjusted)					Model 2: Park Greenness + Park Classification (Adjusted)					Model 3: Park Greenness + Park Classification (Adjusted)				
				95% CI					95% CI					95% CI	
	B	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**
S2											−14.136	13.947	−1.014	−41.621	13.35
S3											−24.385	20.803	−1.172	−65.383	16.613
S4 (more comfortable)											31.476	91.471	0.344	−148.792	211.743

$p < 0.001$ ***, $p < 0.05$ *. Model 2: adjusted for the presence of sidewalks and presence of bikeways. Model 3: adjusted for sidewalk quantity, bikeway quantity, and bikeway comfort level.

Table 6. Multiple linear regression analysis for post- vs. pre-SIP visitation changes.

	Model 1: Park Greenness + Park Classification (Unadjusted)					Model 2: Park Greenness + Park Classification (Adjusted)					Model 3: Park Greenness + Park Classification (Adjusted)				
				95% CI					95% CI					95% CI	
	B	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**	**B**	**SE**	**T**	**Lower**	**Upper**
(Intercept)	−56.179	12.106	−4.641 ***	−80.024	−32.335	−25.068	11.761	−2.132 *	−48.158	−1.979	−36.326	17.643	−2.059 *	−71.095	−1.556
NDVI	157.272	46.684	3.369 ***	65.319	249.225	91.385	37.635	2.428 *	17.498	165.272	126.039	59.523	2.117 *	8.734	243.344
Park classification (Mini as reference)															
Neighborhood	−1.791	5.611	−0.319	−12.842	9.261	0.356	4.854	0.073	−9.173	9.885	−2.915	5.896	−0.494	−14.535	8.705
Community	−3.813	12.165	−0.313	−27.775	20.149	4.52	6.946	0.651	−9.113	18.161	−3.523	12.676	−0.278	−28.505	21.458
Metropolitan/regional	−7.998	21.974	−0.364	−51.28	35.284	−3.535	12.488	−0.283	−28.052	20.981	−2.773	25.543	−0.109	−53.111	47.565
Presence of sidewalks						−12.801	5.506	−2.325 *	−23.610	−1.992					
Presence of bikeways						−4.579	6.008	−0.762	−16.374	7.215					
Sidewalk quantity											0.678	1.932	0.351	−3.129	4.486
Bikeway quantity											−5.256	3.324	−1.581	−11.807	1.294
Bikeway comfort level (S1 less comfortable as reference)															
S2											−10.893	6.603	−1.65	−23.906	2.121
S3											−11.334	9.85	−1.151	−30.745	8.077
S4 (more comfortable)											100.533	43.309	2.321 *	15.181	185.884

$p < 0.001$ ***, $p < 0.05$ *. Model 2: adjusted for the presence of sidewalks and presence of bikeways. Model 3: adjusted for sidewalk quantity, bikeway quantity, and bikeway comfort level.

4. Discussion

The COVID-19 pandemic has impacted people's visitation to public places because of social distancing and shelter-in-place (SIP) orders. Findings from this study showed that overall, in Harris County, Texas, visitation to parks have decreased since the SIP order came into effect. Though the visitation number increased after the SIP order ended compared to during the SIP, the number of visits is still smaller than before the SIP. The results were consistent with most of the countries that applied restrictive regulations to limit public gatherings [41]. However, within the U.S., the results are inconsistent with the study that used geotagged social media data from Instagram in New Jersey, which observed that park visitation was higher during the first month of their stay-at-home order than in the preceding month [43]. One explanation could be the different effective dates and duration of shelter-in-place orders between Texas and New Jersey [3]. Another apparent explanation is that we used different datasets. The Instagram data relied more on the user and their self-reporting, while Safegraph data were collected from mobile phone apps. Any person with a mobile phone could be a data source. Despite the difference in visiting trends, our study found that although park visitation decreased during the SIP, the variation change patterns between two different time periods were related to some of the park characteristics. In one of the previous studies, park characteristics such as the location's latitude and longitude are positively associated with park visitation during the COVID-19 pandemic [64]. Our study further examined the design features of parks.

The results indicated that more greenness within 0.5 miles of a POI was associated with a lower reduction rate in visitation change to parks from before to during and before to after the shelter-in-place order. These results support previous research that divisions with higher enhanced vegetation indices are associated with lower reduction rates in mobility in Maryland, U.S. [44]. These results also lend support to the conclusion from the literature that vegetation-rich parks need to be considered more in the park design and planning process given the benefits provided to support citizen's physical and mental health during a time of pandemic [44,45]. Further, our results demonstrated that the size of parks also impacted visitation patterns, with there appearing to be a lower reduction rate in visiting mini parks compared with neighborhood parks during the SIP order compared to after the SIP order. One explanation is that mini parks are more common in higher-density areas and can be easily accessed without traveling far from individuals' residences, making them more viable recreational spaces during an SIP. The presence of sidewalks was related to higher reduction rates in visitation during-SIP and post-SIP orders compared to pre-SIP. It could be that, in trying to avoid a close encounter with others, people stayed away from areas with sidewalks because sidewalks represent an assigned space for pedestrian movement. Overall, the results suggest the importance of park characteristics such as greenness and dispersed mini parks versus larger parks as maintaining people's visitation to parks during the pandemic and potentially benefiting their mental and physical health.

Results from this study can provide evidence for designers, planners, and public authorities to better prepare for public health emergencies. Research has shown that isolation during the COVID-19 lockdown period may have been a significant factor in causing stress or mental-related diseases [65]. Studies conducted in both the United Kingdom and Italy established the association between the COVID-19 pandemic and an increased risk of developing sleep disorders, depression, anxiety, and poorer well-being [6,66,67]. At the same time, recent studies have indicated the positive effect of green space on mental health during the pandemic, supporting the hypothesis that people may seek physiological and psychological benefits from visiting parks [40,68,69]. Given the pandemic's effect on mental health and the advantages of green space for mental health, we recommend designers, planners, and policymakers invest more in mini parks in cities that are scattered and easily accessible. In addition, increasing greenness density, specifically leafy trees, in parks may maintain park usage during emergency times, while it also necessary to consider how to maintain social distance with park design.

Our study has several strengths. To the best of our knowledge, this study is the first to examine the effect of park characteristics on park visitation change patterns between before, during, and after a SIP order relating to the COVID-19 pandemic. We used SafeGraph POI data to examine the percent changes in park visitation. SafeGraph is free of charge and provides accurate spatial locations with weekly visitation data. In addition to already studied park-related characteristics, NDVI, and park size [44], we also considered the presence of sidewalks and bikeways, the quantity of sidewalks and bikeways, and the comfort level of bikeways for a 0.5-mile radius around each POI. Our results identified specific park features involving park greenness, park type, and the presence of sidewalks as the main predictors of visitation change patterns. Additionally, we provided a timely recommendation to keep parks open in the event of a pandemic.

This study also has some limitations. First, the SafeGraph data were not one park, one POI. This is one major limitation of the POI data: large parks usually contain multiple POIs and an individual may visit multiple POIs in the one park. If we aggregate all attractions by summing the visit counts, this would result in an overestimation of visitation to one park. Thus, we did not use the park boundary as the unit of measurement for NDVI, sidewalk, and bikeway conditions. Instead, we used a 0.5-mile buffer area surrounding each POI. However, for smaller parks, we may have accounted for many areas outside of the park; for larger parks, we may not have covered the entire territory. Second, while we were only able to examine the quantity of greenness using NDVI, we were unable to examine the quality and maintenance of park greenness. Future studies could use human eye-level measurements, especially human perception of greenness. Third, we classified the parks into four categories based upon the park size instead of the park's actual function. It might be that some parks have special functions, such as a dog park or children's park, which may have important implications on park visitation. Fourth, there are other park characteristic-related variables that we did not include in our study, such as park amenities (gathering place, equipment, food access, etc.), entrance fee, and hours. Other factors such as weather conditions, sociodemographic characteristics of the area, surrounding land use, and surrounding retail or other destinations could be control variables. Lastly, we examined park characteristics and park usage variation patterns around the COVID-19 pandemic, with the assumption that park visits support human health. However, we were unable to collect any health-related data. Our study examined a relatively short time period immediately before, during, and after the SIP order. The visitation pattern and its health impacts may display more complex dynamics over a longer period. Future studies could build on this study by examining park visitation change and health conditions using surveys or publicly released health data.

5. Conclusions

The COVID-19 pandemic has affected people's physical and mental health, as well as their lifestyles. In this study, we utilized weekly visitation data from 727 public parks in Harris County, Texas, collected by the commercial organization SafeGraph, to assess the change in visitation between before, during, and after the shelter-in-place order, as well as the shift patterns associated with park characteristics. Our results showed that overall, park visitation decreased during the four-week SIP period compared with the average visitation within three weeks before the SIP period. Although in the four weeks after the SIP period, the visitation increased compared to the during-SIP period, visitation was still less than pre-SIP. The results indicated that the shelter-in-place policy that limited people's access to public places was associated with decreased park visitation. However, the degree of reduction varied according to the park features. Further investigation revealed that greener parks had a much lower reduction rate when compared to less-green parks. Similarly, mini parks showed a significantly lower reduction rate than neighborhood parks. Additionally, parks surrounded by sidewalks were related to a higher reduction rate in visitation, suggesting people's need for social distance. These findings can guide park management and maintenance practices, as well as inform planners and designers to create parks that promote public visitation during pandemics and potentially benefit people's physical and mental health. We believe that planners and policymakers should continue to invest in preferred greener parks and more accessible mini parks. Moreover, in the face of such a global pandemic, park design should also consider how to maintain social distance to reduce visitors' concerns about being exposed to COVID-19.

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