Human Mobility to Parks under the COVID-19 Pandemic and Wildfire Seasons in the Western and Central United States

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Abstract

In 2020, people's health suffered a great crisis under the dual effects of the COVID-19 pandemic and the extensive, severe wildfire in the western and central United States (U.S.). Parks, including city, national, and cultural parks, offer a unique opportunity for people to maintain their recreation behaviors following the social distancing protocols during the pandemics. However, massive forest wildfires in western and central US, producing harmful toxic gases and smoke, pose significant threats to human health and affect their recreation behaviors and visitations to parks. In this study, we employed the Geographically and Temporally Weighted Regression (GTWR) Models to investigate how COVID-19 and wildfires jointly shaped human visitations to parks, regarding the number of visitors, dwell time, and travel distance from home, during June - September 2020. Our findings indicated that people tended to travel closer from home and spent less time at parks as more COVID-19 cases were reported. However, with the stay-at-home restriction lifted and the reopen of some large national parks, people traveled further distances to those places (e.g., Yellowstone National Park) regardless the peak of pandemics in June 2020. Moreover, we found people intended to decrease the visitations to the parks surrounded by wildfires and shorten the time there. This study provides important insights on people's responses in recreation and social behaviors when facing multiple serve crises that impact their health and wellbeing, which could support the preparation and mitigation of the health impacts from future pandemics and natural hazards.

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Key Points:

- We investigated human mobility patterns to parks under COVID-19 pandemic and wildfire season in western and central United States.
- We found a general trend of avoidance to the parks with fewer visitors and dwell time in the places with high COVID-19 cases.
- People travel further and spend longer time at the parks away from the wildfires with less smoke, especially in August - September.

Abstract

In 2020, people's health suffered a great crisis under the dual effects of the COVID-19 pandemic and the extensive, severe wildfire in the western and central United States (U.S.). Parks, including city, national, and cultural parks, offer a unique opportunity for people to maintain their recreation behaviors following the social distancing protocols during the pandemics. However, massive forest wildfires in western and central US, producing harmful toxic gases and smoke, pose significant threats to human health and affect their recreation behaviors and visitations to parks. In this study, we employed the Geographically and Temporally Weighted Regression (GTWR) Models to investigate how COVID-19 and wildfires jointly shaped human visitations to parks, regarding the number of visitors, dwell time, and travel distance from home, during June - September 2020. Our findings indicated that people tended to travel closer from home and spent less time at parks as more COVID-19 cases were reported. However, with the stay-at-home restriction lifted and the reopen of some large national parks, people traveled further distances to those places (e.g., Yellowstone National Park) regardless the peak of pandemics in June 2020. Moreover, we found people decreased the visitations to the parks surrounded by wildfires and shortened the time there. This study provides important insights on people's responses in recreation and social behaviors when facing multiple serve crises that impact their health and wellbeing, which could support the preparation and mitigation of the health impacts from future pandemics and natural hazards.

Plain Language Summary

This study investigates the spatiotemporal patterns of human visitation to parks during the COVID-19 pandemic and wildfire seasons in 2020 across the western and central United States. We estimate how the COVID-19 outbreaks, wildfire occurrence, and wildfire induced air pollutions affect the number of unique visitors to the parks, the minimum dwell time people spent at parks, and the travel distances from home to parks. Overall, people tended to travel closer from home and spent less time at parks where there were more COVID-10 cases reported likely due to the infection protection behavior and risk altitude. Also, during the major wildfire season (August – September), more people traveled further to visit the parks away from the wildfires and stayed longer there. This study explored people's response in physical activity and recreation behaviors under multiple crises that pose threats to their health and wellbeing. Our findings should provide some insights to the preparation of the future pandemics and natural hazards.

1 Introduction

The year 2020 has seen the confluence of two major crises, i.e., the COVID-19 pandemic and the extensive, severe wildfires in August – September, impacting people's health and wellbeing in western and central United States. The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), commonly referred to as COVID-19, was initially detected in Wuhan, China, and has widely spread across the globe (Zhu et al., 2020). On January 30, 2020, the World Health Organization (WHO) declared the outbreak as a public health emergency of international concern, due to its rapid and hazardous spread and the need for a coordinated response among countries worldwide (World Health Organization, 2020). In the United States, there were about 20 million confirmed cases and 344,227 deaths as of December 31, 2020. Given that there was no effective vaccines and treatment available for SARS-CoV-2, non-pharmaceutical interventions (NPIs) have been used as the key weapon against the COVID-19 pandemic. Multiple NPI strategies and policies have been conducted in the US since February 2, 2020 (NAFSA, 2021), including travel bans, lockdowns, school/business closures, movement restrictions, and social distancing policy (Perra, 2021).

Infectious disease transmission and host behaviors are often intertwined (Perra, 2021): on one hand, contact heterogeneity and movements of the host population play critical roles in facilitating disease transmission (A. Yang et al., 2021);

on the other hand, the outbreak severity might trigger some infection prevention behavior of the host and induce the changes to their movements and daily activities (Weston et al., 2018). In the COVID-19 pandemic, due to the risk attitudes and the NPIs, like social distancing and gathering restrictions, human daily activities and mobility has changed significantly worldwide (Chan et al., 2020; Woods et al., 2020). Particularly, several studies have suggested that the usage of public parks and open spaces were impacted by the COVID-19 pandemics and its NPI policies (Gelman et al., 2014; Shoari et al., 2020; Volenec et al., 2021; Xie et al., 2020). Public parks and open spaces serve an important societal function as recreation spaces for diverse communities of people to support community cohesion and city sustainability (Chiesura, 2004; Xie et al., 2020). Additionally, parks have also been well documented to support human physical and mental health (Bedimo-Rung et al., 2005; Ulrich & Addoms, 1981). This is likely true under the COVID-19 pandemic when NPI strategies constrained human mobility and daily activity. Xie et al. (2020) suggested that visitation to the park at the frequency of greater than at least once a week would be beneficial to the overall health condition under the COVID-19 quarantine period. Many of these natural open spaces allow people to conduct their recreation behaviors following the social distancing protocols (Volenec et al., 2021). Thus, people have substantially used parks as a substitute for the indoor fitness and recreation, leading to an increasing trend of visiting the open spaces and public parks in various countries during the COVID-19 pandemic (Geng et al., 2021; Volenec et al., 2021).

Complicating people's response to the pandemic, however, was the massive, severe wildfires in the western and central United States. Global climate change promotes the conditions on which wildfires depend, thus often increases the potential and severity of their occurrences (Jones et al., 2020). Until October 2020, over 44,714 wildfires were occurring in the western and central US, associated with over 7.8 million acres of burned areas (Insurance Information Institute, 2020). The wildfire-induced smoke often consists of highly elevated concentrations of fine particulate matter, carbon monoxide, nitrogen oxides, and volatile organic compounds, which pose major impacts to animal and human health (Tao et al., 2020; D. Yang et al., 2021). Previous studies demonstrated a significant association between wildfire smoke exposure and risk of respiratory illness in humans (DeFlorio-Barker et al., 2019; Hänninen et al., 2009; Moore et al., 2006). Additionally, the wildfire-induced air pollution can even be transported over a long range (e.g., over 1000 km) and impact the illness and death of humans that were far away from the wildfires (Kollanus et al., 2016).

Uncontrolled wildfires can also impact human recreation behaviors and activities, while the available evidence of the impact of wildfires on recreation demand is ambiguous (Nobel et al., 2020). Some findings found that wildfires can increase recreation due to people's curiosity of the wildfire events and their impacts (Sánchez et al., 2016). Others suggested that wildfires can cause the reduction of visitations to the surrounding natural areas and open spaces because of public health concerns and the decreasing attraction to recreation activities (Hesseln et al., 2003).

Understanding the effects of the COVID-19 pandemic and wildfires and their interplay on human recreation behavior and mobility to public parks could help to explore people's social behaviors under multiple severe crises and prepare for future threats to people's health and wellbeing. However, these effects remain poorly understood. In this study, we investigated the spatial and temporal patterns of human's mobility to public parks and open spaces in the western and central US, where COVID-19 and wildfire co-occurred in June – September 2020. Specifically, we focused on how different factors, including the COVID-19 outbreaks, wildfires, air quality, and drought, drive the following three metrics that describe human recreation and visitations at public parks: 1) the number of visitors, 2) the median of minimum dwell time they spent at the park, and 3) the median travel distance from home.

2 Materials and Methods

2.1 Study Area and Human Mobility Data to Parks

The study area covers 12 states in the western and central US (Figure 1). We accessed the human mobility patterns to the parks from the SafeGraph dataset (https://www.safegraph.com/). This dataset provided an aggregated and anonymized foot traffic patterns at over 4.5 million businesses and consumer point-of-interest (POI) across the US based on mobile phone records. Here, we collected the monthly aggregated human mobility patterns to parks from SafeGraph in June – September 2020. The six-digit North American Industry Classification System (NAICS) codes "712130" and "712190" (https://www.naics.com/search/) which identify as park POIs were used to filter for the park-related location from the SafeGraph Dataset. A total of 42,211 park-related POI locations were selected based on the study area. To investigate the people's mobility pattern to park, we use three metrics that attached to the park-related location to describe human mobility and usage of public parks, including 1) the number of unique visitors to POIs, 2) median distance from home travelled by visitors, and 3) median minimum dwell time that people spent at POIs. We then aggregated the park-related POIs with those three metrics to the county level into each month of June -September by ArcGIS 10.8 (ESRI Inc., Redlands, CA).

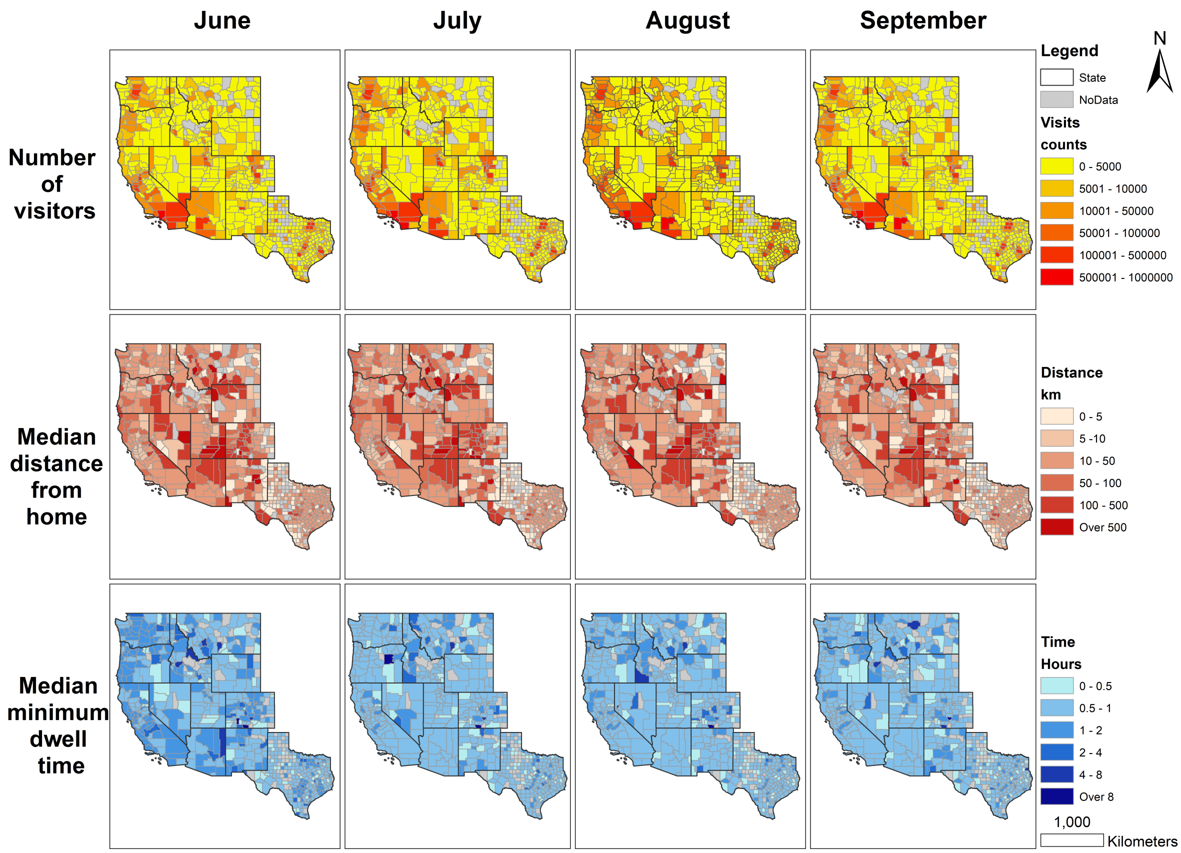

Figure 1. Study area and monthly distribution of the number of visitors, median distance from home, and median minimum dwell time.

2.2 Environmental variables

We included 23 potential variables to consider the potential factors that might influence human recreation behaviors at public parks, including the effects of the COVID-19 pandemic, wildfires, air quality, drought, and land covers. These variables were accessed and processed from multiple sources (see details in Table 1). The wildland fire location dataset was accessed from National Interagency Fire Center. We screened any wildfire events that occurred and lasted for at least a week within each of June – September and computed the Euclidean distance to the closest wildfire events (Fire dist) and the density of wildfires (Fire den) over the study area using ArcMap 10.8. Smoke observations were downloaded from Hazard Mapping System Fire and Smoke Product at NOAA. Given that the smoke was measured every 5 minutes, we extracted the daily maximum and minimum smoke values and then aggregated them to monthly scale. For the land cover variables, we reclassified the 2016 map of USGS National Land

Cover Database (NLCD) into the following five classes to account for the major land cover types in the study areas: forest (original class # 41–43), agricultural (original class #81, 82), grass (original class #51, 52, 71–74), urban and barren land (original class #21–24, 31), and water (original class #11, 12). Other variables, including the meteorological measurements, air quality measurements, and COVID-19 outbreak data were directly accessed from the data sources. All the covariates were aggregated to the county level in each month of June – September.

Table 1. Descriptions and Data Sources of the Covariates

Factors	Covariates (Names)	Des
COVID-19 outbreaks	Confirmed cases (Cases)	The
	Death cases (Death case)	The
Air quality	Carbon monoxide (CO)	Mor
	Sulfur dioxide (SO_2)	Mor
	Nitrogen dioxide (NO_2)	Mor
Wildfire effects	Distance to fire (Fire dist)	Euc
	Fire density (Fire den)	Den
	Minimum smoke (Smk min)	Mor
	Maximum smoke (Smk max)	Mor
Drought	Precipitation (Prcp)	Mor
	Maximum humidity (Max humid)	Mor
	Minimum humidity (Min humid)	Mor
	Vapor pressure (Vdp)	Mor
	Temperature (Temp avg)	Mor
Land cover types	Agriculture (Agr), forest (Forest), grass (Grass), urban (Urban), water (Water)	Perc
Other	Elevation (Elev)	Elev
	Number of parks (Num park)	The
	Number of populations (Pop)	The
	Wind (Wind)	Mor

2.3 Geographically and Temporally Weighted Regression Models

This study employed the Geographically and Temporally Weighted Regression (GTWR) Models to explore the effects of different factors on the spatial and temporal patterns of three metrics that describe the human mobility to public parks at a monthly scale for each county. With the consideration of both spatial and temporal heteroscedasticity simultaneously, the GTWR models can provide spatiotemporal estimation of effects (He et al., 2021; Huang et al., 2010). See following model specification:

$Y_i = \beta_0 (\mu_i, v_i, t_i) + \sum_k \beta_k (\mu_i, v_i, t_i) X_{\text{ik}} + \varepsilon_i$ (1)

Where Y_i is the dependent variable of the ith record of data, which represents the number of visitors, the median of minimum dwell time at parks, or the travel distance from home. X_{ik} are the matrices of the independent variables at the ith record of data. μ_i, v_i, and t_i represent the spatial and temporal information of the ith record of data, i.e., (μ_i, v_i) gives the coordinates and t_i shows the time. $\beta_0(\mu_i, v_i, t_i)$ is the intercept for the ith record, while $\beta_k(\mu_i, v_i, t_i)$ represents the coefficient for the kth independent variable. The coefficients $\beta_k(\mu_i, v_i, t_i)$ can be estimated using the Weighted Least Square as follows:

$$\hat{\beta}_k(u_i, v_i, t_i) = \left[X^T W(u_i, v_i, t_i) X\right]^{-1} X^T W(u_i, v_i, t_i) Y \quad (2)$$

Where $W(u_i, v_i, t_i) = diag(\alpha_{i1}, \alpha_{i2}, \dots, \alpha_{\mathrm{in}})$ and n is the number of observations. $\alpha_{\mathrm{ij}}(1 \leq j \leq n)$ is space-time distance decay function of (μ_i, v_i, t_i) corresponding to the weight that is adopted to calibrate a weighted regression adjacent to the ith record of data. Various of the space-time distance decay functions can be used including Gaussian, exponential, and bi-square distributions. Here, we employed a Gaussian distance function:

$$W_{\mathrm{ij}}^{\mathrm{ST}} = \exp\left[\left(\frac{d_{\mathrm{ij}}^{\mathrm{st}}}{h^{\mathrm{st}}}\right)^2\right] \quad (3)$$

Where $d_{\mathrm{ij}}^{\mathrm{st}}$ represents a spatiotemporal distance between the ith and jth record of data. h^{st} is a spatiotemporal bandwidth, the optimal of which can be computed based on the corrected Akaike Information Criterion (AICc) (Huang et al., 2010; Hurvich et al., 1998).

Before building the GTWR models, we first screened all the 23 potential variables for the multicollinearity. For any variables with the Pearson's correlations greater than 0.5 (see the correlation of the covariates in Figure S1), we selected one of them to be incorporated into the models based on the information criterion (AICc). We also standardized the dependent and independent variables to directly compare the coefficients in the later GTWR models. We investigated the effects of COVID-19 outbreaks and wildfires on the number of visitors, the median of minimum dwell time at the park, and the travel distance from home separately with three different sets of GTWR models. For each set of GTWR models, we generated all additive possible combination of covariates. All the GTWR models were conducted using the GTWR AddIn in ArcMap 10.8 (Huang et al., 2010). The model performance and predictive accuracy were evaluated based on AICc and global R^2, respectively. For model selection, the AICc for each model were computed as the differences in the AICc values between the lowest AICc and each following model. Any candidate model with AICc<2 was accounted for as the competing model that informationally indistinguishable (Anderson & Burnham, 2004). The number of covariates incorporated in the competing models and their global R^2 were also considered in model selection procedures.

3 Result

3.1 Results for the number of visitors

Model 1.1 shown in Table 2 is the top-selected model with the lowest AICc value and a predictive accuracy of a global R^2 as 0.963. We selected this model to describe the effects of different factors including COVID-19 outbreaks, wildfire, drought, and air quality on the pattern of the number of visitors for each county in the western and central US during June – September 2020.

We found that the number of visitors to parks in most counties of the study areas (except western Washington and Oregon, southern California, and southeastern Texas) has a positive correlation with the number of positive COVID-19 cases before the major wildfire season, especially in June (Figure 2a). However, negative correlations have been dominant during the wildfire season in August and September in western Washington and Oregon, California, and Texas. Similarly, before the major wildfire seasons in June and July, most counties have positive correlations between the number of visitors and the monthly average of minimum smoke, while the negative correlations have been detected in Washington, Oregon, California, and Colorado (Figure 2b). For the monthly average of daily minimum humidity, there were more visitors to the parks when the humidity is higher in most counties in the study areas, especially in the southern California (Figure 2c). Additionally, more visitors have been detected closer to wildfires in June and July at most of the counties in western Washington and Oregon, California, Colorado, and eastern Wyoming and Montana, while people started to avoid wildfires in August and September (Figure 2d). For air quality, negative correlations were found between SO_2/CO and the number of visitors in most areas, while the positive correlations were found for NO_2 and the number of visitors (Figures 2 e – g).

Table 2. Model performance and predictive accuracy for the ten top candidate GTWR models to estimate the effects on number of visitors to parks. We reported the number of covariates included in the candidate models (K), the difference of the AICc between the candidate model and the top-selected model (AICc), and the global R^2.

No.	Model structure
1.1	Cases + Min humid + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass + CO + NO_2 +
1.2	Min humid + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass + CO + NO_2 + SO_2 + N
1.3	Cases + Min humid + Wind + Fire dist + Elev + Water + Agr + Grass + CO + NO_2 + SO_2 + Num
1.4	Cases + Min humid + Wind + Fire den + Elev + Smk min + Water + Agr + Grass + CO + NO_2 +
1.5	Cases + Min humid + Wind + Elev + Smk min + Water + Agr + Grass + CO + NO_2 + SO_2 + Nur
1.6	Cases + Prcp + Vdp + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass + CO + NO_2 -
1.7	Cases + Min humid + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass + Num park
1.8	Death cases + Min humid + Wind + Fire dist + Elev + Smk min + Agr + Grass + CO + NO_2 + SC
1.9	Cases + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass + CO + NO_2 + SO_2 + Num p
1.10	Cases + Temp avg + Min humid + Wind + Fire dist + Smk max + Water + Agr + Grass + NO_2 +

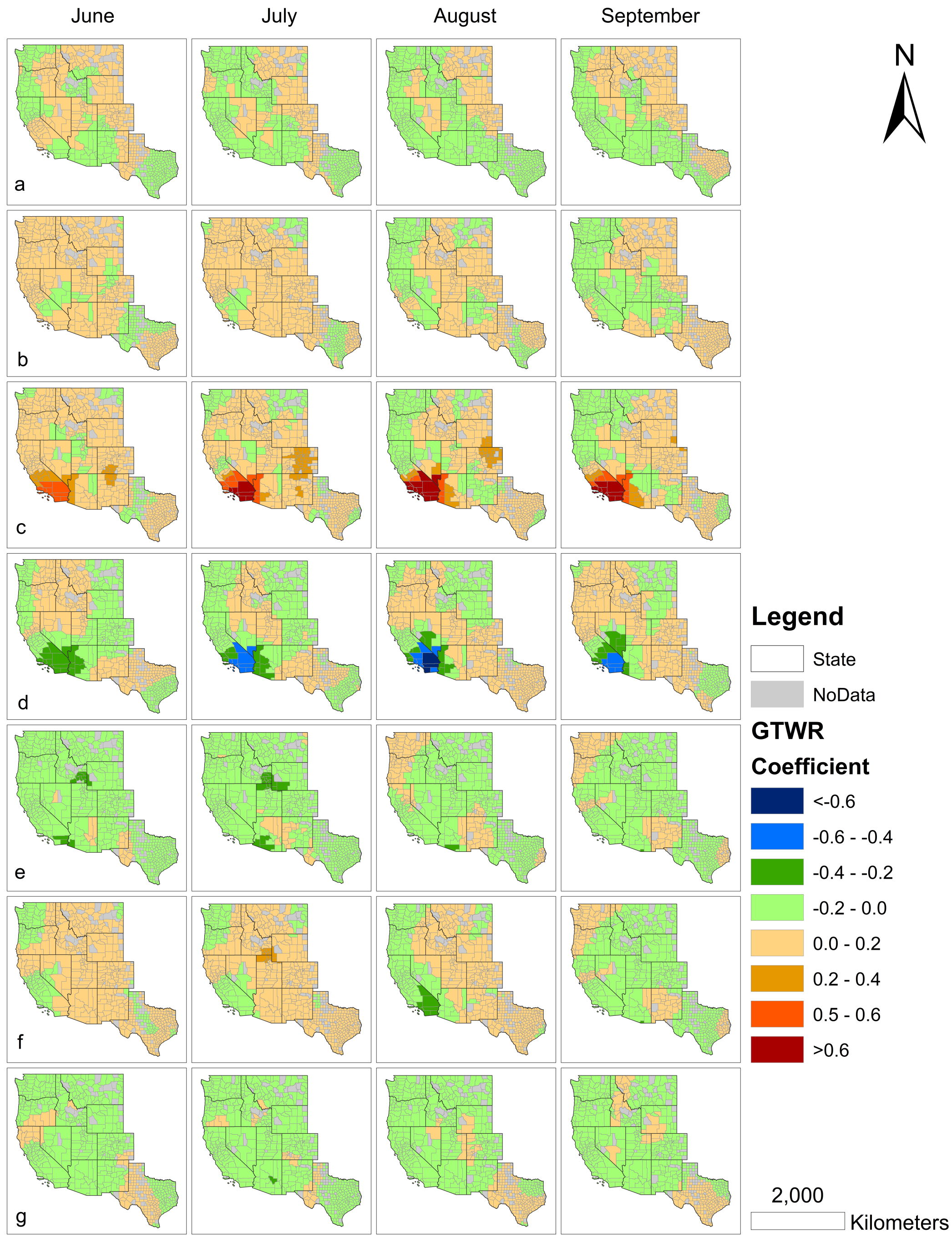

Figure 2. Spatiotemporal impacts of a) Cases, b) Smk min, c) Min humid, d)

Fire dist, e) CO, f) NO_2, and g) SO_2 derived from the top-selected GTWR model on the pattern of the number of visitors in each county of the western and central US during June – September 2020.

3.2 Results for the median of minimum dwell time

With three competing models (Models 2.1 – 2.3 in Table 3) that are informationally indistinguishable (AICc <2), we selected Model 3 as the best model, which is the most parsimonious model with the best predictive power (global R^2=0.166), to describe the spatiotemporal pattern of the median minimum dwell time at parks for each county in the study area. For the effects of COVID-19 outbreaks, we found people spent less time in the counties with more positive cases, except Arizona and Utah in June – July and Washington and eastern Montana/Wyoming in August – September (Figure 3a). For the effects of monthly average of minimum smoke, we found the number of counties with positive correlations on the median of minimum dwell time increased from June – September (Figure 3b). A similar pattern has been detected for the effects of the monthly average of minimum humidity (Figure 3c). For the effects of wildfires, we found people spent more time at parks with higher wildfire density in most counties of the study area (e.g., in Washington, Oregon, Colorado, and New Mexico) in June and July (Figure 3d). However, people avoided the wildfires with the negative correlation between dwell time and wildfire density in most areas in August and September except in some parts of California, Colorado, and New Mexico. Additionally, the median minimum dwell time was also negatively correlated with the monthly average temperature in the majority of the study area (Figure 3e).

Table 3. Model performance and predictive accuracy for the ten top candidate GTWR models to estimate the effects on the median of the minimum dwell time spent at parks. We reported the number of covariates included in the candidate models (K), the difference of the AICc between the candidate model and the top-selected model (AICc), and the global R^2.

No.	Model structure
2.1	Cases + Temp avg + Prcp + Vdp + Wind + Fire dist + Smk min + Water +Agr + Grass + CO + N
2.2	Cases + Temp avg + Prcp + Min humid + Wind + Fire den + Smk min + Water +Agr + Grass + C
2.3	Cases + Temp avg + Prcp + Min humid + Wind + Fire den + Smk min + Water +Agr + Grass + N
2.4	Cases + Temp avg + Min humid + Wind + Smk max + Water +Agr + Grass + CO + NO_2 + SO_2 +
2.5	Cases + Temp avg + Max humid + Wind + Fire den + Smk max + Water +Agr + Grass + NO_2 + S
2.6	Cases + Temp avg + Max humid + Wind + Fire dist +Smk max + Water +Agr + Grass + NO_2 +SO
2.7	Cases + Temp avg + Prcp + Min humid + Wind + Fire den + Water +Agr + Grass + Num park
2.8	Temp avg + Prcp + Min humid + Wind + Fire den + Smk min + Water +Agr + Grass + CO + NO
2.9	Death case + Prcp +Vdp + Wind + Fire dist + Elev + Smk min + Urban + Water + Forest + CO -
2.10	Cases + Temp avg + Prcp + Min humid + Fire den + Smk min + Water +Agr + Grass + Num park

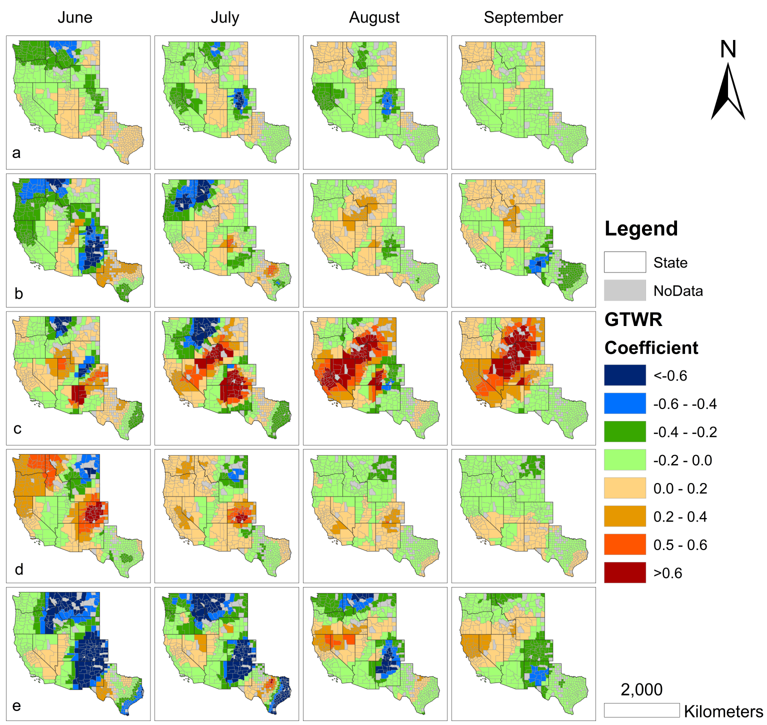

Figure 3. Spatiotemporal impacts of a) Cases, b) Smk min, c) Min humid, d) Fire den, and e) Temp avg derived from the top-selected GTWR model on the pattern of the median minimum dwell time at parks in each county of the western and central US during June – September 2020.

3.3 Results for the travel distance from home

Model 3.1 in Table 4 with the lowest AICc value and the global R^2 of 0.400 was selected as the best model to describe how different factors affected the travel distance from home. We found people traveled a longer distance from home to parks in some counties with higher COVID-19 positive cases of Montana, Wyoming, Colorado, and New Mexico. However, this pattern diminished gradually from June – September (Figure 4a). For the effects of the monthly average of minimum smoke, the number of counties with positive correlations decreased significantly from June – September (Figure 4b). For the wildfire effects, we found people traveled further to the counties in parts of California, Utah, and Arizona where the park is far away from the fire in June and July before the major wildfire season (Figure 4c; positively correlated with distance to wildfire). In August and September, this pattern extended to other parts of the study area, except for the western Montana, Idaho, and Texas. For the effects of precipitation and vapor pressure, most study areas detected positive correlations (Figure 4e and 4f). The effects of other factors such as population and land cover types for the number of visitors, median of minimum dwell time at the park, and travel distance from home were given in Figures S2, S3, and S4, respectively.

Table 4. Model performance and predictive accuracy for the ten top candidate GTWR models to estimate the effects on the travel distance from home. We reported the number of covariates included in the candidate models (K), the difference of the AICc between the candidate model and the top-selected model (AICc), and the global R^2.

No.	Model structure
3.1	Cases + Prcp + Vdp + Wind + Fire dist + Elev + Smk min + Water + Agr + Forest + Num park
3.2	Death case + Prcp + Vdp + Wind + Fire dist + Elev + Smk min + Urban + Water + Agr + Forest
3.3	Cases + Prcp + Vdp + Wind + Fire dist + Elev + Smk min + Water + Agr + Forest + NO_2+ Num
3.4	Cases + Prcp + Vdp + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass + NO_2 + SO_2
3.5	Cases + Temp avg + Max humid + Wind + Fire den + Smk max + Water + Agr + Grass + NO_2 +
3.6	Cases + Vdp + Wind + Fire dist + Elev + Smk min + Urban + Water + Agr + Grass + CO + NO_2
3.7	Cases + Prcp + Wind + Fire den + Elev + Smk max + Water + Agr + Forest + NO_2 + SO_2 +Num
3.8	Cases + Vdp + Wind + Fire den + Elev + Smk min + Urban + Water + Agr + Grass + CO + NO_2
3.9	Death case + Prcp + Max humid + Wind + Fire dist + Elev + Smk min + Water + Agr + Grass +
3.10	Cases + + Temp avg + Prcp + Wind + Fire dist + Smk max + Water + Agr + Forest + NO_2 + SO_2

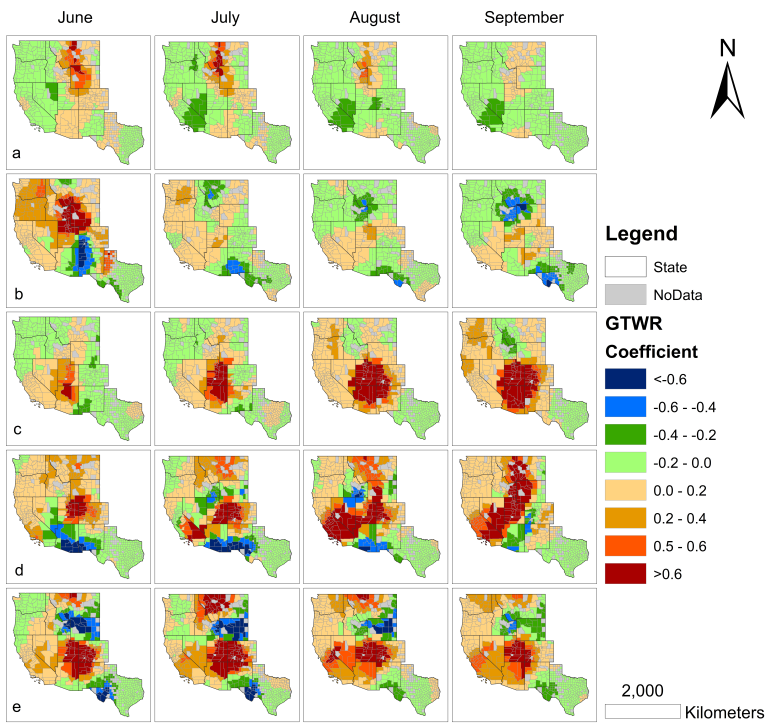

Figure 4. Spatiotemporal impacts of a) Cases, b) Smk min, c) Fire dist, d) Prcp, and e) Vdp derived from the top-selected GTWR model on the pattern of the travel distance from home in each county of the western and central US during June – September 2020.

4 Discussion

The pandemic has imposed constraints on people's social behavior, mobility, and daily activities globally (Nouvellet et al., 2021; Van Bavel et al., 2020). Parks and natural open spaces are receiving more attention than the previous years from the public because of their irreplaceable functions for benefiting people's physical and mental health (Geng et al., 2021). Parks provide critical ecosystem services during the pandemic to support outdoor recreations without violating social distancing restrictions and mitigate the stress associated with the COVID-19 (Geng et al., 2021; Xie et al., 2020). Accompanied with the pandemic, massive wildfires in 2020 in the western and central US also affect people's visitation to parks and natural open spaces given the public health concern and the loss of recreation in those places. In this study, we explored three metrics that describe human visitation at parks, including the number of visitors, the median of minimum dwell time at parks, and the travel distance from home. Additionally, we examined the effects of different factors, such as the COVID-19 pandemic, wildfires, and drought, on those metrics.

Our results suggested that the reported COVID-19 cases affect how people visit parks likely due to the potential of infection protection behavior and risk altitude. There was an increasing number of counties where people avoided visiting the parks when the number of the COVID-19 cases was high from June - September (i.e., the number of visitors negatively correlated with COVID-19 cases). This reflects similar patterns seen in several previous studies on how infectious diseases might impact the changes in human mobility and behaviors. People who stay at home or avoid places with high disease rates are shown to reduce the links of possible contagion (Funk et al., 2010). Also, in most counties within the study area, people tended to travel closer from home to parks and spend less time there when more COVID-19 cases were reported, especially in June to August. This pattern might be explained by two possible reasons: people may restrict their long-time outdoor recreation behavior, or, with the stay-at-home order lifted, they spend time doing other things. This is consistent with the findings from Odell (2021), who reported that the time that people spent on physical activity decreased after stay-at-home orders. Interestingly, we also detected a positive pattern between distance from home and COVID-19 cases in Montana, Wyoming, Colorado, and Arizona in June – July. The COVID-19 case had a small peak during this period. With some businesses (e.g., public parks, green space, and national parks) reopened as early as June, people might have started to loosen the stay-at-home restrictions and travel to parks or natural open spaces for outdoor recreation following the social distancing practice. For instance, Yellowstone National Park fully reopened at the beginning of June, and the visitation in some months of 2020 since then was even higher compared to the 2019 records (Warthin, 2020, 2021).

Our result also indicated that people who visit parks tended to avoid wildfires and smoke in most counties from June – September. Particularly, during the major wildfire season (August to September), people tended to decrease visitations to parks that are surrounded by wildfires and reduce the time spent in the park. Moreover, we found people in the southwest of the study area traveled longer distances from home in June – July to the parks away from wildfires. This pattern then expanded to the western and central states during the major wildfire season (August - September). Previous studies found that wildfires are likely to have negative impacts on recreation, and those impacts could potentially last post-fire for a while (Flowers, 1985; Loomis et al., 2001). Surprisingly, our findings also detected that the wildfires in some southwestern states, like California, Colorado, Arizona, and Montana, promoted people's visitations to parks, given the increasing number of visitors and dwell time near fires in June and July. This might be explained by people's attitudes towards wildfire events. People's curiosity about the wildfire events and their impacts can encourage their visitations close to wildfires (Sánchez et al., 2016), especially for the areas where fires only occasionally occur. In places with a long history of wildfire records, people may be less interested in wildfires and not change their recreation behaviors because of that (e.g., keep visiting the parks or open spaces close to fires).

Wildfire smoke exposure can have serious impacts on human health, causing direct death, respiratory, cardiovascular, mental, and perinatal diseases. Smoke can be transported far away from fires and affect people there (Kollanus et al., 2016). Our findings suggested that between June and July, the monthly average of the daily minimum smoke value was positively correlated with the number of visitors but negatively correlated with the dwell time at the parks, indicating that people still visited parks when the daily minimum smoke was quite large but cut the time they stayed in the park. During the major wildfire season, people tended to visit the parks with less smoke in the western part of the study area. Given the health-protective behaviors, people might avoid outdoor recreation, especially for people with respiratory diseases like asthma and chronic obstructive pulmonary disease (Henderson et al., 2011; Moore et al., 2006; Rappold et al., 2011, 2019; Reid et al., 2016). Additionally, given the growing evidence of associations between wildfire smoke exposure and the increased risk of respiratory infections (Martin et al., 2013; Reid et al., 2016), people are more likely to get more stress and concerns about wildfire-induced smoke under the COVID-19 pandemic.

Our study is not without limitations. First, to explicitly understand how wildfires impact human recreation behaviors, it is critical to study the historical wildfire records locally, since people's altitudes to the fires can vary in space and time due to many factors like their experience with wildfires and education levels (Edgeley & Burnett, 2020). Second, the top-selected model only explained 16.6% of the variance in the spatiotemporal patterns of the median of minimum dwell time at parks, indicating that there could be some other factors that might impact the time that people spent. For example, different parks with different sizes, facilities, and features can have different levels of recreation, which would determine the group of visitors they attract, the purpose of their visits, and the time they spend in those places (Larson et al., 2014; Manning et al., 2000).

5 Conclusions

This study investigated how the cooccurrence of the COVID-19 pandemic and wildfires impact the spatiotemporal patterns of human mobility to public parks. We employed the GTWR models to examine the effects of the COVID-19 pandemic, wildfires, air quality, and drought on three metrics that describe people's visitation to parks, including the number of visitors, dwell time they spent at parks, and the travel distance from home. Our findings suggested a general trend of avoidance to the parks with fewer visitors and dwell time in the places with high COVID-19 cases, which is likely due to people's infection protection behavior and risk altitude. However, in June, with the movement restriction orders just lifted, some long-distance travels to parks were observed in some counties in Montana, Wyoming, and Colorado. We also found that people tended to travel further and spend longer time at the parks away from wildfires with less smoke, especially during the major wildfire seasons between August and September. Our findings are helpful to understand the spatiotemporal patterns of human recreation and social behaviors under multiple severe crises, which can support the preparation and mitigation of future threats to people's health and wellbeing.

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Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data

All the data being used in this study can be archived from figshare at https://doi.org/10.6084/m9.figshare.15023253.v1.

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