A Spatial Analysis of Parks in King County, Washington: Identifying Access Disparities Through Isochrone-Based Cluster Analysis

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ABSTRACT Washington's King County Parks agency seeks to "steward, enhance and acquire parks to inspire healthy communities." To aid planning, we identify regions of relatively low park access using a walking-based approach. We define access as the number of parks reachable within a 10-, 20-, or 30-minute walk from the centroid of each Census block group. Cluster analysis reveals distinct spatial patterns: high-access clusters are concentrated in Seattle's urban core, while low-access clusters are primarily in eastern and southern King County, highlighting regions for potential targeted infrastructure investment. This case demonstrates the importance of measuring "access" using walking distances that account for local road networks. Our methodology, implemented with open-source R packages and publicly available data, provides a reproducible framework for both practitioners and educators. Additionally, the supplemental code vignette *(nepf_iso_vignette)* offers a step-by-step walkthrough of the analysis. Planners can apply these methods to assess access to parks or other local amenities, while students can follow the vignette to develop their own spatial analyses. Our results inform future park development and offer a foundation for further research on equitable access to parks and green space across King County's diverse communities. KEYWORDS park access, urban planning, isochrones, spatial analysis, cluster analysis

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INTRODUCTION

Benefits of Parks and Green Space

Public parks and green spaces play a crucial role in promoting community health and well-being. They are also central to achieving the United Nation's Sustainable Development Goal 11 (SDG 11), which calls for inclusive, safe, resilient, and sustainable cities and communities [1]. Parks embody several SDG 11 targets, such as Target 11.3 (enhancing inclusive urbanization and participatory planning), Target 11.6 (reducing the environmental impact of cities), and Target 11.7 (providing universal access to safe, inclusive, and accessible green and public spaces).

At the individual level, access to parks is associated with increased physical activity and reduced risks of chronic disease, while at the community level, parks foster social inclusion, trust, and cohesion through shared public experiences [2–4]. These social outcomes align directly with SDG 11's emphasis on inclusivity and social sustainability. Green spaces also connect residents to nature, helping to alleviate emotional stress and mental fatigue [5, 6]. Environmentally, they advance urban resilience—a core component of SDG 11—by reducing urban heat island effects, improving air quality, sequestering carbon, and mitigating flood risks through permeable surfaces [7–9].

For children, these effects are especially pronounced. Access to green space relates positively to a child's mental health, restoring attention span, improving memory, and moderating stress [10, 11]. Conversely, children from

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neighborhoods without park access face higher risks of inactivity, obesity, and attention-related disorders, even after controlling for income, age, sex, race, and ethnicity [12]. Ensuring access to such spaces thus directly supports SDG Target 11.7, which seeks to guarantee universal access to safe, inclusive, and accessible green spaces, particularly for vulnerable populations such as children and those in disadvantaged areas.

Access Inequities

Despite the well-documented benefits of parks and green space, access to these amenities is not uniform. Multiple studies have found that neighborhoods with lower income or higher proportions of residents of color tend to have fewer and lower-quality park resources [13–18]. These contemporary patterns are not accidental but reflect the enduring influence of historical planning and housing policies that structured urban development [19]. For instance, combining historical redlining maps from the Homeowner's Loan Corporation (HOLC) with contemporary satellite imaging reveals that neighborhoods with worse HOLC grades (i.e., those deemed a greater investment risk) consistently have lower present-day green space coverage [20]. Because HOLC grades were largely determined by racial status, with predominately white neighborhoods receiving higher grades and communities of color receiving lower grades [21], the lasting impact of this maldistribution is profound: communities of color are systematically limited in their access to parks and green spaces.

These findings underscore that unequal access to parks and green space persists in many U.S. cities. While the present study does not analyze race, income, or disadvantage directly, this body of literature provides our motivation for examining geographic access. Understanding where residents can and cannot access parks and green space is a critical first step in documenting potential disparities and informing future research on equitable access. Thus, advancing SDG 11's vision of equitable urban environments requires first identifying where spatial disparities exist.

Measuring Access

A necessary first step in quantifying these inequities is to empirically determine which residents do and do not have access to public parks and green space. This is the task we undertake here. To do so, we must operationalize "access." Common approaches include counting the number of parks within a defined administrative unit ("container-based method") or calculating the total park acreage within a neighborhood boundary [22, 23]. Though intuitive, these measures are highly sensitive to how spatial boundaries are defined and to the scale at which analyses are conducted. This sensitivity is known as the Modifiable Areal Unit Problem (MAUP), which encompasses both zoning effects (changes arising from alternative boundary configurations) and scale effects (changes in results when data are aggregated at different spatial resolutions). The consequence of MAUP is that two neighborhoods with identical spatial distributions of parks may appear to have different levels of "access"—and statistical relationships between park access and demographic characteristics may also differ—depending solely on how boundaries are drawn [24].

Beyond simple counts or acreage, scholars have incorporated park congestion into access measures [25, 26]. Doing so highlights how "access" based solely on park count or size may obscure overcrowding in densely populated areas. Congestion-based measures recognize that access is not only about spatial proximity but also about whether a park can reasonably accommodate its surrounding population. Many congestion measures, however, rely on predefined administrative boundaries to estimate population demand and therefore remain susceptible to MAUP.

Some studies have addressed this limitation through more spatially refined methods. For example, researchers employ dasymetric mapping in combination with Voronoi polygons to estimate park service areas and population demand without relying on conventional administrative units [25]. Together, these methods minimize the influence of census-unit size and boundary definitions, providing a more spatially accurate assessment of park accessibility and potential park congestion. Nevertheless, congestion measures generally do not account for pedestrian networks or physical and natural barriers that influence whether residents can realistically reach a park.

Other work has focused on travel time, asking how far a resident must go in order to reach a park. A simple approach is Euclidean distance: the straight-line distance between one's place of residence and a park is measured and a cutoff point determines whether the park is "accessible" [27]. Though relatively easy to implement, Euclidean distances ignore physical and natural barriers, such as highways and waterways, providing a false sense of how far a park is from an individual [28]. Euclidean distances also fail to account for built pathways (e.g., roads) that shape human movement and travel. While adjustment factors can be applied to approximate real-world conditions, such corrections are inherently subjective and unlikely to capture the true complexity of pedestrian movement [28].

More involved metrics include the Environmental Protection Agency's *Walkability Index* and the Trust for Public Land's *ParkScore*. The *Walkability Index* provides aggregated scores based on street intersection density, land use diversity (e.g., types of businesses and amount of occupied housing), and proximity to transit stops [29]. These scores range from 1 ("least walkable") to 20 ("most walkable") and approximate whether people are likely to choose walking as a mode of transportation. Similarly, *ParkScore* measures park access by estimating the percentage of residents who live within a 10-minute walk of a park. Walking routes are obtained from Esri's StreetMap Premium network dataset and account for barriers like highways, train tracks, and waterbodies [30].

While both these measures can provide greater detail than Euclidean distance, we argue that they nonetheless miss the larger point—access is shaped by one's distinct environment. Very few can simply open their front door and walk straight into a park. Likewise, aggregated indices and scores wash away important street-level differences in road access. Both the *Walkability Index* and *ParkScore* operate at predefined administrative scales, reintroducing MAUP. As a result, estimates of park access remain sensitive to how neighborhood boundaries are defined and at what spatial scale accessibility is measured, even when the underlying distribution of parks and residents remains unchanged.

More broadly, "access" is a multidimensional construct [24], encompassing *availability*, *accessibility*, *accommodation*, *affordability*, and *acceptability* [31]. While originally developed in the context of medical care, this framework underscores that spatial proximity represents only one dimension of access. In the context of public parks, *availability* (the presence and distribution of park space and amenities), *accessibility* (the ability to physically reach parks), and *accommodation* (whether parks provide the facilities and features residents wish to use) are particularly salient. A park may exist within a neighborhood yet remain functionally inaccessible due to distance, transportation barriers, unsafe crossings, or steep terrain (*accessibility*). Likewise, amenity-poor parks (e.g., those lacking playgrounds, trails, fitness equipment) may not adequately serve nearby residents (*accommodation*) [32, 33]. (Measures of park congestion, by contrast, assess whether available park resources are sufficient to accommodate the size of the surrounding population.)

Taken together, prior research demonstrates that access can be operationalized several ways, each with inherent opportunities and constraints. The choice of method depends on data availability, local context, and research objectives [24]. The goal of this work is to empirically determine whether spatial disparities in park access exist across King County, WA. To do so, we focus on *accessibility*, using isochrones to capture whether residents can reach a park by foot.

Isochrone Access

Isochrones are a fundamental tool in spatial analysis, identifying areas reachable within equal travel times. Travel times are measured by accounting for real-world constraints such as street connectivity and barriers (e.g., highways and lakes). This approach is particularly useful in King County, where topography strongly influences walking routes and travel times. While our analysis is limited by insufficient data on park amenities, isochrones provide a flexible and behaviorally grounded measure of access that goes beyond simple Euclidean distance or aggregated scores [34]. The result is a nuanced and locally tailored measure of access that better reflects the structural and geographic realities of King County.

By conceptualizing access as the ability to reach a park on foot, we capture a critical first step in documenting potential spatial inequities. Children's independent mobility is typically limited to walking distances, and vehicle ownership and public transit access are systematically lower in low-income neighborhoods [35–37], increasing reliance on walking [38]. A walking-based measure thus reflects real-world mobility constraints in disadvantaged communities and provides a foundation for future research that can integrate additional dimensions of equity, such as amenities, congestion, and park quality.

Determining park access with isochrones can be performed using two complementary approaches: population-based and place-based [39]. The population-based approach begins with residents and evaluates which parks are reachable from their locations, centering the experience of park users. The place-based approach begins with individual parks and examines the populations residing within their service areas, centering the distribution and reach of specific facilities.

While both approaches provide valuable information about whether urban green spaces meet community needs, we employ a population-based approach because our primary objective is to measure the accessibility of parks from the geographic areas where residents live. King County Parks commissioned this study to better understand the geographic distribution of park access and the communities that can reach their facilities. This resident-centered approach allows us to identify communities with comparatively limited opportunities to reach public parks by foot. It also provides a foundation for future equity analyses, as access estimates can be linked with demographic characteristics to identify populations that may face greater barriers to park access.

CASE EXAMINATION: KING COUNTY PARKS

King County, Washington

King County is home to nearly 1,400 public park sites. King County Parks, the agency tasked with providing and maintaining those parks, envisions "parks, trails, and natural lands for all" and strives to ensure that these spaces are "equitably distributed" [40]. King County Parks partnered with the University of Washington to have a team of three graduate students and two undergraduate students, led by one research scientist, carry out the following analysis over the course of a 10-week summer fellowship program.

Given King County's diverse geographic characteristics—ranging from dense urban neighborhoods to sprawling suburban communities and rural areas—traditional Euclidean measurements prove inadequate for accurately assessing park access. The county's complex landscape, including water bodies and varied street network connectivity, necessitates a spatial analysis approach that better reflects real-world pedestrian movement patterns and accessibility barriers.

To support the claim that isochrones are particularly well-suited for King County, we provide figure 1, which shows two walking measures from the center of Volunteer Park (Seattle): Euclidean distance (left) and isochrone distance (right). As the images makes clear, Euclidean measures tend to exaggerate the distance one could travel in a set time, as they ignore the configuration of the street network and physical and natural barriers. The isochrones instead constrain movement to walkable routes represented in the road and path network, accounting for barriers such as water bodies and street connectivity. Although our isochrone model does not directly adjust walking speed for slope or elevation, the resulting travel areas nevertheless

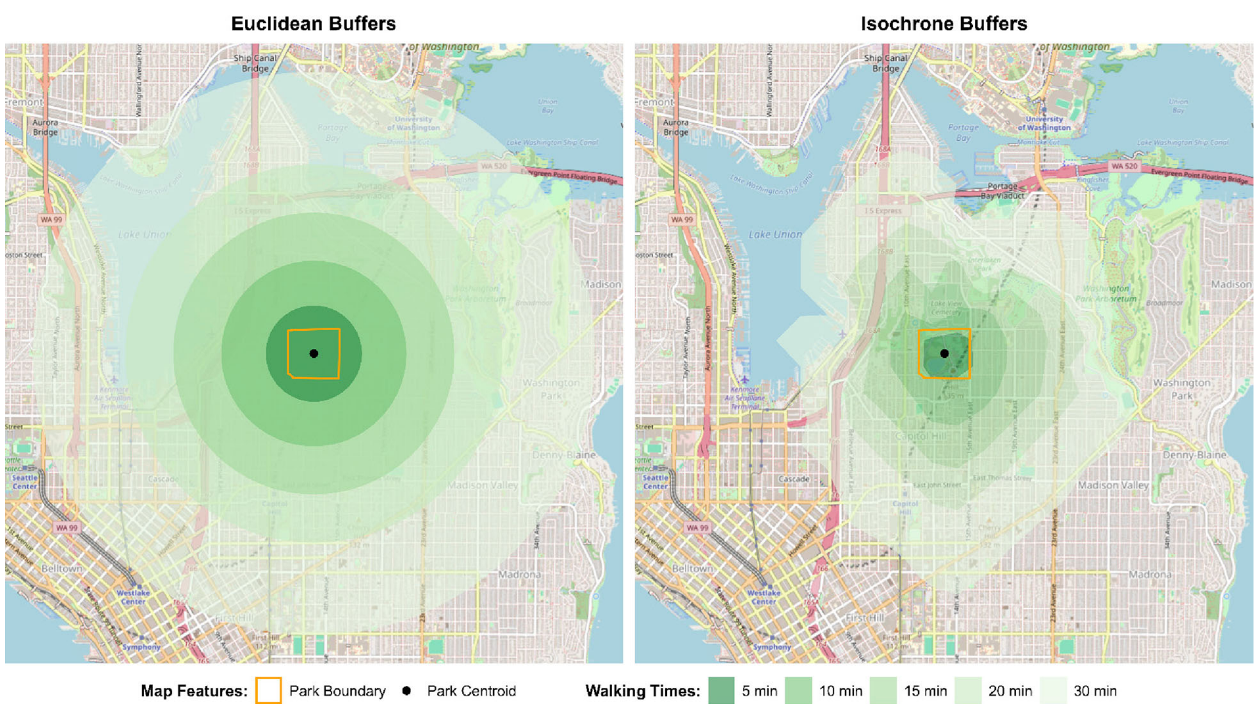

FIGURE 1. Travel distances from Volunteer Park.

reflect how King County's topography shapes the structure of the transportation network. Consequently, isochrone estimates provide a more realistic representation of pedestrian access than straight-line distance measures.

Data Sources

Our analysis makes use of two spatial datasets: (1) Census Bureau block group polygons for King County, accessed using the R package *tidycensus* (v1.7.3) [41]; and (2) public park polygons obtained from King County's Geographic Information System Center. These datasets provide the geographic boundaries of King County block groups and publicly available park sites, respectively.

Because the objective of this study was to inform King County Parks on the communities served by the parks and green space under their jurisdiction, we limited the parks dataset to sites managed at or below the county level and classified as *Park Site*. Facilities classified as public pools (*Pool Site*), shopping centers (*Shop Site*), and trails (*Trail Site Regional*) were excluded to maintain consistency in park typology and management structure. The final sample included 1,398 park sites.

Park Access Isochrones

Isochrone distances are based on factors that estimate travel time, accounting for *mode of travel* (e.g., walking, driving) and *local street network configuration* (obtained via OpenStreetMap (OSM) data [42]), which includes street network connectivity and physical and natural barriers. Building on this conceptual framework, we operationalize isochrone distances to construct the spatial measures used in our cluster analysis. To illustrate the workflow, we demonstrate these steps using the seven adjacent block groups that comprise Vashon Island, King County (figure 2). We select Vashon Island because it provides a compact, manageable area that demonstrates workflow and gives results without long computation times (see code vignette).

First, the centroid (i.e., a polygon's geometric center) of each King County block group was identified using the **sf** package (1.0.19) [43] in R (figure 3, Panel A). Though centroids are an imperfect measure of a resident's starting point, isochrones rely on a point location (see *Limitations* section). Next, isochrones measuring 10-, 20-, and 30-minute walking times were built around each centroid

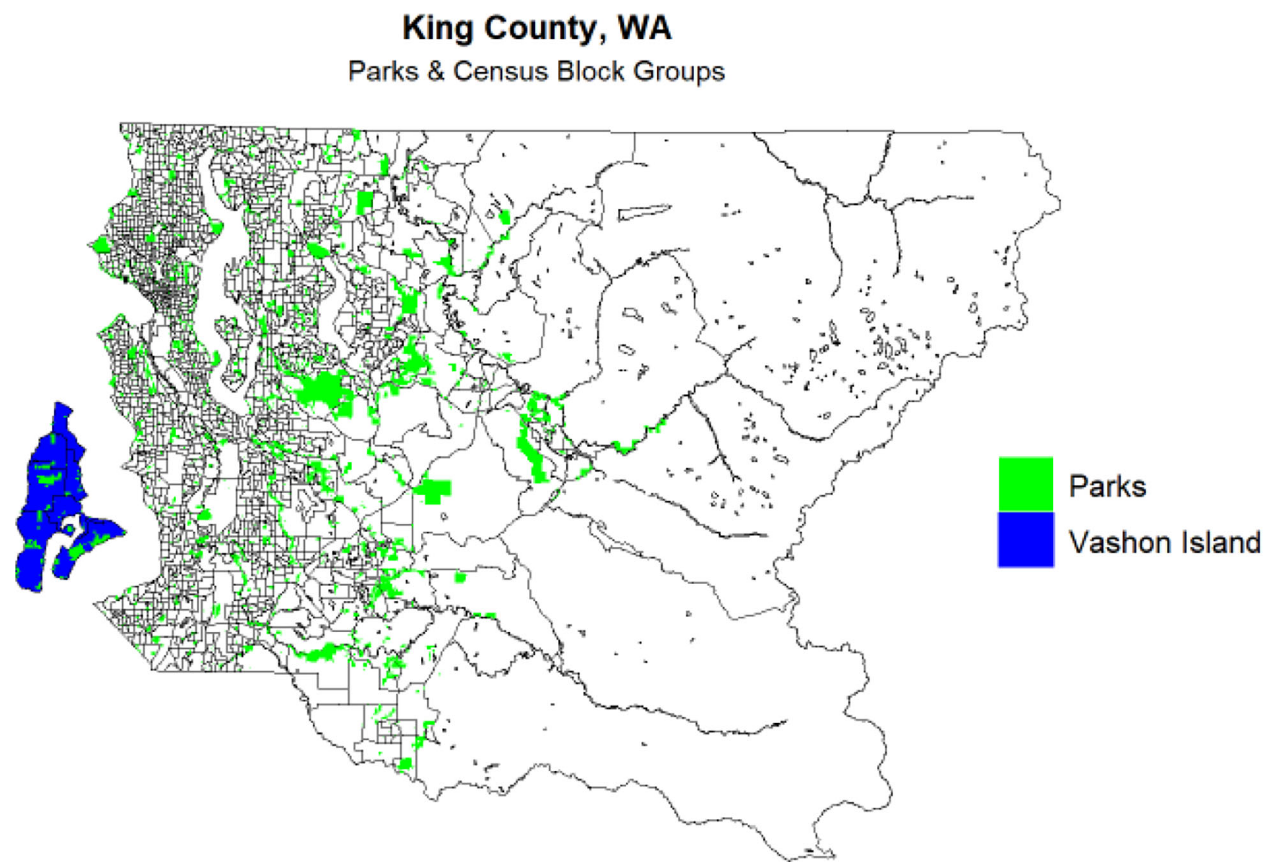

Figure 2. Location of Vashon Island.

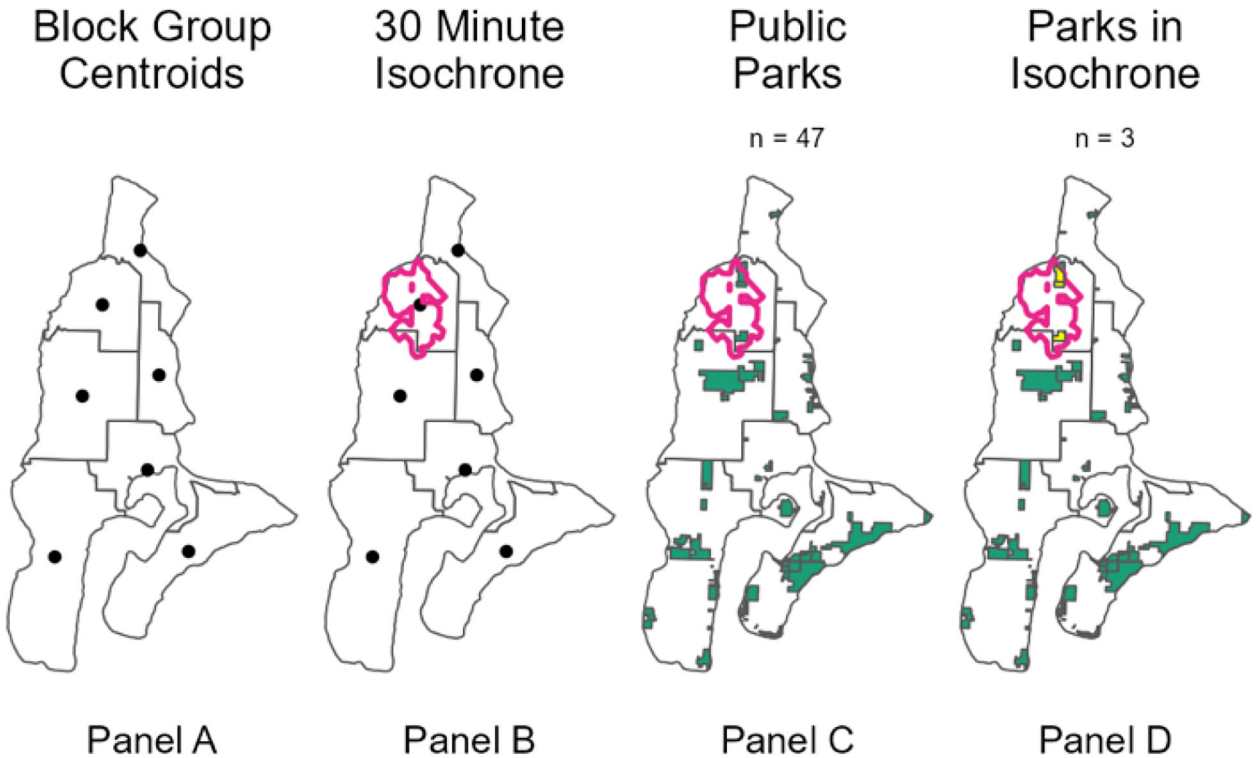

FIGURE 3. Construction of park accessibility measure for Vashon Island.

(figure 3, Panel B). Isochrones were generated using the R package **osrm** (4.2.0) [42], which draws on publicly available OSM data to account for street network configuration. OSM uses road centerlines to approximate pedestrian travel, which can lead to possible over- and underestimations of accessibility (see *Limitations* section). We specify a standard walking speed of 5 km/h (∼3 mph) for all calculations, representing an average pedestrian. We then overlay King County's public parks and green spaces polygons (figure 3, Panel C) and count the number of parks whose boundaries intersect with each walking distance isochrone (figure 3, Panel D).

In other words, the isochrones serve as spatial buffers, allowing us to identify and count the number of parks intersected. This becomes our measure of access: the total number of park polygons one could reach walking 10-, 20-, and 30-minutes in any direction from a block group centroid. Park access values were derived for all King County block groups (n = 1,544) in this manner. Due to data limitations, it was not possible to specify park access points. Thus, the measure of access is derived from the nearest edge of each park. Figure 4 plots the raw data generated through the above steps, for all of King County. Specifically, these data reflect the number of park boundaries one encounters when walking 10-minutes in any direction from each block group centroid.

Park Access Clusters

The aim of the cluster analysis is to identify areas in King County where park access is consistently high or low relative to neighboring block groups. Specifically, we ask: *Which neighborhoods are surrounded by similarly high- or low-access areas, and where do access disparities appear concentrated?* This information can help guide future park investment and infrastructure planning by highlighting areas where residents may experience greater barriers to reaching parks on foot.

We begin with Global Moran's I, which provides a countywide assessment of spatial dependence in park access. This statistic indicates whether block groups with similar access levels tend to cluster together, spread apart, or are randomly distributed [44]. Values range from −1 to 1: values near −1 indicate strong negative spatial dependence (high-access areas near low-access areas), values near 1 indicate strong positive dependence (similar-access areas clustered together), and values near 0 suggest little or no spatial pattern. Establishing global spatial dependence first helps determine whether local-level analyses are meaningful.

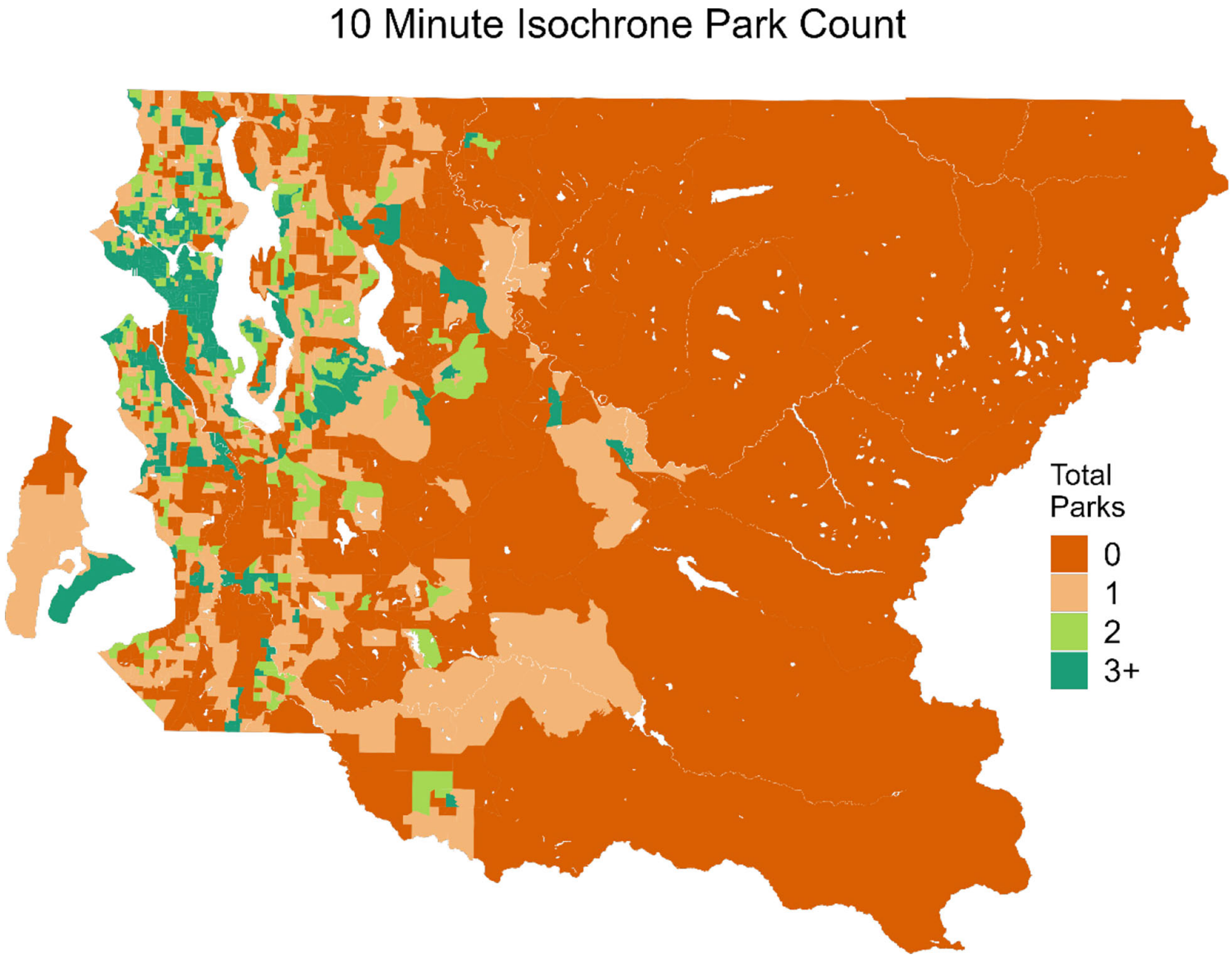

Figure 4. Raw park counts within the 10-minute isochrone of King County block groups.

Next, we conduct local cluster analysis using Local Moran's I to identify high- and low-access clusters of park access across King County. Statistically speaking, we compare each block group's park access value with that of its neighbors to detect spatial patterns, such as whether high-access areas are located near other high-access areas. We define "neighbors" using a Queen's contiguity weights matrix, where block groups sharing any portion of a boundary are considered neighbors. Queen's contiguity is particularly useful when working with irregularly shaped units, like Census block groups, because it captures a broader set of spatial relationships by including neighbors that touch at either edges or vertices [44]. By contrast, Rook's contiguity defines neighbors solely based on shared edges, which can isolate small or oddly shaped geometries. Queen's contiguity helps ensure that spatial clustering reflects meaningful geographic proximity rather than artifacts of unit shape.

Spatial weights were row-standardized so that the weights assigned to each block group's neighbors sum to one. For example, a block group with two neighbors assigns a weight of 0.5 to each, whereas a block group with four neighbors assigns 0.25 to each. These weights were used to compute a spatial lag[1] of park access for each block group, defined as the weighted average park access value of its neighboring block groups. Local Moran's I evaluates whether a block group's park access value correlates with the weighted average park access of its neighbors. Positive values indicate that a block group has access levels like surrounding block groups (e.g., high access surrounded by high access or low access surrounded by low access), while negative values indicate spatial dissimilarity (e.g., high access isolated among low access or low access

1. The term "spatial lag" is adapted from time-series statistics, where a "lag" refers to a variable observed at an earlier point in time. In spatial analysis, the concept is extended to represent the value of a variable in neighboring locations rather than at earlier times.

isolated among high access). Cluster types were determined by labeling block groups with statistically significant ($p < 0.05$) Local Moran's I values as high-high, low-low, high-low, or low-high, while all others were labeled not significant. High-high clusters represent areas of consistently high access, and low-low clusters represent areas of consistently low access. Analyses were conducted using the R package **spdep** (v1.3.10) [45].

Cluster Analysis Results

Figure 5 presents park access clustering at 10-minute (Panel A), 20-minute (Panel B), and 30-minute (Panel C) isochrone intervals. Across all three intervals, we see that Global Moran's I is highly statistically significant and positive (10-minute: 0.63, $p < 0.001$; 20-minute: 0.87, $p < 0.001$; 30-minute: 0.94, $p < 0.001$), indicating that block groups with high access tend to be found clustered together, while block groups with low access are also found near to one another.

This conclusion is corroborated by the Local Moran's I values, which are displayed in the maps themselves. Specifically, high-access areas (colored in teal), represent regions where the park access of a block group is relatively high *and* the park access of neighboring block groups is relatively high. High-access clustering appears primarily within Seattle block groups, in northwestern King County. Conversely, orange areas reflect the opposite—low-access regions where a block group has relatively low park access *and* is surrounded by block groups with similarly low park access. Low-access clustering is found in the eastern and southern regions of King County.

As walking time increases, we observe the high- and low-access clusters expand. This reflects that as isochrone distances increase, neighboring block groups increasingly share the same parks within their isochrones. Consequently, the Local Moran's I detects stronger spatial similarity, producing larger contiguous clusters of high- or low-access areas. High-access block groups and their neighbors continue to have relatively greater park accessibility, while low-access block groups and their neighbors continue to have relatively limited park accessibility, even as walking distances increase.

A small number of spatial outliers (high-low and low-high) are detected in the 10- and 20-minute isochrone analyses. High-low outliers represent block groups with relatively high park access surrounded by lower-access neighbors, whereas low-high outliers represent the opposite pattern. Because these outliers are few in number and disappear in the 30-minute analysis, they do not indicate persistent spatial patterns and therefore provide limited guidance for countywide park planning. Accordingly, our interpretation focuses on the more stable high-high and low-low clusters that consistently identify areas of relatively high and low park accessibility.

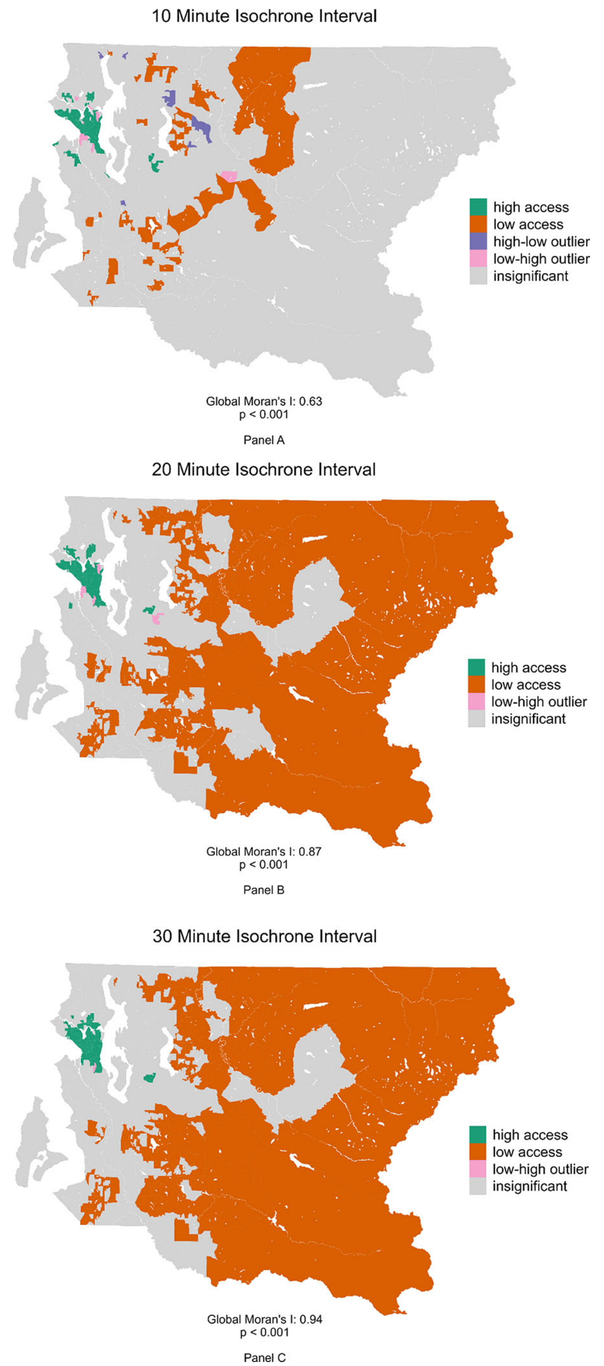

FIGURE 5. King County Park accessibility clusters.

Bivariate Association

We now expand this analysis and incorporate an equity lens by examining how park access patterns relate spatially to the distribution of youth populations. Specifically, we ask whether areas with comparatively low park access are located near areas with higher concentrations of children. As noted, parks and green spaces relate positively to a child's mental and physical health [10–12]. Accordingly, we focus on the proportion of residents under 18 years of age within each block group as an indicator of youth population. Using a proportion rather than a population count accounts for differences in block group population size, allowing comparisons across neighborhoods. This provides a useful measure for examining whether block groups with comparatively limited park access are located near block groups with higher concentrations of youth.

To examine the spatial relationship between park access and youth populations, we conduct a bivariate spatial association analysis. The proportion of residents under 18 years of age in each block group was calculated using 2023 U.S. Census Bureau American Community Survey population estimates. Using the same row-standardized Queen's contiguity weights defined for the park access analysis, we calculated a spatial lag of youth proportion for each block group, defined as the weighted average proportion of residents under 18 years of age in neighboring block groups. The bivariate analysis therefore evaluates the relationship between park access in each block group and youth concentrations in surrounding block groups.

Park access and the spatial lag of youth proportion were then standardized (z-scores), with values greater than zero indicating above-average values and values less than zero indicating below-average values. Finally, areas were classified into four quadrants based on standardized park access and the spatial lag of youth proportion.[2] The first term refers to the focal block group's park access, while the second term refers to the youth proportion of neighboring block groups: high-high (above-average park access and above-average neighboring youth proportion), low-low (below-average park access and below-average neighboring youth proportion), high-low (above-average park access and below-average neighboring youth proportion), and low-high (below-average park access and above-average neighboring youth proportion).

2. Quadrant classifications are based on the sign of these standardized values rather than local significance testing.

Our analysis reveals evidence of a significant bivariate spatial association across King County (figure 6). The dominant clustering pattern is regions with low park access and higher-than-average neighboring youth proportions, suggesting areas where limited park accessibility overlaps with nearby concentrations of youth populations. Conversely, regions of high park access with lower-than-average neighboring youth proportions are also present, primarily in the Seattle area. These clusters indicate areas where park accessibility may exceed the relative concentration of youth populations.

This analysis represents one of many possible extensions of the spatial framework presented in this study. By comparing the spatial distribution of park access with a sociodemographic variable such as youth proportion, the analysis helps identify areas where spatial mismatches between park accessibility and community characteristics may be most pronounced and where park provision could be most beneficial. Similar bivariate spatial approaches could be extended to other vulnerable or policy-relevant populations, including older adults, low-income households, communities of color, and households without access to private transportation. In addition, future work could incorporate health outcomes, such as physical activity levels or chronic disease prevalence, or examine access to other types of amenities (e.g., schools, transit, or healthcare facilities) to further contextualize patterns of spatial equity across King County.

LIMITATIONS

Despite the usefulness of proxying access with isochrones, this method presents several important limitations. To begin, isochrones could only be built off point locations, which is why we calculate walking distances from block group centroids, rather than borders. Thus, the resultant 10-, 20-, and 30-minute walking estimates assume travel begins at the centroid of each block group, even though residents are spatially distributed throughout the polygon. In geographically large or irregularly shaped block groups, centroid-based measures may misrepresent the distance some residents must travel to reach a park.

Given greater computational capacity, isochrones could be generated from individual residences rather than from block group centroids. This would eliminate reliance on arbitrary centroid locations and enable access to be

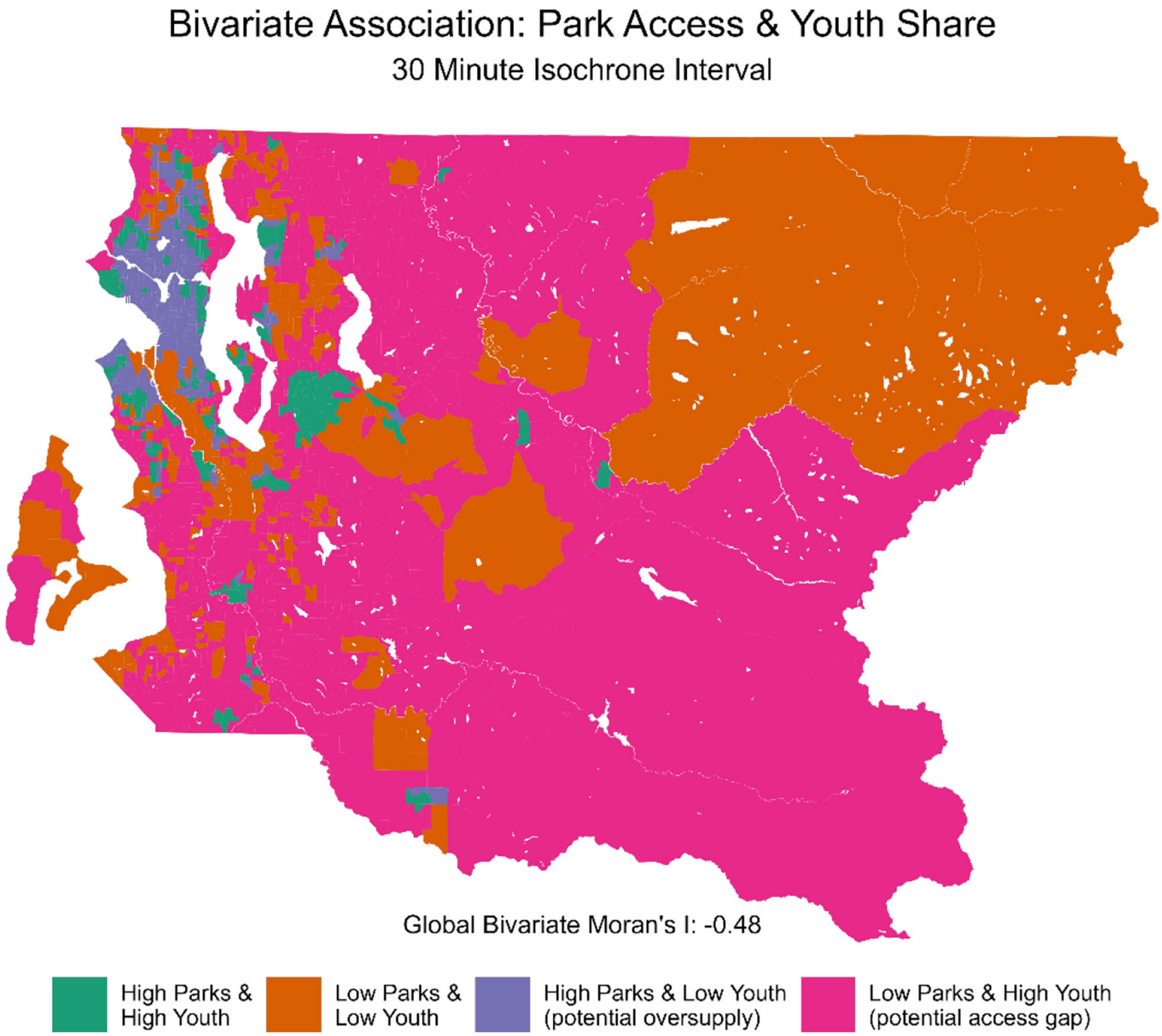

FIGURE 6. Bivariate analysis.

measured at a finer spatial resolution (i.e., residential parcels rather than aggregated block groups). Although a residential point dataset is available through the King County Geographic Information Systems Center, the computational demands of generating isochrones for the roughly 500,000 residential parcels made this approach infeasible for the present study.

All analyses were conducted using the Windows Terminal Servers maintained by the Center for Studies in Demography & Ecology at the University of Washington. The Terminal Servers are Dell R6525 PowerEdge servers running the Microsoft Windows Server 2022 operating system. Each server is equipped with dual 48-core AMD 7413 processors.

Generating a single isochrone required approximately 10 to 14 seconds, depending on the defined walking times of 10-, 20-, and 30-minutes (with longer times requiring more processing time). As such, generating isochrones for all 1,544 Census block groups at 10-, 20-, and 30-minute walking intervals required approximately 4 to 6 hours per interval. Consequently, scaling this to individual residences would require 2 to 3 months of processing time, making it impractical for the project's timeline.

Relatedly, the pedestrian travel networks used to generate isochrones rely on OSM data. While OSM provides detailed street centerline information, it does not systematically or consistently capture sidewalk presence, continuity, width, curb ramps, crossing aids, surface quality, or Americans with

Disabilities Act (ADA) compliance. Sidewalk data, where present, are often incomplete and unevenly mapped across jurisdictions. This limitation is not unique to the present study; the absence of standardized, comprehensive sidewalk network data has been identified as a broader challenge in spatial access research [46]. As such, road networks are commonly used as proxies for walkable infrastructure.

Relying on road centerlines to approximate pedestrian travel may lead to overestimation of true access in areas where sidewalks are absent, disconnected, poorly maintained, or unsafe. Conversely, informal pedestrian paths not captured in OSM could lead to slight underestimation in some localized contexts. Importantly, because pedestrian infrastructure is often unevenly distributed across neighborhoods, especially those shaped by historical disinvestment, reliance on incomplete sidewalk data may obscure meaningful disparities in feasible walking access.

Another limitation concerns how park access itself was operationalized. Our measure counts the number of park polygons intersecting each isochrone. However, intersection between an isochrone and a park boundary is not equivalent to functional park access. This approach assumes that individuals may enter a park at any point along its boundary. In practice, parks may have fencing and limited access points. Particularly for large parks, the time required to reach a designated entrance may exceed the time required to reach the nearest boundary segment. As such, our method may artificially inflate access values by treating boundary overlap as equivalent to entry. With additional time and data collection, park access points could be identified and incorporated into the network analysis, such that access reflects walking time to verified entrances rather than to any boundary segment. While doing so would substantially improve measurement precision, assembling and validating entrance data for nearly 1,400 park sites would require considerable additional effort beyond the scope of the present study.

Additionally, we specify a uniform walking speed of 5 km/h (~3 mph) for all residents. While this represents a commonly used average walking pace, it does not account for variation across age groups or mobility limitations. Consequently, access estimates may overstate feasible walking ranges for certain populations.

Finally, our access metric reflects the number of parks intersecting each isochrone but does not capture differences in park size, quality, or amenity richness. A cluster of several small parks will generate higher access scores, even if those parks offer limited facilities. Conversely, an isochrone intersecting only a single park may provide greater recreational value if that park is larger or more amenity-rich [32, 33]. Although King County provides data on park amenities (e.g., playgrounds, sports fields, trails, and facilities), these records were incomplete and inconsistently populated across park sites. Because amenity information was missing for a meaningful share of parks, incorporating these data into a weighted quality index would have introduced systematic bias and reduced comparability across block groups. We therefore relied on park counts as a consistent, though simplified, measure of park access.

CONCLUSION

This study empirically assessed spatial disparities in park and green space access across King County, WA, using walking-based isochrones and cluster analysis. Our findings reveal distinct high- and low-access areas, with high-access clusters concentrated in the urban core of Seattle and low-access clusters primarily in eastern and southern regions of King County. By employing isochrones rather than simple Euclidean distances or aggregated indices, we account for real-world constraints such as street connectivity and physical and natural barriers, producing a more behaviorally grounded measure of pedestrian accessibility. This approach highlights the importance of considering both spatial proximity and network-based travel conditions when evaluating access to public parks.

For King County Parks, these findings provide a spatial framework for identifying areas where park access patterns may warrant additional investigation and targeted planning. Importantly, low-access clusters should be interpreted within their local geographic context. Low-access areas in rural eastern King County may reflect lower population densities and greater distances between destinations, where improving access may require different strategies than in more densely settled communities. In contrast, the low-access clusters in southwestern King County occur in areas experiencing continued residential growth and urbanization, where limited walking access may affect larger and growing populations. These areas may represent opportunities for further evaluation of strategies such as improving pedestrian connections to existing parks or assessing the need for additional parks.

Future research should build on this framework by incorporating additional dimensions of park access and community need. For example, our bivariate analysis (figure 6) identifies areas where low park accessibility overlaps spatially with higher proportions of residents under 18 years of age, providing a foundation for examining how access patterns relate to demographic, social, and health-related factors. Additional analyses could incorporate other populations, such as older adults or individuals with mobility limitations, as well as measures of park quality, amenities, and congestion. Future research could apply complementary accessibility approaches, such as the Two-Step Floating Catchment Area method, which incorporates both park supply (e.g., park size, amenities, or capacity) and potential demand (e.g., the number and characteristics of residents within a park's service area). Such approaches may help distinguish areas with limited geographic access from areas where existing parks may be insufficient relative to the number of residents they serve. Sensitivity analyses could also evaluate how results change when park access measures are weighted by park size, type, amenities, or other indicators of recreational value.

These extensions would provide a more comprehensive understanding of park accessibility and help identify where investments may have the greatest potential benefit. The present study establishes a reproducible baseline for identifying potential spatial disparities in park access and provides a foundation for future analyses that support equitable and context-specific park planning.

CASE STUDY QUESTIONS

Metric Strengths and Limitations

1. This article measures "access" as the number of park boundaries reachable within 10-, 20-, and 30-minute walking isochrones from a block group centroid. What aspects of park access does this approach capture effectively, and what important factors does it overlook?
2. Consider the framework of access [31], which includes *availability*, *accessibility*, *accommodation*, *affordability*, and *acceptability*. Describe how each of these applies to parks. How might relying solely on park counts mislead planners about the recreational value available to a community?

Methodological Assumptions and Local Context

3. Under what conditions is an isochrone-based approach most applicable, and what are its main limitations (e.g., use of centroids, assumed walking speed)?
4. How might these limitations affect conclusions about access equity, particularly for individuals with different mobility levels (e.g., wheelchair users, elderly residents)?
5. What natural and structural barriers are present in other counties? How could you account for these barriers in an analysis?
6. County park datasets are often unevenly documented; some parks may lack acreage, amenity records, or ADA compliance information. This is a challenge without a clean solution. In this analysis, we use park counts as a simple, consistently available measure. How would you decide whether this simplification is appropriate for a given purpose? When working with incomplete data, how would you account for the tendency of data gaps to cluster in historically underinvested areas when interpreting results and presenting findings to stakeholders?

Equity and Sociodemographics

7. Figure 6 shows how park access clusters across King County, WA, colocate with the share of youth populations. What other sociodemographic variables (e.g., mobility, car ownership, income) would be relevant for extending this to an equity-focused analysis?
8. How would these variables help identify who is affected by low-access areas and inform decision-makers prioritizing park investments?

Broader Applications

9. Beyond parks, what other urban amenities or municipal services could benefit from a similar access analysis, particularly in terms of equitable distribution?
10. As reviewed above, there are many ways to define park accessibility. Choose one stakeholder (e.g., city parks department, public health agency, disability advocacy organization, neighborhood association). How would you scope an analysis of park accessibility to meet that stakeholder's needs? What criteria would guide your decision to simplify or expand the definition of accessibility, and why?

DATA ACCESSIBILITY STATEMENT

All data used in this analysis are publicly available online and are linked within the supplemental material *(nepf_iso_vignette.html)*.

SUPPORTING INFORMATION

All R code for the preceding analyses are provided in the *nepf_iso_vignette.html* file, within the supplemental material.

AUTHOR CONTRIBUTIONS

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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