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Using GIS-based Spatial Analysis to Determine Urban Greenspace Accessibility for Different Racial Groups in the Backdrop of COVID-19: A Case Study of Four US Cities

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Abstract: As the United States leads COVID-19 cases on global charts, its spatial distribution pattern offers a unique opportunity for studying the social and ecological factors that contribute to the pandemic's scale and size. We use a GIS-data-based approach to evaluate four American cities – Anchorage (Alaska), Atlanta (Georgia), Phoenix (Arizona), and Portland (Oregon) characterized by the significant composition of different racial and ethnic group populations. Building upon previous studies that investigated urban spatial inequalities using the environmental justice framework, we examine: (1) the relative racial vulnerability of Census Block Groups (CBG) and ZIP Code Tabulation Areas (ZCTA) to COVID-19 (2) green space distribution at CBG and ZCTA scale. Using standard normalization methods, we ranked racial vulnerability against % available green space for each city. Our results highlight the legacy of past and present urban planning injustices. The project is useful from environmental justice, public health management, and urban planning perspectives.

Keywords: urban inequality; racial vulnerability; environmental justice; green space; COVID-19

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The data that support the findings of this study are available from the corresponding author, AP, upon reasonable request.

Code availability

Not applicable

Authors' contributions

Arun Pallathadka: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Visualization, Writing - Original Draft, Review, & Editing

Laxmi Pallathadka: Conceptualization, Methodology, Formal Analysis, Investigation, Writing-Original Draft, Review, & Editing

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Dorn Van Dommelen: Writing – Original Draft, Review & Editing

1. Introduction

The first case of COVID-19 in the United States (U.S.) was reported on Jan 20, 2020, in Snohomish County, WA, and the disease spread with varying intensities of outbreak from state to state. Some states reached their peak early while the virus took longer to spread in others. The pandemic has impacted all 50 states and over 33 million confirmed cases have been reported as of June 15, 2021, by the WHO. With a vast number of cases being reported in population centers such as California, Florida, Texas, and New York (Oster, 2020), the cases have increased at an alarming rate since the initial spread in mid-March of 2020. The U.S government took some necessary steps to stop the spread of infectious disease with travel restrictions across the country (Exec. Order No. 13909, 2020). During the period, the COVID-19 response was highly decentralized, and the states were subjected to varying levels of enforcement as per the directives issued by state and local officials. Travel restrictions, stay-at-home orders, social distancing, and mask-mandates were some of the guidelines that were suggested to control the spread of the disease. The U.S. performed a high number of COVID-19 tests but suffered setbacks due to faulty diagnostic kits initially, and the early spread of the disease went undetected for weeks. As of June 15, 2021, 480 million tests have been conducted in the country. Over 597 thousand deaths due to COVID-19 have been reported across the U.S (CDC, 2021).

The geographic areas and hotspots in the U.S. which have been most affected by COVID-19 have changed over time, and various social and ecological factors have played an important role in controlling the spread of this pandemic (Desjardins et al., 2020; Hohl et al., 2020). This changing spatial pattern can be evaluated by identifying hotspots and green zones at different stages of the pandemic and comparing the pattern of socio-ecological factors in the various cities. Previous studies have found that the spatial scope of an infectious disease can be controlled by several factors associated with the transmission such as epidemiological, demographic, social, and ecological (Gostin, 2019; Kubota et al., 2020; Sobral, 2020; Tamerius et al., 2013). According to Houeto (2019), a complex suite of sociological and economic factors such as education, occupation, and income influence human movement across the landscape and can have critical impacts on outbreak dynamics and the spatial spread of infectious disease. It is also known that many pronounced changes in human social ecology have rapidly altered the spread of infectious diseases such as population size and density; urbanization; political ignorance; differences in built environment; science and technology; and poor health awareness (Weiss & McMichael, 2004). Among the social factors, population density has been identified as a crucial entity for the transmission of the pandemic. Oster (2020) has identified that counties with small population sizes are less likely to be considered a hotspot and the cases are monitored with the primary focus on the trends in the counties nearby. Also, due to the limited interaction between people in cities with lesser population size delays the impact and slows down the process of transmission.

The green spaces of a city, such as parks, have a positive impact on the health of its inhabitants (Cicea & Pirlogea, 2011). Cities with insufficient green space for their residents suffer from an overflow of people in a few available parks, which makes it difficult to follow social distancing. Studies also show that green spaces improve the quality of life during pandemic outbreaks (Kleinschroth & Kowarik, 2020; Xie et al. 2020). Additionally, outdoor spaces such as parks and trails are considered relatively safer due to constant air circulation (Mayo Clinic, 2020, Olin, 2020). Similarly, lakes, beaches, and wetlands are considered safer for recreation, with appropriate social distancing in place (CDC, 2020a). Liu et al. (2019), however, argue that an increase in the green space of a city will not directly lead to healthier living conditions because not all residents have equal access to green spaces.

In a study about spatial disparities in the distribution of parks and green spaces, Nesbitt et al. (2018) suggest that disadvantaged neighborhoods like those inhabited by poor, Black, or Hispanic populations are underexposed to green spaces. Shorter living distance to the park does provide spatial access but factors such as safety, traffic, and walkability affect the park utilization as well. Nesbitt et al. (2018) conclude that the access to urban vegetation is lesser for racialized minorities but less common according to multivariate analyses. They also opine that variables like education, income, and population density should be taken into account during this investigation.

Ethnic and racial disparities correspond heavily to the inequalities in social determinants and seem to increase the risk of COVID-19 (CDC, 2020b). Although African American and LatinX communities constituted only 13% and 18% of the US population in 2020 respectively, 22% of COVID-19 deaths were African Americans and 38% were Latinx. American Indian and Alaska Natives make up 2.1% of the entire US population, however, COVID-19 mortality rates were 2.4 times higher than that of White Americans during the first wave (CDC, 2020). Similarly, Ramirez & Lee (2020) concluded that the rate of death due to COVID is relatively higher in rural counties due to lack of access to health care, poverty, and unhygienic living conditions. They also suggest that the number of cases is alarmingly high in people of Hispanic, Non-Hispanic Black, and non-Hispanic Native Hawaiian or Pacific Islander origins considering the fact that they only make up 25.6% of Colorado's population. Karaca-Mandin et. al (2021) analyzed COVID-19 hospitalization data in 12 states between April and June 2020, concluding that the percentage of hospitalizations among white patients was much lower compared to their representative share in the State population in all 12 states, while the percentage of hospitalizations among Black patients were much higher. The impact of COVID-19 is visibly higher in such communities of color compared to white Americans and Asian Americans. Further research is required in this part to assess the impact of the COVID-19 outbreak on various races and communities. The association between green space and infectious disease has not yet been explored completely.

While racial disparity of green space accessibility has been widely studied at the census tract level (Dai, 2011; Lanza et al., 2019; Liu et al., 2021; Wen et al., 2013), studies at the census block group (CBG) level are lacking, except a study by So (2016). CBG is the smallest geographic census unit and is a subset of census tract; census tracts have populations ranging from 1,200 to 8000, compared to CBGs which range from 600 to 3,000 people. Additionally, many ecological variables are available at a much finer scale than a census tract. Therefore, using census tract might mask the spatial heterogeneity of ecological variables. Therefore, using block groups offers a much finer geographic resolution to better understand spatial disparities in sociodemographic and ecological variables. Nonetheless, many studies rely on census tracts since all data are not generally accessible at the CBG scale, and some other researchers who employ qualitative data avoid the best resolution for ethical concerns. Thus, there exists a significant gap in that these social and ecological factors have not been thoroughly studied as a unit at CBG scale. The compilation of such data could help in estimating disease spread at multiple scales (Table 1). Yi Lu et al. (2020) showed that the disparity is significantly smaller in areas with a higher ratio of green spaces at the county level, and Andersen et al. (2021) revealed that race is one of the factors associated with community-level COVID vulnerability. CDC data reveals that there is a great deal of disparity in COVID-19 vulnerability among different races and ethnicities. Racial vulnerability (RV) is, therefore, the response pattern of different races and ethnicities to COVID-19, based on infection and mortality rate in the US. We define RV as each racial group's relative vulnerability to COVID-19 based on national-scale disparities in COVID-19 infection and mortality rates (Louis-Jean et al. 2020; Muñoz-Price et al.2020; Zelner et al. 2021).

COVID-19 data is typically available for limited geographies at a resolution of ZIP Code Tabulation Areas (ZCTA), a geographical unit for which the US census bureau publishes data. Thus, we also related RV and green space to COVID-19 numbers at ZCTA for available geographies.

Since COVID-19 cases are found in cities of different sizes, we see a need for a standardized mechanism to identify how RV at the CBG contributes to the spread of COVID-19 and how governments can ensure equity in green space access. Thus, we base our research on the following questions:

1. What are the spatial patterns of RV to COVID-19 in cities?
2. How does green space distribution relate to RV at the CBG and ZCTA scales?

Table 1. Brief literature review on empirical studies investigating the relationship between COVID-19 and urban environment

Authors	**Study Area**	**Focus**	**Summary**
Andersen et al. 2021	All counties and county-equivalents in the USA	Geographic hotspots and community drivers associated with spatial patterns of COVID-19 transmission	The factors associated with community-level vulnerability included age, disability, language, race, occupation, and urban status
Dong et al. 2020	Wuhan, China	Connectivity and public green space (PGS) use	There is no high correlation between PGS use and its connectivity
Louis-Jean et al. 2020	Selected counties or county-equivalents, and cities in the USA	Racial Disparities	This communication provides a brief overview of the health inequalities resulting in African Americans dying disproportionately during the COVID-19 pandemic
McPhearson et al. 2021	New York City, USA	Spatial and Social Distributions of the first wave of COVID-19 and social vulnerability indicators	Social Vulnerability indicators (e.g., race, language, income, etc.) drive spatial patterns in the prevalence of COVID-19 testing, confirmed cases, death rates, and severity
Pan et al. 2021	All urban boroughs of London	Public green space (PGS) accessibility and high choice measures	The results indicate higher transmission possibility without characterizing the infrastructure and social conditions
Tribby and Hartmann 2021	New York City, USA	Built environment characteristics and COVID-19 cases	Positive associations between COVID-19 cases and % black, Hispanic population, % population over 65
Yi Lu et al. 2020	135 most urbanized counties across the United States	Relationship between green spaces and racial disparity to COVID-19 at the county level	The disparity is significantly smaller in areas with a higher ratio of green spaces at the county level
Zelner et al. 2021	Michigan, USA	Racial Disparities	Presents racial disparity trends

2. Environmental Justice Framework

Environmental injustice greatly impacts communities of color and low-income communities. People might live in the same area but their race, ethnicity, wealth, or income might cause them to experience widely varying qualities of air, water, and life. The pandemic has shone a light on social and environmental injustices in terms of healthcare, housing, and urban green spaces (Bashir et al., 2020, Haase 2020, Prowers et al., 2021). Environmental justice seeks to reduce health disparities while identifying and addressing the social inequalities involved. The environmental justice framework is an important tool where the health inequities and public health outcomes are evaluated by assessing the environmental exposure, biological, and socioeconomic factors. It sheds light on the community democratic decision-making processes and political forces and involves residents and local organizations, researchers, advocates, and policymakers (Kreger et al, 2011). The objective is to provide and maintain a healthy and sustainable environment for everyone without the intersections of race, class, gender, ability, age, and climate. The framework of environmental justice extends beyond air pollution and also includes the provision of green spaces, water quality, protection from environmental events, and noise pollution (Pearce, 2013). The studies consistently point out that the communities of color and low-income or otherwise vulnerable individuals are at greater risk of exposure, and they have fewer resources to respond to the health issues posed by the environmental factors (Norris et al., 2020; Watson et al., 2020).

Urban areas are active environmental systems having mutually dependent ecological, physical, and social components. The structure and diversity of urban landscapes often demonstrate stratification of wealth and power in the community (Schell, 2020; Watson et al., 2020). The constant processes of suburbanization have contributed immensely to the contemporary patterns of environmental racism. Environmental racism not only refers to people of color and low-income groups getting disproportionately exposed to pollution but also involves biases in natural resource policy and uneven enforcement of environmental regulations (Pulido, 2016). Some geographic studies of environmental racism have discussed the spatial relationships between environmental hazards and the demographic data to evaluate the presence of inequity (Brulle & Pellow, 2006; Mohai et al., 2009). In our research we consider this case of environmental injustice to examine the access to green spaces for different racial groups and examine the disproportionate impact it has on the health of the vulnerable population in the context of the COVID-19 pandemic.

One of the most notable observations in 2020 about documented COVID-19 infections and deaths has been the significant impact the pandemic has had on people of color. According to data from the American Public Media Research Lab, Asian Americans have faced a mortality rate of one in 1040 individuals, compared to one in every 390 for Indigenous Americans. White Americans have recorded one fatality for every 665 individuals, whereas Blacks have recorded one for every 555 individuals (APM, 2021). A possible explanation for this disparity is that whites and Asians are comparatively healthier, wealthier, and better educated than other racial and ethnic groups, though internal disparities do exist within white and Asian communities (CDC, 2016).

In theory, everyone can get COVID; however, we believe there is a need to assess relative RV to COVID-19 at the census block group level to properly share resources among all population groups to build community resilience against future pandemics. Urban green spaces are an example of resources that provide several ecosystem benefits, especially during times of social and economic crises (Grima et al., 2020). More green and open places allow people to engage in physical and mental recreation during pandemics such as COVID-19. The RV concept we propose stems from historical urban planning policies, and it can only be addressed by an equitable and collaborative distribution of resources. Thus, we propose the following framework (Fig.1), in which high RV to COVID-19 is aggravated by a scarcity of green spaces, while low RV to COVID-19 is aided by an abundance of green spaces.

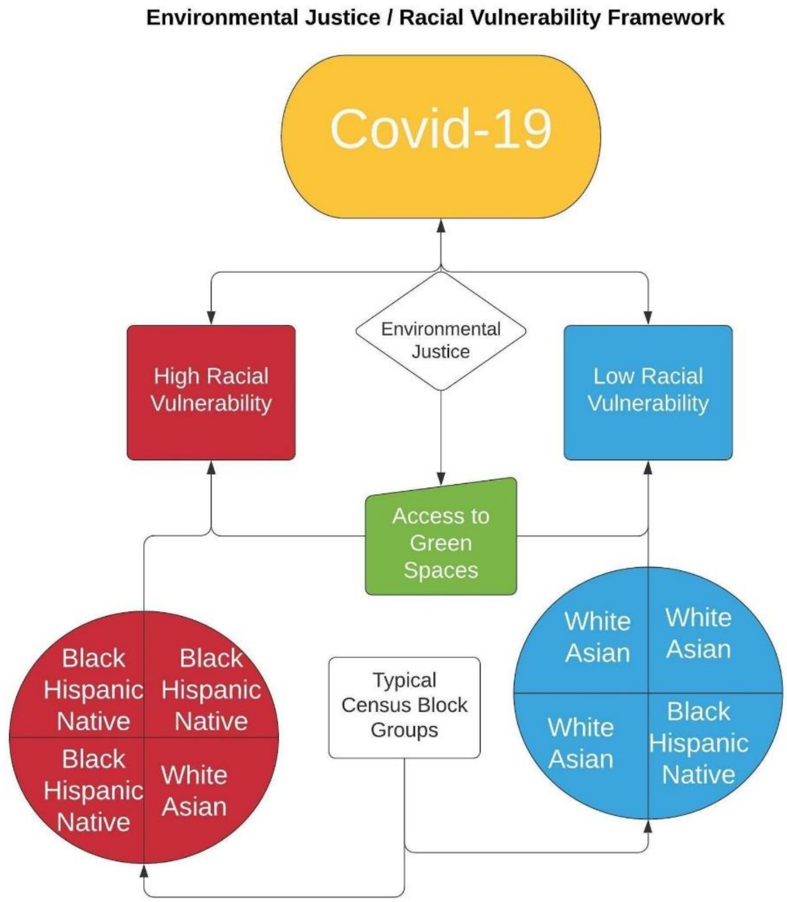

Fig 1. Environmental Justice/RV Framework for understanding spatial variation of COVID-19

3. Study Area

Our study area includes Anchorage (AK), Portland (OR), Phoenix (AZ), and Atlanta (GA), USA. These four cities were chosen because they vary in size, population, population density, and climate characteristics (Table 2). These cities also displayed an increasing pattern of COVID-19 infection and mortality rates in 2020 (Fig. 2). We intentionally avoided cities with very high population densities (e.g., New York, San Francisco) because our findings might be skewed. Instead, we seek to investigate cities of wide variations to identify whether we could find comparable or different trends.

Anchorage has the smallest population, but it has one of the highest per capita green space distributions in the country, with a total of 4,429 hectares of park and open spaces (MUNI, 2018; Pallathadka, Chang & Ajibade, 2021). Anchorage is also a very diverse city, ranking in the 80th percentile of American cities for ethnic diversity (Farell, 2018). In addition to having a large number of Alaska Natives, Anchorage saw a remarkable increase in racial diversity since 1980. It has become a magnet for Asian, Pacific Island, Latino, and multiracial populations. While many neighborhoods in Anchorage are relatively homogeneous in terms of race and ethnicity, several are incredibly diverse. According to Chad Farrell (2018), Anchorage possesses the three most diverse census tracts in the entire United States as well as more than half a dozen census tracts that rank quite high in terms of diversity. These tracts are not concentrated in just one part of the city but are distributed across the broad areas of the city identified as “downtown” and “midtown”, near many of the parks previously mentioned. Similarly, Anchorage’s schools are exceptionally diverse with 19 of the 20 most diverse elementary schools in the United States being found in the municipality (Farrell, 2018).

Portland is a fascinating test case due to its largely white population. A look back at Portland's and Oregon's history reveals a discriminatory past in which non-whites were not legally allowed to buy land or become permanent inhabitants. Even after the legislation was repealed in 1926, segregation and other government measures hindered minorities from ever completely settling in Portland's neighborhoods. Although recent decades have shown promise with modest gains in non-white population, Portland, as one of America's largest white cities, proves to be a useful study city for analyzing trends in urban policy and how they impact local inhabitants. Furthermore, Forest Park in northwest Portland is one of the largest urban parks in the country (City of Portland, 2021).

Phoenix has the largest population among our study cities. Phoenix is also one of the fastest-growing cities in the United States, with a sizable Hispanic community. Phoenix was previously a part of Northern Mexico until the United States annexed the northern zone of Mexico during the Mexican-American War in 1848. Phoenix was founded 20 years later. Prior to the 20th century, more than half of the population was Mexican citizens and Mexican-Americans, and they had very friendly ties with the non-Hispanic community — but that began to change as more people moved westward in the 20th century. Despite problems of housing segregation in the early 20th century and politics around immigration and crime from the 1990s onwards, Phoenix has maintained a remarkable diversity in its population in recent years. With its distinctive arid environment, Phoenix has been expanding parks and green spaces to address a variety of issues, including urban heat islands (City of Phoenix, 2010).

Atlanta displays the highest population density among our study cities. It is also distinctive in that the majority of the population is black. Jim Crow laws caused social segregation in Atlanta in the early 20th century, thus it was only natural that Atlanta would also serve as a major civil rights hub in the 1960s. In the 1970s, African Americans were the majority in Atlanta for the first time. As African Americans suburbanized in the 2000s, racial transformation has been ongoing. Despite existing social challenges, Atlanta is expanding its park and trail network as part of the Atlanta Beltline plan, which is anticipated to be completed by 2030 (City of Atlanta, 2021).

Table 2. Main physical and sociodemographic characteristics of study cities

City	**Anchorage**	**Portland**	**Atlanta**	**Phoenix**
Climate Classification (Köppen)	Subarctic (Dsc)	Warm summer Mediterranean (Csb)	Humid subtropical (Cfa)	Hot desert (BWh)
Population	291,538	653,115	498,044	1,680,992
Population Density (Km^2)	58	1,739	5,188	1,255
Precipitation (mm)	422.5	914.5	1,262.5	204
Park Acreage (2018)	10,946	12, 591	3,867	43,609
Park Acres as % of Land Area	39.90	15.70	4.60	14.30
Total COVID-19 Deaths (as of June 1, 2021)	174	500 ~	1,500 ~	7,500 ~
Total COVID-19 Cases (as of June 1, 2021)	30,556	31,808	150,000 ~	275,000 ~

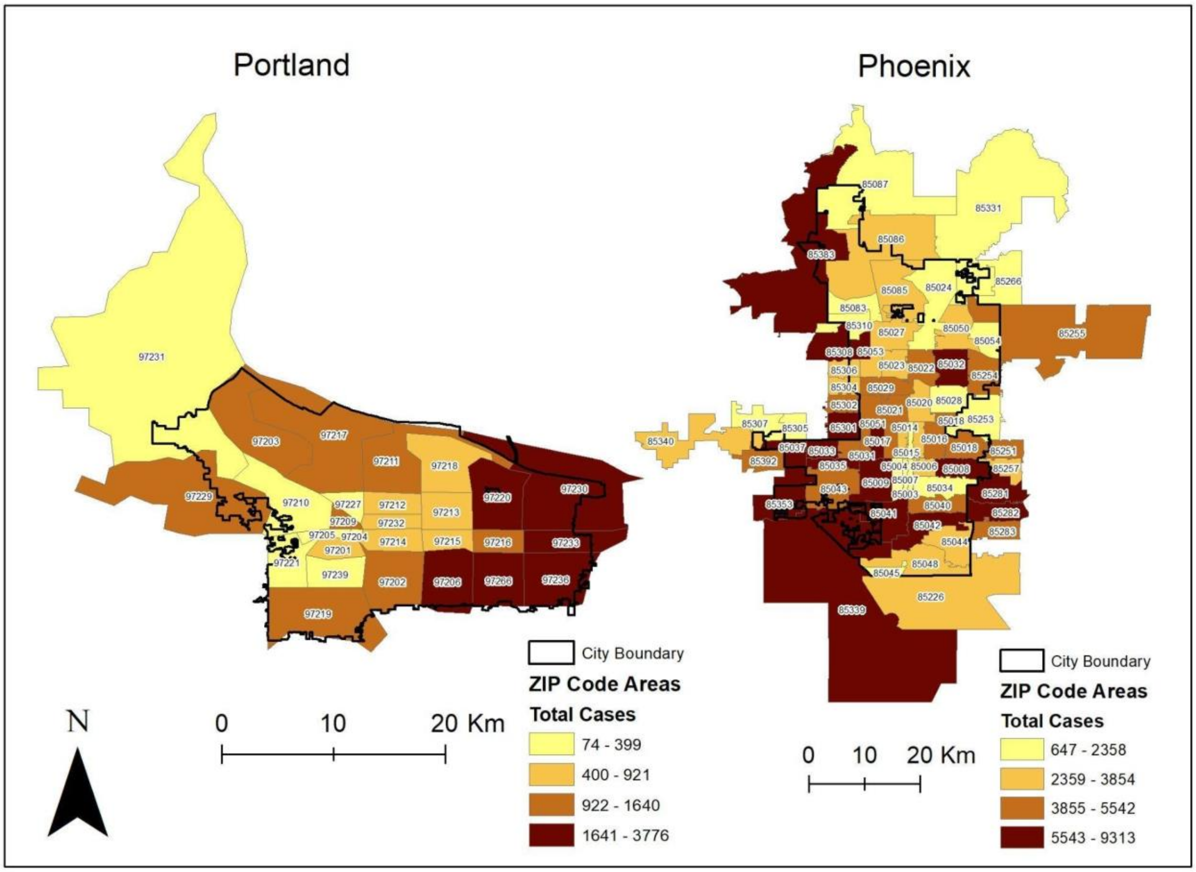

Fig 2. Map showing total COVID-19 cases by ZIP code in study cities as of June 15, 2021. Anchorage and Atlanta's data were unavailable/incomplete

4. Data and Methods

4.1 Data

4.1.1. Demographic data

Population and Demographic data for 2018 was obtained from the American Community Survey (ACS) platform's 2018 5-year estimates (U.S. Census Bureau, 2020). The ACS platform provides nationwide population estimates at different scales, census block groups (CBGs) being the smallest unit. We obtained TIGER line shapefiles and CBGs from the US Census Bureau. We created COVID-19 case data at the ZIP code level by merging the ZIP Code Tabulation Areas (ZCTA) shapefile with publicly available statistics of COVID-19 cases by ZIP code.

4.1.2. Green Space Layers data

We created the green space layer by combining three different datasets (Table 3). The first dataset i.e., parks and trails layer was obtained from each city's GIS department, the second dataset i.e., beaches (where applicable) was sourced from State GIS departments, and the third dataset i.e., Wetlands was accessed from the National Wetlands Inventory (U.S. Fish and Wildlife Service, 2020).

Table 3. Data and Data Sources

Data	American Community Survey (ACS)	COVID-19	Green Space Layers
Year (s)	2018 (5-Year Estimates)	2020	2020
Type (s)	Survey	Summary	Vector
Variable (s)	% White Population % Black Population % Asian Population % Hispanic Population* % Native Population**	COVID-19 cases	Parks Trails Wetlands Beaches
Purpose	Combine and calculate racial vulnerability (RV)	Summarize COVID-19 cases	Combine and calculate green space availability
Source	US Census Bureau	State Health Departments	City and State GIS Departments

*Hispanic = Non-white Hispanic
**Native = American Indian & Alaska Native + Native Hawaiian and Other Pacific Islander Population

4.2. Methods
4.2.1. Spatial Analysis

We performed spatial analysis (Fig. 3) on ArcGIS Desktop using *spatial analyst* tools (ArcMap 10.8.1). First, we imported the census and green space datasets into ArcMap and intersected each dataset with the polygons of the respective city. Following that, we summarized both datasets for each CBG. Then, for each racial group with a positive (+) relationship with COVID-19 (E.g., Native, Table 4), we normalized their values using a linear standardization formula to rescale values between 0-1 (Eq. 1) (Chang et al., 2021).

$$V_i = \frac{X_i - X_{imin}}{X_{imax} - X_{imin}} \text{ (Eq.1)}$$

i is the variable being analyzed, in this case either racial group or green space
j is the city in which the analysis is being done: Anchorage, AK; Atlanta, GA; Phoenix, AZ; or Portland, OR.
$x_{i,j}$ is the normalized value of variable *i* for a given CBG in city *j*
$x_{i,j}$ is the value of variable *i* for a given CBG in city *j*
$x_{min\,i,j}$ is the minimum value of variable *i* for all CBGs in city *j*
$x_{max\,i,j}$ is the maximum value of variable *i* for all CBGs in city *j*

For racial groups that are negatively linked to COVID-19, we used the following linear standardization formula with the same descriptions (Eq. 2):

$$V_i = \frac{X_{imax} - X_i}{X_{imax} - X_{imin}} \text{ (Eq. 2)}$$

We then combined the top quartile (top 25% normalized values) of RV and green space to determine their corresponding overlaps. We showed four different combinations: high-high, high-low, low-high, and low-low. The last class low-low represented the remaining 75% outliers that were considered low concern.

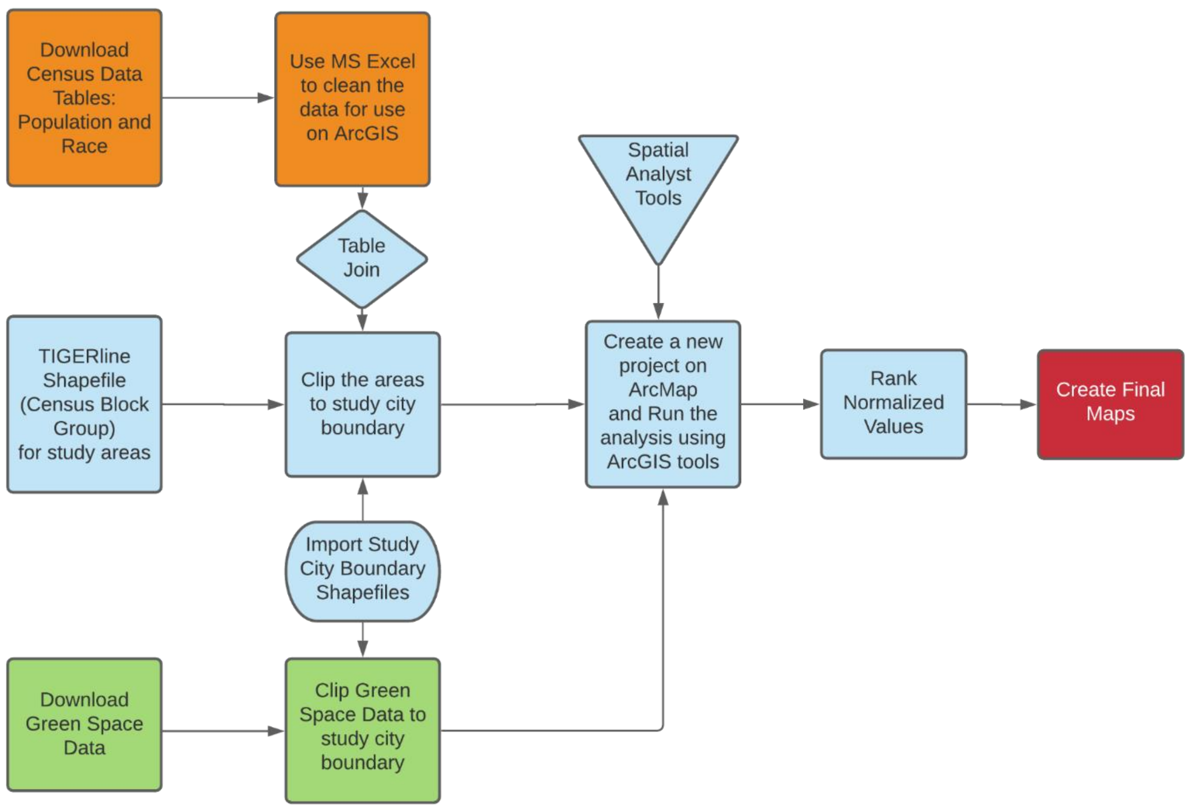

Fig 3. Spatial Analysis Flowchart

4.2.2. Statistical Analysis

We conducted Hot Spot Analysis (Getis-Ord Gi*) on ArcGIS Desktop (ArcMap 10.8.1) to identify statistically important areas. The Getis-Ord Gi* statistic is calculated by the Hot Spot Analysis tool for each feature in a dataset. The z-scores and p-values that follow indicate where features with high or low values cluster spatially. This tool works by analyzing each element in the given context of its surroundings (Getis & Ord, 1992; Ord & Getis, 1995). A high-value feature is not automatically assumed to have statistical significance. To be a statistically significant hot spot, a feature must have a high value and be surrounded by other features with high values as well. By definition, a hot spot is a high cluster area, whereas a cold spot is a low cluster area of a particular data set. We used an average of 2000 meters distance threshold for running the hot spot analysis. We also tested spatial autocorrelation of how one object measures to the other over a given space (Moran, 1950). This test determines whether the dataset has a clustering, random, or scattered distribution.

Table 4. Relative racial vulnerability variables' relationship to COVID-19

Variable	**Hypothesized relation**	**Justification**	**References**
Percent White Population (RV1)	Negative (-)	High white population makes a place less vulnerable to COVID-19; white people have second-lowest number of infections of and deaths per capita across the U.S.	Stokes et al., 2020; Killerby et al., 2020; Gold et al., 2020; Price-Haygood et al., 2020; Millet et al., 2020; Garcia et al., 2020; Simons et al., 2018;
Percent Black Population (RV2)	Positive (+)	High black population makes a place more vulnerable	
Percent Asian Population (RV3)	Negative (-)	Asians have the lowest per capita infections and deaths across the US	
Percent Hispanic Population (RV4)	Positive (+)	High Hispanic population makes a place more vulnerable	
Percent Native Population (RV5)	Positive (+)	Native population has the highest per capita infections and deaths across the US	

5. Results

5.1. Census Block Group Analysis Results

We observe high RV in Anchorage on the north and east sides of Downtown Anchorage, as well as around Anchorage Airport in the center (Fig. 4). Meanwhile, the majority of the south side has a low level of RV. Green spaces, on the other hand, are abundant in Anchorage Municipality's south, west, and east sides (Fig. 4). The hotspot results for RV data (Fig. 4) identify neighborhoods in the north as having high RV clusters, while neighborhoods in the south are recognized as coldspots, indicating low vulnerability clusters. The green space hotspot results are not detailed here (Fig. 4), however, they reveal a general clustering to the south of the city municipality. We find a negative correlation (Table 5) between high RV and green space availability using the Pearson correlation test ($r = -0.145$, $p < 0.01$). This suggests that, to a certain extent, the availability of green places decreases as RV increases (Fig. 5).

In Portland, north (along the Columbia River), northeast, and southeast sides of Portland have a high RV. On the other hand, low RV exists on the city's west side / Willamette River, and southwest side (Fig. 4). The hotspot findings support this finding of RV (Fig. 4). Portland's green space hotspots are primarily on the west side, with cold spots in much of the city center. A small area of green space hot spot in the southeast corner stands out as an exception. In Portland also, we observe a negative correlation (Table 5) between high RV and green space availability using the Pearson correlation test ($r = -0.193$, $p < 0.05$), signaling a scarcity of green spaces as RV increases.

In Phoenix, high RV can be found on the west side and in the vicinity of the airport. Most of the north side and the south mountain in the south side have low RV. This pattern of RV is confirmed by the hotspot results (Fig. 4). The distribution of green areas in Phoenix is noteworthy, with three distinct hot spots intersecting with low racial vulnerable hot spots, followed by a strong display of cold spots in high racial vulnerable hot spots. Green space is abundant on the north, center, and south mountain areas. We find a negative correlation (Table 5) between high RV and green space availability using the Pearson correlation test ($r = -0.121$, $p<0.05$), indicating that the availability of green places decreases as RV increases (Fig. 5).

We see substantial RV in Atlanta's south, southwest, and west sides. The majority of the north side has a low level of RV. The RV hotspot results (Fig. 4) clearly define clusters of high RV in the south, with cold spots in the north indicating low RV there. Two of the three ZIP codes, 30318 and 30331, have reported the majority of the COVID-19 infections and deaths in Atlanta; a number (46% of the high RV) of block groups with high RV fall within these two ZIP codes (Fig. 4). Atlanta's green spaces are distributed randomly. We don't notice a clear pattern, however, some of the green spaces that have recently appeared in the south have contributed to the gentrification phenomenon there (Immergluck & Balan, 2017). The hot spot results for green spaces (Fig. 4) support this interpretation by revealing no distinct hot spot or cold spot clusters. We do not find a significant correlation (Table 5) between RV and green space availability in Atlanta.

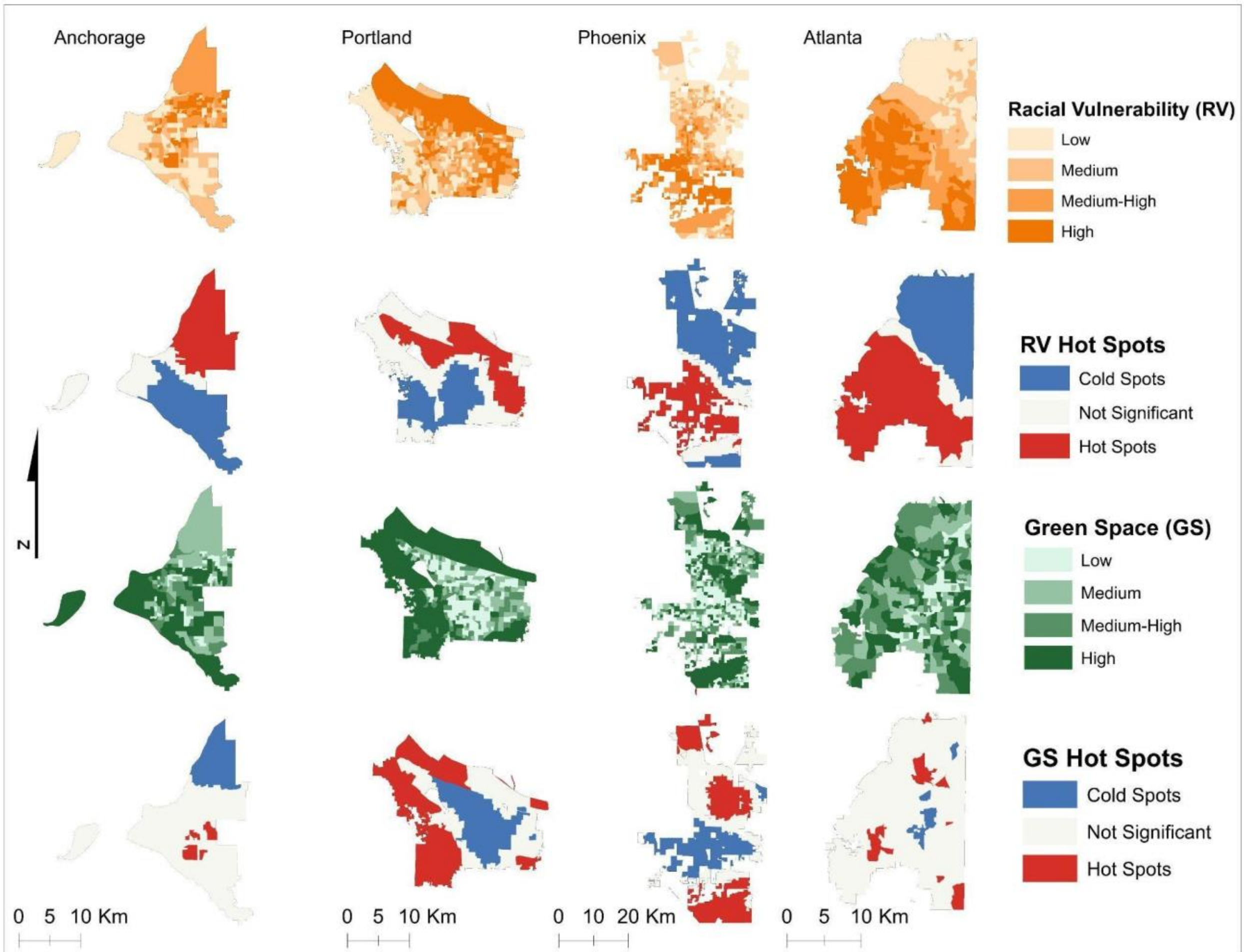

Fig 4. Racial vulnerability, green space, and their corresponding Hot Spots' distribution in study cities

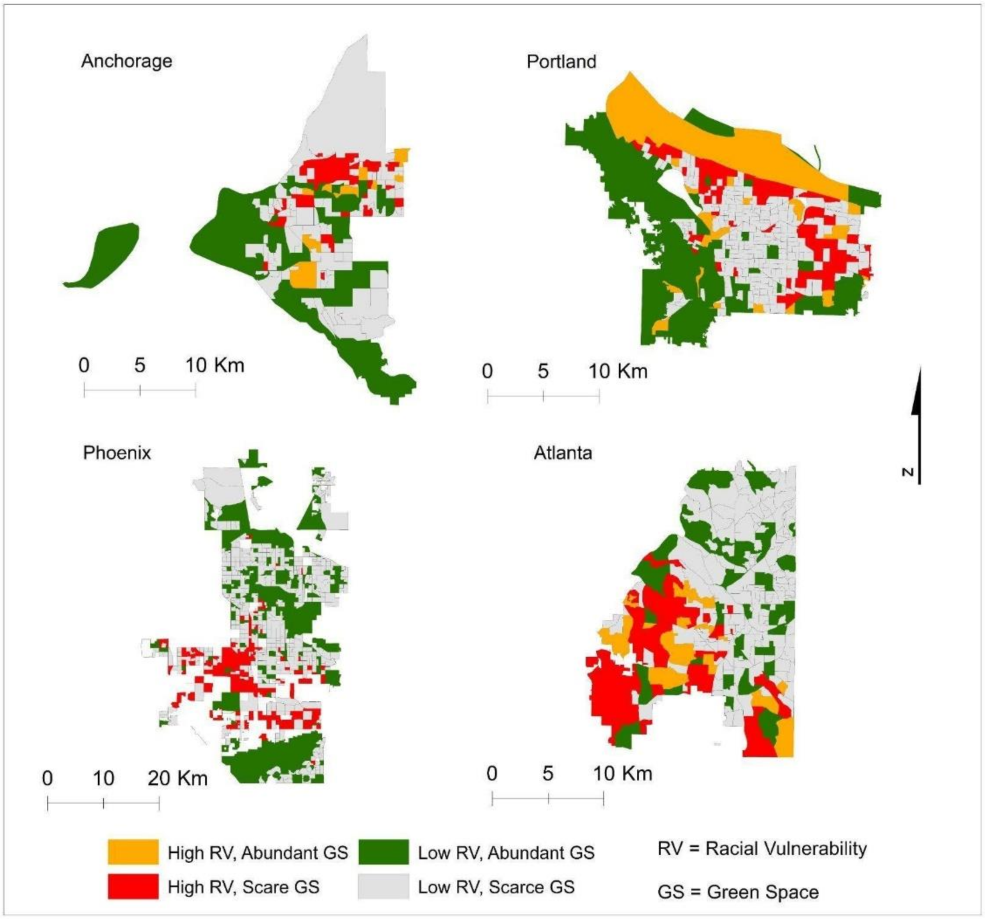

Fig 5. CBG Vulnerability map showing the overlaps between RV and green space

Table 5. Pearson's correlation coefficients among different combinations of variables (RV and green space) in Anchorage, Atlanta, Phoenix, and Portland. The variable *n* indicates the number of census block groups included in our analysis of each city. ** indicates $p < 0.01$; * indicates $p < 0.05$; Blank cells indicate $p \geq 0.05$.

Study City	Correlation	Global Moran's I Result
Anchorage *n* =187	-0.145 *	Clustered
Atlanta *n* =302		Only Racial Vulnerability clustered
Phoenix *n* =871	-0.121**	Clustered
Portland *n* = 449	-0.193**	Clustered

5.2 ZCTA Analysis Results

In Portland, the east side has a high racial vulnerability to COVID-19 (Fig. 6). The west and south of Portland have low racial vulnerability. The hot spot findings further support this observation. The postal code areas generally demonstrate similar trends as CBGs in green space distribution, with high density of green spaces in the southeast and southwest corners of the city. The hot spots of green spaces in the city, however, indicate a stronger presence in the southwest and towards the center. Nine of the ten zip codes in Portland with the highest COVID-19 incidences, all in the north or east, contained high RV and low green space availability areas. We see a positive correlation between COVID-19 numbers and racial vulnerability using the Pearson correlation test ($r = 0.796$, $p <0.01$, Table 6); other relationships are not significant in Portland at the ZIP code level.

In Phoenix, the south and center areas have a high racial vulnerability to COVID-19, and this observation is supported by the hot spots analysis (Fig. 7). The postal codes in the north have a low racial vulnerability. The green space in the city has two hot spots, one in the center-north and another one in the far south. The cold spots of green space are in the southwest and center ZIP code areas. Nine of the top ten zip codes with the highest number of COVID-19 cases, all in the south or west, have a high RV and a scarcity of green space. Like Portland, we also see a positive correlation between COVID-19 numbers and racial vulnerability using the Pearson correlation test ($r = 0.444$, $p < 0.01$, Table 6); the only other significant relationship is found between racial vulnerability and green space availability ($r = 0.387$, $p <0.01$).

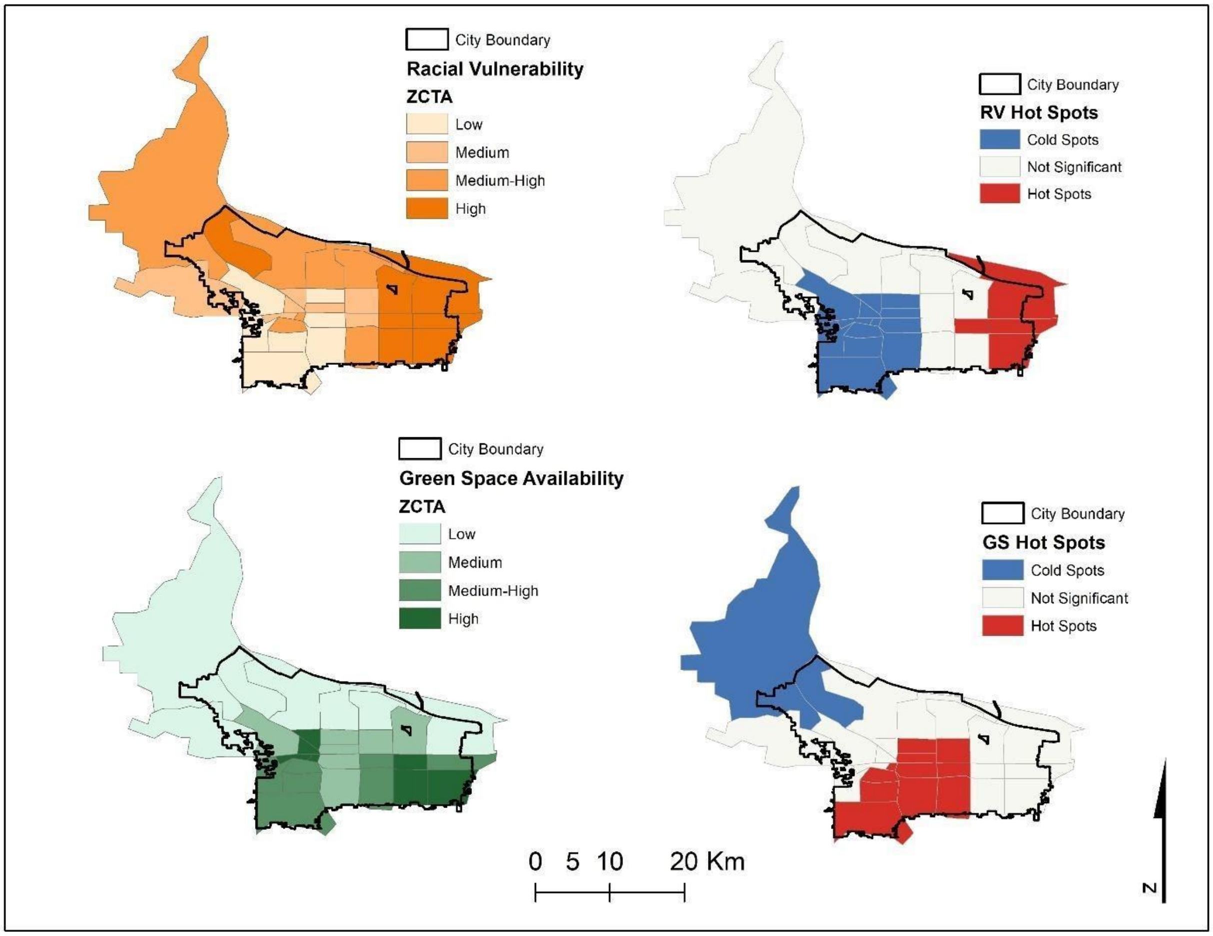

Fig 6. ZCTA-level maps showing racial vulnerability, green space density, and their corresponding hot spots for Portland

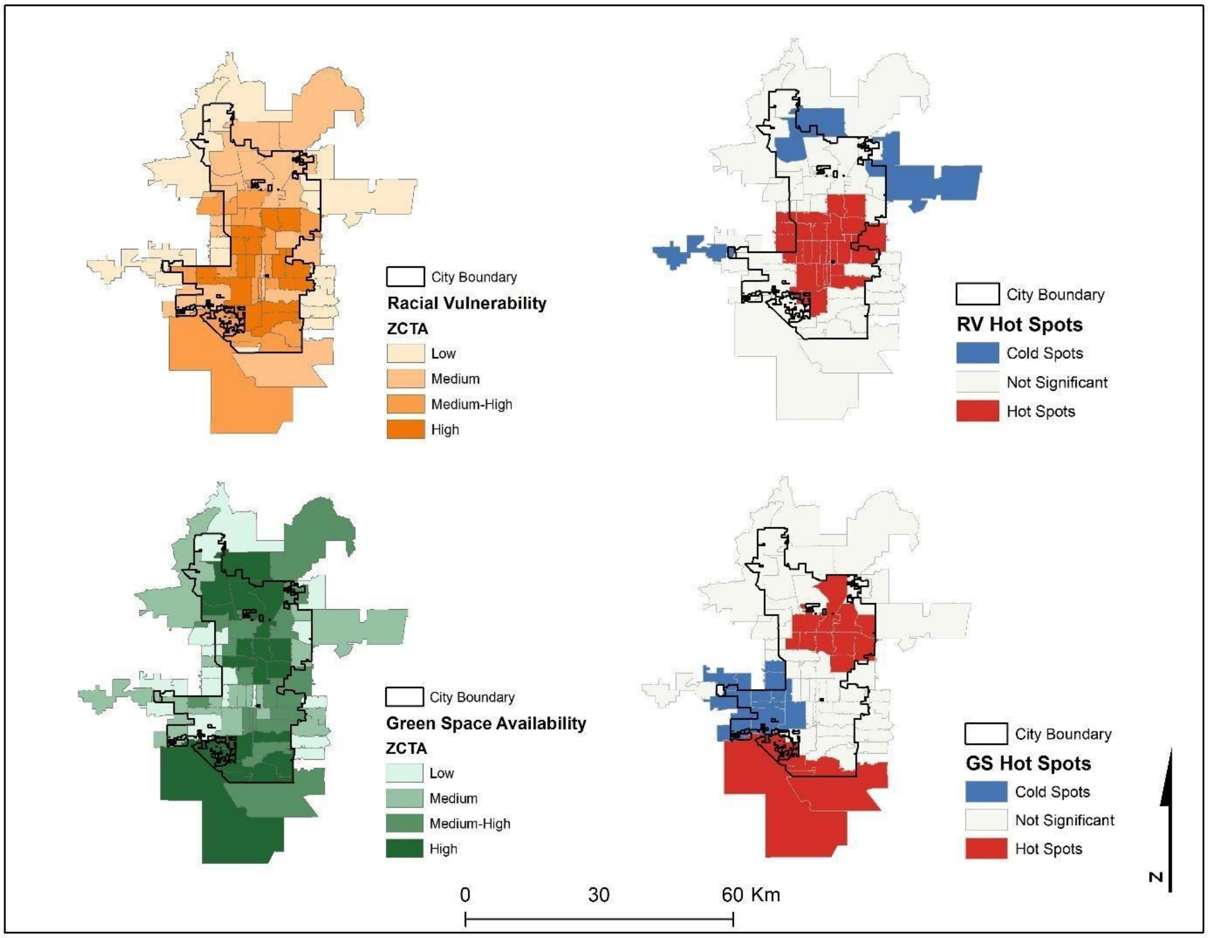

Fig 7. ZCTA-level maps showing racial vulnerability, green space density, and their corresponding hot spots for Phoenix

Table 6. Pearson's correlation coefficients among different combinations of variables in Portland and Phoenix. The variable *n* indicates the number of census block groups included in our analysis of each city. ** indicates p < 0.01; * indicates p < 0.05; Blank cells indicate p ≥ 0.05.

Study City	**Variables Correlated**	**Correlation**	**Global Moran's I Result**
Portland *n* = 27	COVID-19 count vs Racial Vulnerability	0.796**	Clustered
	COVID-19 count vs Green Space Availability		Clustered
	Racial Vulnerability vs Green Space Availability		Clustered
Phoenix *n* = 66	COVID-19 count vs Racial Vulnerability	0.444**	Clustered
	COVID-19 count vs Green Space Availability		Clustered
	Racial Vulnerability vs Green Space Availability	0.387**	Clustered

6. Discussion

6.1. Spatial Patterns of Racial Vulnerability and Green Spaces

Like many other urban areas in the United States, Anchorage has, historically, seen a concentration of poverty and RV in areas near the center of the city where, traditionally, there has been little green space. In the case of Anchorage, the location of a large military base to the north of the city, and along the urban edge, has further impacted access to green space in several key neighborhoods. To the east and south of Anchorage, the city limits end where the second-largest state park in the United States begins and Bureau of Land Management lands and coastal areas are found. Neighborhoods in much of this area are populated by a more racially homogenous and white population that has taken root in a large suburban area known as the "Hillside", where developments and zoning requirements have generally led to upper-middle-class housing construction. Similarly, the west of Anchorage has access to a large park area carved out of a decommissioned military base after World War II (Pallathadka, Chang & Ajibade, 2021). These suburban areas developed at a time when park planning and public interest in preserving green spaces was high. In more urban areas, where zoning and historical development favored more intense urban uses, access to green space is more limited and coincides closely with indices of high RV. That said, municipal park planners and agents of conservation organizations have worked hard to extend public parks and access to green spaces in underserved parts of the municipality. Particular success is found in the extension of a network of trails and parks in Anchorage's "Midtown" along creek bottoms and the coast.

Portland is one of the whitest cities in the United States, and this is not by chance. Following WW2, discriminatory measures such as redlining and gentrification ensured that people of color were pushed east of the Willamette River (Billings Jr., 2000; Hannah-Jones, 2010). One of the reasons people of color attempted to relocate to the Portland area in the first place was to work on the city's flourishing industrial landscape, which included a busy river port (Semuels, 2021). In the 1950s, Interstate-205, then on the outskirts of Portland, was developed as a bypass for Interstate-5. This area, surrounding the Interstate-205, evolved into black and brown neighborhoods, the legacy of which can still be seen today. For decades, these neighborhoods were neglected and underinvested (Hannah-Jones, 2010). Portland saw a new economic boom in the 1990s with technology and manufacturing, and many young people relocated there, bringing a new wave of gentrification with them. The new technology wave primarily benefited white and Asian populations, but it had little impact on black and brown groups. Asians continue to have the most income inequality as a group in the US, yet relatively higher-earning Asians have been able to migrate into white neighborhoods in the Portland region (Kochhar & Cilluffo, 2020). Since the 1990s, significant city investments in green spaces have gentrified several neighborhoods, mainly those that were historically non-white. According to one report, Portland is the fourth fastest gentrifying city in the United States (Homes & Gardens of the Northwest staff, 2017).

Phoenix has a sizable Hispanic (43%) and Black (7%) population, and the city has always had people of color since its foundation; nevertheless, the city's urban planning is also a story of segregation (Harvey, 1996; Bolin et al. 2005). Because of the flooding of the Salt River in the 19th century, whites began to migrate northward, forcing the areas between the CBD and the Salt River to lean industrial and form temporary ghettos. Communities of color began to concentrate in South Phoenix, where the majority of the industries thrived. Minorities in South Phoenix have been deprived of their fair share of urban resources as a direct result of urban policies (Bolin et al., 2002, Bolin et al., 2005). Although the lack of sufficient green spaces in these neighborhoods has historical roots, present challenges stem from the industrial landscape and gentrification risks. The City of Phoenix is actively working on a South Phoenix Development Plan, which includes plans for improved mobility (Taros, 2021).

Atlanta is one of the few large cities where the black population exceeds 50% of the total population, however, there are significant inequities in Atlanta's black-majority society. According to the 2018 American Community Survey conducted by the United States Census Bureau, Atlanta has the highest average household income inequality (Lu & Tanzi, 2019). The majority of Atlanta's black, Hispanic, and other native communities have traditionally lived in the city's south and west sides, but these areas have suffered from decades of urban mismanagement. However, recent large-scale developments over a short period of time have made it difficult for long-term inhabitants to keep their homes. The Atlanta Beltline is a prime example of such initiatives, with property values increasing 17.9 percent to 26.6 percent closer to the Beltline between 2011 and 2015, depending on the stretch of the Beltline (Immergluck & Balan, 2017). Redlining, as in other cities, has played a significant part in white communities settling on the north side. Asians have gradually moved to the north side. However, past segregation has significantly contributed to today's RV distribution.

6.2 Green Spaces in COVID-19 Context

Green spaces are constructed for a variety of purposes, but it is a novel idea to see them as a space that may promote recreation while also enabling social distancing. In the case of Anchorage, prior research found a significant link between park size and the diversity of park values (Brown, 2008). In times of pandemics such as COVID-19, Anchorage's relatively larger green spaces can thus ideally serve all groups, vulnerable included, to adequate recreation if such green spaces are located in an equitable manner. However, some of Anchorage's green spaces, such as Kincaid Park, Chugach State Park, and Far North Bicentennial Park are relatively inaccessible by public transportation; the city can enhance access by providing public transportation as well as information.

There are several
green spaces in Portland, including parks, trails, and wetlands, but they are not equally distributed over space. Many of the city's green spaces in the northeast and north are adjacent to industrial parks, making them undesirable for recreation in several sections (Stroud, 1999). Because COVID-19 hot spot areas in Portland generally overlap with industrial parks, the practical recreational use of those parks may be minimal. Furthermore, Forest Park in Portland's northwest section is inaccessible by public transportation, leaving it solely accessible to people who own automobiles. This makes it difficult for vulnerable populations to benefit from Forest Park's large network of trails and green open space. The lesson from Portland is that cities should build parks that serve everyone and provide meaningful access, rather than offering symbolic services.

The climate influences how green and open areas are developed in Phoenix. However, many of the open areas, such as North Mountain and South Mountain parks, primarily serve wealthy neighborhoods with greater access, often by foot and bicycle, while offering minimal public transportation for residents from other parts of the city (Hoover et al., 2021). With new green space installations, the underprivileged areas in this city have often suffered from gentrification (Richardson, Mitchell, & Edelbi, 2020); improved stakeholder involvement and community outreach would help to prevent gentrification while also increasing green and open spaces.

For years, Atlanta has had inadequate green space management; numerous non-profits operate in the Atlanta region to improve the issue and better manage the existing parks and open spaces (Watkins et al., 2018). Nevertheless, new improvements come with the threat of gentrification (Immergluck & Balan, 2017). Atlanta’s green space problem is multifaceted – there is the problem of creating adequate green space, and then there is the challenge of expanding access to existing green spaces.

6.3. Environmental Justice

This study describes the spatial patterns of racial demographics of four distinctly different cities across the United States, while associating spatial variability of green spaces in these cities. Our results indicate that none of the four cities in this study have sufficient green spaces in CBGs and ZCTA predominantly occupied by people of color. Our study compliments several other environmental justice studies since the onset of COVID-19 pandemic that have demonstrated the disproportionate distribution of resources. Although the RV concept introduced in this study is novel and specific to the ongoing pandemic's impact, it has existed from an environmental justice perspective for decades (Boone et al., 2009; Rigolon & Németh, 2018; Taylor et al., 2007).

During the pandemic, we saw an increased usage of these urban green spaces as they offered opportunities of physical and mental well-being, while following social distancing guidelines. A study conducted by University of Vermont enumerates benefits of green spaces that extend beyond health and well-being (Grima et al., 2020). Therefore, expanding green space coverage and accessibility would contribute to mitigating not just the present pandemic, but also future pandemics (Tribby & Hartmann, 2021; Yi Lu et al., 2020). The lack of adequate green spaces in Phoenix, for example, has been an issue even before the pandemic, as suggested by Truman (2014). Park et. al (2020) study disparities in community green space accessibility in Atlanta and also find similar results to our study. Another example of a study related to spatial distribution of urban resources is Karaya et. al (2020) who conclude that COVID-19 infection rates in the US have been influenced by minority status, household composition, housing status, and disability. These studies provide empirical evidence for policy makers to re-think urban zoning and increase the proximity of communities of color to urban green spaces.

6.4 Limitations

We are aware, like with other works, that our research has limitations. We proposed a framework in which Asians and whites are less vulnerable to COVID-19. This trend may or may not change as the pandemic progresses and eventually concludes. As a result, the contribution of this study is not necessarily identifying who is always vulnerable, but rather relating it to what resources are available to those who are highly vulnerable at any given time. Our framework would aid in the assessment of excessive and inadequate resource distribution between demographic groups; we propose that such distributions be fair and appropriate. This is not a study to recommend a specific set of indicators. Instead, we are exploring how GIS can be used to combine social and ecological factors for a given geographic area with a framework founded on RV patterns exhibited by the COVID-19 pandemic. Hence, this is a demonstration of how social and ecological factors can be effectively used to identify potentially problematic areas during a pandemic for the just allocation of resources.

Aside from race and ethnicity, poverty, income, immigration status, and language proficiency can all have an impact on the population during a pandemic. From the standpoint of ecological variables, climatic factors such as temperature, precipitation, and humidity may play a role in the spread of COVID-19, however research on this topic is limited. Climate suitability could also be the deterministic driver of COVID-19 spread. Future research could delve into some of these relationships in order to better inform urban planners and policymakers.

In addition to the limitations stated above, there are certain data limitations. For example, Anchorage has not yet made its COVID-19 data available at zip code-scale owing to privacy concerns, as Anchorage Municipality has a very low population density. In Atlanta, two of the zip codes with the highest infection rates comprise nearly all our racially vulnerable block groups, but the comprehensive zip code data here is lacking for further comparisons (Raymond, 2020).

7. Conclusions

Green spaces are normally considered to improve a neighborhood's health and well-being. Pandemics like COVID-19 highlight a gap in urban park placement. Inequality exists in public spaces, both in terms of access and amenities. Parks and trails are examples of public spaces where social distancing is possible, and the risk of infection is low. In our study, we analyzed RV at the CBG and ZCTA scale and related it to the availability of public green spaces. We discovered disparities in the distribution of public green space in all four study cities, and the findings of our study emphasized the legacy of historical issues in urban planning. The recurrent theme we find in our results in the context of COVID-19 is that people of color experience a disproportionate impact from COVID-19, and they also have substantially fewer green open areas for recreation. In Portland and Phoenix, we found that COVID-19 cases follow the RV framework, and more COVID-19 cases occurred in racially vulnerable CBGs and ZCTAs. This shows that urban policies have a far-reaching impact that extends well beyond initially perceived injustices. While these policies cannot be drastically changed, and parks cannot be built quickly, understanding social constraints and ecological repercussions can help urban planners take tangible steps toward solutions. Cities would do well to guarantee that vulnerable communities have access to sufficient amounts of green space.

The importance of our study stems from the fact that public green spaces have societal value. Although the benefit may be intangible to ordinary people in day-to-day life, recent events involving lockdowns, masking, and social distance protocols clearly highlight the need for activities such as walking, inhaling fresh air, and simply being outside. The pandemic and subsequent lockdowns highlighted the importance of public open places across the world. In the future, while designing new green areas, planners and policymakers must consider RV as well as physical and mental health repercussions.

References

1. Andersen, L. M., Harden, S. R., Sugg, M. M., Runkle, J. D., & Lundquist, T. E. (2021). Analyzing the spatial determinants of local COVID-19 transmission in the United States. *Science of The Total Environment*, 754, 142396. DOI:https://doi.org/10.1016/j.scitotenv.2020.142396
2. APM. (2021). https://www.apmresearchlab.org/COVID/deaths-by-race
3. Bashir, M. F., Jiang, B.M.A, Bilal, Komal, B., Bashir, M. A., Farooq, T. H., Iqbal, N., & Bashir, M. (2020). Correlation between environmental pollution indicators and COVID-

19 pandemic: A brief study in Californian context. *Environmental Research*, 187, 109652. DOI:https://doi.org/10.1016/j.envres.2020.109652.

4. Billings Jr., D. (2000). White Space, Black Space: Community Gardens in Portland, Oregon. Dissertations and Theses. Paper 4550. Portland State University. DOI:https://doi.org/10.15760/etd.6435
5. Bolin, B., Nelson, A., Hackett, E., Pijawka, D. Smith, S., Sadalla , E., Sicotte, D., Matranga, E., & O'Donnell, M. (2002). The Ecology of Technological Risk in a Sunbelt City. *Environment and Planning* A 34,317-339.
6. Bolin, R., Grineski, S., & Collins, T. (2005). The geography of despair: Environmental racism the making of South Phoenix, Arizona, USA. *Human Ecology Review*, 12(2), 156-168.
7. Boone, C. G., Buckley, G. L., Grove, J. M., & Sister, C. (2009). Parks and people: An environmental JUSTICE inquiry in Baltimore, Maryland. *Annals of the Association of American Geographers, 99*(4), 767-787. DOI:10.1080/00045600903102949
8. Brown, G. (2008). A theory of urban park geography. *Journal of Leisure Research, 40*(4), 589-607. DOI:10.1080/00222216.2008.11950154
9. Brulle, R. J., & Pellow, D. N. (2006). ENVIRONMENTAL JUSTICE: Human Health and Environmental Inequalities. *Annual Review of Public Health*, 27(1), 103–124. DOI:https://doi.org/10.1146/annurev.publhealth.27.021405.102124
10. Centers for Disease Control and Prevention. (2016). Products - Data Briefs - Number 247 - May 2016. Centers for Disease Control and Prevention. Retrieved June 23, 2022, from - https://www.cdc.gov/nchs/products/databriefs/db247.htm.
11. Centers for Disease Control and Prevention. (2020a). Visiting Beaches and Pools. Retrieved June 23, 2022, from - https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/beaches-pools.html
12. Centers for Disease Control and Prevention. (2020b). Cases, Data, and Surveillance. Centers for Disease Control and Prevention. Retrieved June 23, 2022, from - https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-race-ethnicity.html
13. Centers for Disease Control and Prevention. (2021). COVID Data Tracker. Retrieved June 23, 2022, from - https://COVID.cdc.gov/COVID-data-tracker/#datatracker-home.
14. Chang, H., Pallathadka, A., Sauer, J., Grimm, N., Zimmerman, R., Cheng, C., Iwaniec, D., Kim, Y., Lloyd, R., McPhearson, T., Rosenzweig, B., Troxler, T., Welty, C., Brenner, R., & Herreros-Cantis, P. (2021). Assessment of Urban Flood Vulnerability Using the Social-Ecological-Technological Systems Framework in Six US cities. *Sustainable Cities and Society*, 68-102786. DOI: https://doi.org/10.1016/j.scs.2021.102786
15. Cicea, C., & Pirlogea, C. (2011). Green Spaces and Public Health in Urban Areas. Theoretical and Empirical Researches in Urban Management, 6(1), 83-92. http://www.jstor.org/stable/24873277.
16. City of Atlanta. (2021). The Atlanta Beltline Project. Retrieved June 23, 2022, from - https://www.atlantaga.gov/government/departments/city-planning/office-of-zoning-development/the-atlanta-beltline
17. City of Phoenix. (2010). Tree and Shade Master Plan. Retrieved June 23, 2022, from - https://www.phoenix.gov/find-it/Pages/results.aspx?k=tree%20and%20shade%20masterplan

18. City of Portland. (2021). Retrieved June 23, 2022, from - https://www.portlandoregon.gov/parks/43178
19. Dai, D. (2011). Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning*, 102(4), pp.234-244. DOI:10.1016/j.landurbplan.2011.05.002
20. Desjardins, M. R., Hohl, A., & Delmelle, E. M. (2020). Rapid surveillance of COVID-19 in the United States using a prospective space-time scan statistic: Detecting and evaluating emerging clusters. Applied Geography, 102202. DOI:https://doi.org/10.1016/j.apgeog.2020.102202
21. Dong, Y., Liu, H., & Zheng, T. (2020). Does the Connectivity of Urban Public Green Space Promote Its Use? An Empirical Study of Wuhan. *International Journal of Environmental Research and Public Health*, 17(1), 297. DOI:https://doi.org/10.3390/ijerph17010297
22. Executive Order No. 13909, Fed. Reg. 16227 (March 18, 2020)
23. Farrell, C. (2018). “The Anchorage Mosaic: Racial and Ethnic Diversity in the Urban North” in Imagining Anchorage: The Making of America’s Northernmost Metropolis (pp.374-391)Chapter: 17. University of Alaska Press
24. Garcia, M. A., Homan, P. A., García, C., & Brown, T. H. (2020). The color of COVID-19: Structural racism and the disproportionate impact of the pandemic on older black And LATINX ADULTS. *The Journals of Gerontology: Series B, 76*(3). DOI:10.1093/geronb/gbaa114
25. Getis, A. & J.K. Ord. (1992). "The Analysis of Spatial Association by Use of Distance Statistics". *Geographical Analysis* 24(3).
26. Gold, J. A., Wong, K. K., Szablewski, C. M., Patel, P. R., Rossow, J., Da Silva, J., Natarajan, P., Morris, S., Fanfare, R.N., Brown-Rogers, J., Bruce, B.B., Browning, S., Hernandez-Romieu, A.R., Furukawa, N.W., Kang, M., Evans, M., Oosmanally, N., Tobin-D’Angelo, M., Drenzek, C., Murphy, D., Hollberg, J., Blum, J.M., Jansen, R., Wright, D.D., Sewell III, W. M., Owens, J. D., Lefkove, B., Brown, F.W., Burton, D.C., Uyeki, T.M., Bialek, S.R., & Jackson, B. R. (2020). Characteristics and clinical outcomes of adult patients hospitalized With COVID-19 — Georgia, MARCH 2020. MMWR. Morbidity and Mortality Weekly Report, 69(18), 545-550. DOI:10.15585/mmwr.mm6918e1
27. Gostin, L., JD. (2019). Is Affording Undocumented Immigrants Health Coverage a Radical Proposal? Retrieved June 23, 2022, from - https://jamanetwork.com/channels/health-forum/fullarticle/2759639
28. Grima, N., Corcoran, W., Hill-James, C., Langton, B., Sommer, H., & Fisher, B. (2020). The importance of urban natural areas and urban ecosystem services during the COVID-19 pandemic. *PLOS ONE*, 15(12), e0243344. DOI:https://doi.org/10.1371/journal.pone.0243344
29. Hannah-Jones, N. (2010). In Portland's heart, 2010 Census shows diversity dwindling. OregonLive. Retrieved June 23, 2022, from - https://www.oregonlive.com/pacific-northwest-news/2011/04/in_portlands_heart_diversity_dwindles.html#:~:text=Portland%2C%20already%20the%20whitest%20major,areas%20have%20grown%20more%20diverse.&text=The%20city%20core%20didn't,moved%20in%2C%20the%20data%20show.
30. Harvey, D. (1996). Justice, Nature and the Geography of Difference.

Blackwell, London.
31. Haase, A. (2020). COVID-19 as a Social Crisis and Justice Challenge for Cities. *Frontiers in Sociology*, 5. DOI:https://doi.org/10.3389/fsoc.2020.583638.
32. Hohl, A., Delmelle, E.M., Desjardins, M.R. & Lan, Y., (2020). Daily surveillance of COVID-19 using the prospective space-time scan statistic in the United States. *Spatial and Spatio-temporal Epidemiology*, 34, p.100354. DOI:https://doi.org/10.1016/j.sste.2020.100354
33. Hoover, F., Meerow, S., Grabowski, Z. J., & McPhearson, T. (2021). Environmental justice implications of siting criteria in urban green infrastructure planning. *Journal of Environmental Policy & Planning*, *23*(5), 665-682. DOI:10.1080/1523908x.2021.1945916f
34. Homes & Gardens of the Northwest staff. (2017). Portland is 4th fastest gentrifying U.S. city, says Realtor.com (photos). Oregonlive. Retrieved June 23, 2022, from - https://www.oregonlive.com/hg/2017/02/portland_gentrification_4_real.html.
35. Houeto, D. (2019). The social determinants of emerging infectious diseases in Africa. *MedCrave Online Journal of Public Health*. 8. 57–63. DOI:10.15406/mojph.2019.08.00286.
36. Immergluck, D., & Balan, T. (2017). Sustainable for whom? Green urban development, environmental gentrification, and the Atlanta Beltline. *Urban Geography*, 39(4), 546–562. DOI:https://doi.org/10.1080/02723638.2017.1360041
37. Karaca-Mandic, P., Georgiou, A., & Sen, S. (2021). Assessment of COVID-19 Hospitalizations by Race/Ethnicity in 12 States. *JAMA Internal Medicine*, 181(1), 131. DOI:https://doi.org/10.1001/jamainternmed.2020.3857
38. Karaye, I. M., & Horney, J. A. (2020). The Impact of Social Vulnerability on COVID-19 in the U.S.: An Analysis of Spatially Varying Relationships. *American Journal of Preventive Medicine*, 59(3), 317–325. DOI:https://doi.org/10.1016/j.amepre.2020.06.006
39. Killerby, M. E., Link-Gelles, R., Haight, S. C., Schrodt, C. A., England, L., Gomes, D. J., Shamout, M., Pettrone, K., O'Laughlin, K., Kimball, A., Blau, E. F., Burnett, E., Ladva, C. N., Szablewski, C. M., Tobin-D'Angelo, M., Oosmanally, N., Drenzek, C., Murphy, D. J., Blum, J. M., & Wong, K. K. (2020). Characteristics Associated with Hospitalization Among Patients with COVID-19 — Metropolitan Atlanta, Georgia, March–April 2020. *Morbidity and Mortality Weekly Report*, 69(25), 790–794. DOI:https://doi.org/10.15585/mmwr.mm6925e1
40. Kleinschroth, F., & Kowarik, I. (2020). COVID-19 crisis demonstrates the urgent need for urban greenspaces. *Frontiers in Ecology and the Environment*, 18(6), 318–319. DOI:https://doi.org/10.1002/fee.2230
41. Kochhar, R., & Cilluffo, A. (2020). Income Inequality in the U.S. Is Rising Most Rapidly Among Asians. Pew Research Center's Social & Demographic Trends Project. Retrieved June 23, 2022, from - https://www.pewresearch.org/social-trends/2018/07/12/income-inequality-in-the-u-s-is-rising-most-rapidly-among-asians/.
42. Kreger, M., Sargent, K., Arons, A., Standish, M., & Brindis, C. D. (2011). Creating an environmental justice framework for policy change in childhood asthma: a grassroots to treetops approach. *American journal of public health*, *101 Suppl 1*(Suppl 1), S208–S216. DOI:https://doi.org/10.2105/AJPH.2011.300188

43. Kubota Y, Shiono T, Kusumoto B, Fujinuma J (2020) Multiple drivers of the COVID-19 spread: The roles of climate, international mobility, and region-specific conditions. *PLoS ONE* 15(9): e0239385. DOI:https://doi.org/10.1371/journal.pone.0239385
44. Lanza, K., Stone, B., & Haardörfer, R. (2019). How race, ethnicity, and income moderate the relationship between urban vegetation and physical activity in the United States. *Preventive Medicine*, 121, 55–61. DOI:https://doi.org/10.1016/j.ypmed.2019.01.022
45. Lu, W., & Tanzi, A. (2019). Bloomberg.com. Retrieved June 23, 2022, from - https://www.bloomberg.com/news/articles/2019-11-21/in-america-s-most-unequal-city-top-households-rake-in-663-000
46. Liu, L., Zhong, Y., Ao, S., & Wu, H. (2019). Exploring the Relevance of Green Space and Epidemic Diseases Based on Panel Data in China from 2007 to 2016. *International journal of environmental research and public health*, 16(14), 2551. DOI:https://doi.org/10.3390/ijerph16142551
47. Liu, D., Kwan, M.-P., & Kan, Z. (2021). Analysis of urban green space accessibility and distribution inequity in the city of Chicago. *Urban Forestry & Urban Greening*, *59*, 127029. DOI:https://doi.org/10.1016/j.ufug.2021.127029
48. Lu, Y., Chen, L., Liu, X., Yang, Y., Sullivan, W. C., Xu, W., Webster, C., & Jiang, B. (2021). Green spaces MITIGATE racial disparity of Health: A higher ratio of green spaces indicates a Lower racial disparity in Sars-cov-2 infection rates in the USA. *Environment International*, 152, 106465. DOI:10.1016/j.envint.2021.106465
49. Louis-Jean, J., Cenat, K., Njoku, C. V., Angelo, J., & Sanon, D. (2020). Coronavirus (COVID-19) and Racial Disparities: A perspective analysis. *Journal of Racial and Ethnic Health Disparities*, 7(6), 1039-1045. DOI:10.1007/s40615-020-00879-4
50. Mayo Clinic. (2020). Stay safe, have fun during the COVID-19 pandemic. Retrieved September 05, 2020, from https://www.mayoclinic.org/diseases-conditions/coronavirus/in-depth/safe-activities-during-COVID19/art-20489385
51. McPhearson, T., Grabowski, Z., J., Herreros-Cantis, P., Mustafa, A., Ortiz, L., Kennedy, C., Tomateo, C., Lopez, B., Olivotto, V., & Vantu, A. (2020): Pandemic Injustice: Spatial and Social Distributions of the first wave of COVID-19 in the US Epicenter. *Advance*. Preprint. DOI:https://doi.org/10.31124/advance.13256240.v2
52. Millett, G. A., Jones, A. T., Benkeser, D., Baral, S., Mercer, L., Beyrer, C., Honermann, B., Lankiewicz, E., Mena, L., Crowley, J.S., Sherwood, J., & Sullivan, P. S. (2020). Assessing differential impacts of COVID-19 on black communities. *Annals of Epidemiology*, 47, 37-44. DOI:10.1016/j.annepidem.2020.05.003
53. Mohai, P., Pellow, D., & Roberts, J. T. (2009). Environmental Justice. *Annual Review of Environment and Resources*, 34(1), 405–430. DOI:https://doi.org/10.1146/annurev-environ-082508-094348
54. Municipality of Anchorage (MUNI). (2018). Retrieved June 23, 2022, from - https://www.muni.org/departments/parks/Pages/default.aspx
55. Muñoz-Price, L. S., Nattinger, A. B., Rivera, F., Hanson, R., Gmehlin, C. G., Perez, A., Singh, S., Buchan, B.W., Ledeboer, N.A., & Pezzin, L. E. (2020). Racial disparities in incidence and outcomes among patients with COVID-19. *JAMA Network Open*, 3(9). DOI:10.1001/jamanetworkopen.2020.21892
56. Nesbitt, L., Meitner, M., Girling, C., Sheppard, S., & Lu, Y. (2018). Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities.

Landscape and Urban Planning, 181, 51-79 DOI:https://doi.org/10.1016/j.landurbplan.2018.08.007

57. Olin, A. (2020). In the COVID-19 era, a renewed appreciation of our parks and open spaces. The Kinder Institute for Urban Research. Retrieved June 23, 2022, from- https://kinder.rice.edu/urbanedge/2020/04/10/COVID-19-era-renewed-appreciation-our-parks-and-open-spaces.
58. Ord, J.K. & A. Getis. (1995). Local Spatial Autocorrelation Statistics: Distributional Issues and an Application. *Geographical Analysis*, 27(4).
59. Oster, A.M, Kang, G.J, Cha, A.E., Beresovsky, V., Rose, C. E., Rainisch, G., Porter, L., Valverde, E. E., Peterson, E. B., Driscoll, A.K., Norris, T., Wilson, N., Ritchey, M., Walke, H. T., Rose, D. A., Oussayef , N. L., Parise, M. E., Moore, Z. S., Fleischauer, A. T., Honein, M. A., Dirlikov, E., & Villanueva, J. (2020). Trends in Number and Distribution of COVID-19 Hotspot Counties — United States, March 8–July 15, 2020. *Morbidity and Mortality Weekly Report*, 69:1127–1132. DOI: http://dx.doi.org/10.15585/mmwr.mm6933e2
60. Pallathadka, A. K., Chang, H, & Ajibade, I. (2021) The Spatial Patterns of Pluvial Flood Risk, Blue-Green Infrastructure, and Social Vulnerability: A Case Study from Two Alaskan Cities. *International Journal of Geospatial and Environmental Research*: Vol. 8(3), Article 2. Available at: https://dc.uwm.edu/ijger/vol8/iss3/2
61. Pan, J., Bardhan, R., & Jin, Y. (2021). Spatial distributive effects of public green space and COVID-19 infection in London. *Urban Forestry & Urban Greening*, 62, 127182. DOI:https://doi.org/10.1016/j.ufug.2021.127182
62. Park, Y., & Guldmann, J.M. (2020). Understanding disparities in community green accessibility under alternative green measures: A metropolitan-wide analysis of Columbus, Ohio, and Atlanta, Georgia. *Landscape and Urban Planning*, 200, 103806. DOI:https://doi.org/10.1016/j.landurbplan.2020.103806
63. Pearce J. (2013). An Environmental Justice Framework for Understanding Neighbourhood Inequalities in Health and Well-Being. In: Manley D., van Ham M., Bailey N., Simpson L., Maclennan D. (eds) Neighbourhood Effects or Neighbourhood Based Problems?. *Springer*, Dordrecht. DOI:https://doi.org/10.1007/978-94-007-6695-2_5
64. Prowers, M., Brown, P., Poudrier, G., Ohayon, J. L., Cordner, A., Alder, C., & Atlas, M. G. (2021). COVID-19 as Eco-Pandemic Injustice: Opportunities for Collective and Antiracist Approaches to Environmental Health. *Journal of Health and Social Behavior*, 62(2), 222–229. DOI:https://doi.org/10.1177/00221465211005704
65. Price-Haywood, E. G., Burton, J., Fort, D., & Seoane, L. (2020). Hospitalization and mortality among black patients and white patients with COVID-19. *New England Journal of Medicine*, 382(26), 2534-2543. DOI:10.1056/nejmsa2011686
66. Pulido, L. (2016). Geographies of race and ethnicity II. *Progress in Human Geography*, 41(4), 524–533. DOI:https://doi.org/10.1177/0309132516646495
67. Ramírez, I., & Lee, J. (2020). COVID-19 Emergence and Social and Health Determinants in Colorado: A Rapid Spatial Analysis. *International Journal of Environmental Research and Public Health*, 17(11), 3856. DOI:https://doi.org/10.3390/ijerph17113856
68. Raymond, J. (2020). These zip codes are where there have been the most COVID cases in Atlanta's largest counties. 11Alive.com. Retrieved November 15, 2020, from - https://www.11alive.com/article/news/health/coronavirus/coronavirus-numbers/these-zip-

codes-are-where-there-have-been-the-most-COVID-cases-in-atlantas-largest-counties/85-d4d82d1a-2eb9-4f55-974d-9b09fdb1c877

69. Richardson, J., Mitchell, B., & Edlebi J. (2020). *Gentrification and disinvestment*. National Community Reinvestment Coalition. Retrieved June 22, 2021 from - https://ncrc.org/gentrification20/
70. Rigolon, A., & Németh, J. (2018). What shapes uneven access to urban Amenities? Thick injustice and the legacy of racial discrimination In Denver's Parks. *Journal of Planning Education and Research*, *41*(3), 312-325. DOI:10.1177/0739456x18789251
71. Schell, C. J., Dyson, K., Fuentes, T. L., Des Roches, S., Harris, N. C., Miller, D. S., Woelfle-Erskine, C. A., & Lambert, M. R. (2020). The ecological and evolutionary consequences of systemic racism in urban environments. *Science*, 369(6510), DOI:https://doi.org/10.1126/science.aay4497
72. Semuels, A. (2021). The Racist History of Portland, the Whitest City in America. The Atlantic. Retrieved June 22, 2021 from - https://www.theatlantic.com/business/archive/2016/07/racist-history-portland/492035/.
73. So, S.W. (2016). Urban green space accessibility and environmental justice: A gis-based analysis in the city of Phoenix, Arizona (Doctoral dissertation, University of Southern California)
74. Sobral, M. F., Duarte, G. B., Da Penha Sobral, A. I., Marinho, M. L., & De Souza Melo, A. (2020). Association between climate variables and global transmission of sars-cov-2. *Science of The Total Environment*, 729, 138997. DOI:10.1016/j.scitotenv.2020.138997
75. Stokes, E. K., Zambrano, L. D., Anderson, K. N., Marder, E. P., Raz, K. M., El Burai Felix, S., Tie, Y., & Fullerton, K. E. (2020). Coronavirus disease 2019 Case surveillance — United STATES, January 22–May 30, 2020. *Morbidity and Mortality Weekly Report*, 69(24), 759-765. DOI:10.15585/mmwr.mm6924e2
76. Stroud, E. (1999). Troubled waters in Ecotopia: ENVIRONMENTAL racism in Portland, Oregon. *Radical History Review*, 1999(74), 65-95. DOI:10.1215/01636545-1999-74-65
77. Tamerius, J. D., Shaman, J., Alonso, W. J., Bloom-Feshbach, K., Uejio, C. K., Comrie, A., & Viboud, C. (2013). Environmental Predictors of Seasonal Influenza Epidemics across Temperate and Tropical Climates. *PLoS Pathogens*, 9(3). DOI:10.1371/journal.ppat.1003194
78. Taros, M. (2021). South Phoenix will soon get its own development plans. But will it stop displacement? The Arizona Republic. Retrieved June 22, 2021 from - https://www.azcentral.com/story/news/local/phoenix/2021/04/10/south-phoenix-development-plans-focus-community-vision/7148841002/
79. Taylor, W. C., Floyd, M. F., Whitt-Glover, M. C., & Brooks, J. (2007). Environmental justice: A framework for collaboration between the public health and parks and recreation fields to study disparities in physical activity. *Journal of Physical Activity and Health, 4*(S1). DOI:10.1123/jpah.4.s1.s50
80. Tribby, C. P., & Hartmann, C. (2021). COVID-19 cases and the Built ENVIRONMENT: Initial evidence from New York City. *The Professional Geographer*, 73(3), 365-376. DOI:10.1080/00330124.2021.1895851
81. The Trust for Public Lands. (2009). Retrieved June 22, 2021 from - http://cloud.tpl.org/pubs/ccpe_Acreage_and_Employees_Data_2010.pdf
82. Truman, C. (2014). Environmental Justice: Developing Green Spaces for South Phoenix. https://doi.org/10.13140/2.1.1202.3360

83. U.S. Census Bureau. (2020). American Community Survey. https://www.census.gov/programs-surveys/acs
84. U. S. Fish and Wildlife Service. (2020). The National Wetlands Inventory. https://www.fws.gov/wetlands/
85. Watkins, S. L., Vogt, J., Mincey, S. K., Fischer, B. C., Bergmann, R. A., Widney, S. E., Westphal, L. M., & Sweeney, S. (2018). Does collaborative tree planting between nonprofits and neighborhood groups improve neighborhood community capacity? *Cities, 74*, 83-99. DOI:10.1016/j.cities.2017.11.006
86. Watson, M. F., Bacigalupe, G., Daneshpour, M., Han, W. J., & Parra-Cardona, R. (2020). COVID-19 Interconnectedness: Health Inequity, the Climate Crisis, and Collective Trauma. *Family Process*, 59(3), 832–846. DOI:https://doi.org/10.1111/famp.12572
87. Weiss, R. A., & McMichael, A. J. (2004). Social and environmental risk factors in the emergence of infectious diseases. *Nature medicine*, 10(12 Suppl), S70–S76. DOI:https://doi.org/10.1038/nm1150
88. Xie, J., Luo, S., Furuya, K., & Sun, D. (2020). Urban Parks as Green Buffers During the COVID-19 Pandemic. *Sustainability*, 12(17). DOI:https://doi.org/10.3390/su12176751
89. Lu, Y., Chen, L., Liu, X., Yang, Y., Sullivan, W. C., Xu, W., Webster, C., & Jiang, B. (2021). Green spaces mitigate racial disparity of health: A higher ratio of green spaces indicates a lower racial disparity in SARS-CoV-2 infection rates in the USA. *Environment International*, 152, 106465. DOI:https://doi.org/10.1016/j.envint.2021.106465
90. Wen, M., Zhang, X., Harris, C. D., Holt, J. B., & Croft, J. B. (2013). Spatial disparities in the distribution of parks and green spaces in the USA. *Annals of behavioral medicine : a publication of the Society of Behavioral Medicine*, 45 Suppl 1(Suppl 1), S18–S27. DOI:https://doi.org/10.1007/s12160-012-9426-x
91. Zelner, J., Trangucci, R., Naraharisetti, R., Cao, A., Malosh, R., Broen, K., Masters, N., & Delamater, P. (2020). Racial Disparities in Coronavirus Disease 2019 (COVID-19) Mortality Are Driven by Unequal Infection Risks. *Clinical Infectious Diseases*, 72(5). DOI: https://doi.org/10.1093/cid/ciaa1723