

Evaluating methodological approaches to urban park accessibility: a comparative analysis of statistical, network-based, and gravity measures in Quincy, Illinois

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Research Article

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Evaluating methodological approaches to urban park accessibility: a comparative analysis of statistical, network-based, and gravity measures in Quincy, Illinois

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Abstract

Access to urban parks is a vital measure for fostering equitable and sustainable urban development. Nevertheless, the findings are highly dependent on methodological decisions. This study examines the effects of various GIS-based methods on measuring park accessibility in Quincy, Illinois. Using consistent datasets on park distribution, transportation networks, and population, three analytical frameworks are used, including statistical indicators, network-based accessibility, and gravity-based spatial interaction models. Accessibility is measured using different modes of travel (walking and driving), distance thresholds, and park destination choices (centroids, edges, and entrances). Results reveal significant differences in spatial accessibility patterns among methods. A pairwise Spearman rank-correlation analysis of the 14 measures showed that measures sharing the same travel mode and destination representation agreed most strongly, while those with different travel modes showed weak agreement, indicating that travel mode is the main source of divergence. Statistical indicators reveal general disparities in the provision of parks, but not the real travel patterns. Gravity-based models take into account supply-and-demand dynamics but are also influenced by park size and population distribution. Compared to network-based metrics, gravity-based models' planning utility is limited in low park-supply environments because they generate fragmented, hard-to-generalize patterns. Conversely, network-based measures, especially those based on entrance-based destinations, are theoretically more likely to reflect actual access conditions because they apply real road networks and place destinations at actual park entry points. The findings highlight the significance of the methodological choice and justify the application of behaviorally informed, network-based methods to urban planning practice.

Keywords: Park accessibility; Gravity model; Network analysis; GIScience; Spatial equity

1. Introduction

Parks play a vital role in enhancing environmental, health, and urban well-being outcomes and are therefore important components of sustainable urban planning, particularly in mid-sized cities where service disparities often arise. With the rapid pace of urbanization worldwide, the need for equitable park provision has become a growing priority for planners and policymakers, while pressure on existing green infrastructure also increases (Wolch, Byrne, and Newell 2014). Socially, equal access to parks supports health and well-being, fosters social connections, and is a vital component of urban well-being. The public health significance of inequities in park access is clear, as it has been consistently associated with obesity, cardiovascular disease, and mental health conditions (Chiesura 2004). Inequitable distribution and access to green spaces, however, reflect underlying socio-spatial injustices, presenting challenges for urban planning and policy. Such inequities are particularly evident in mid-sized American cities, where financial constraints, sprawl, and fragmented governance and agency over parks and open spaces frequently result in chronic underinvestment in green infrastructure for low-income and peripheral communities (Rigolon 2016).

Park accessibility is difficult to measure, as park locations, transportation infrastructure, population density, and measurement approaches influence it. Importantly, the selection of a measurement method not only affects the technical aspect but also dictates the communities that appear as underserved and, ultimately, where to allocate planning resources (Wang, Wang, and Liu 2021). Conventional methods (e.g., straight-line distance, centroid-based) can be overly simplistic, which might not reflect real-world access conditions. Furthermore, centroid representation of large parks can significantly overestimate travel distance to park entrances, causing systematic underestimation of accessibility for neighboring areas. To overcome this limitation, this research seeks to highlight more precise GIS techniques, such as network distance and spatial interaction modeling, which consider both park size (supply) and population (demand).

Quincy offers a perfect case study in terms of its compact urban structure, varied travel patterns, and spatially uneven park distribution, allowing comparisons of accessibility by walking and driving, and demonstrating the impact of methodological decisions on equity. Quincy is representative of a larger class of mid-sized, car-dependent US cities for which there is still a dearth of rigorous GIS-based accessibility evidence, in contrast to the well-researched, pedestrian-friendly cities that predominate the park accessibility literature.

This project aims to compare the measurement of access to urban parks using different GIS-based approaches under varying assumptions about distance, transportation mode, and park access locations. The findings are therefore intended to contribute not only to methodological debate but also to practical planning guidance for cities sharing similar spatial and demographic characteristics. The primary objective is:

- To evaluate statistical, network-based, and gravity-based accessibility measures to assess how methodological choices influence observed patterns of park access.
- To identify approaches that are theoretically best positioned to represent everyday access conditions in the study area.

2. Accessibility Measurement

Spatial accessibility refers to the ease of reaching a chosen location, encompassing both distance and site characteristics (Handy and Niemeier 1997). It is generally understood as the ability to move from a residence to a park, a vital determinant of park use and its potential to promote physical health, mental well-being, and social interaction (Chiesura 2004), since accurate measurement of access is key to equitable and sustainable urban development (Chiesura 2004). However, park accessibility is not straightforward to measure, as it is a multi-dimensional concept depending not only on proximity but also on park size, distribution, transport provision, and user behavior (Zhang, Lu, and Holt 2011). Numerous studies show that access is unevenly distributed, with low-income and minority communities facing lower access to parks and green spaces (Rigolon 2016; Wolch, Byrne, and Newell 2014), prompting methodological efforts toward more robust GIS-based access metrics. There are three dominant methods: statistical index, spatial proximity, and spatial interaction (gravity-based) models (Wang, Wang, and Liu 2021), alongside the more recent two-step floating catchment area method and its variations, which addressed several limitations of earlier approaches (Luo and Wang 2003; Dai 2011).

2.1. Statistical Index Approach

The statistical index approach measures accessibility based on the quantity and/or distribution of park amenities in defined areas, such as census tracts or neighborhoods (Talen 1997). These indicators typically include park area as a percentage of the total land area and park area per person. The measures are widespread as they are easy to calculate, easy to interpret, and applicable to comparisons of accessibility by region (Talen 1997).

This method has certain disadvantages. One of the key issues is the Modifiable Areal Unit Problem (MAUP), which entails differences in outcomes as a consequence of changing the spatial boundaries; because statistical measures are

based on fixed administrative units, they do not necessarily reflect the nature of people's park access in the real world (Openshaw 1984). For instance, people could go outside their neighborhood to go to parks, but such cross-boundary activities would not be recorded in zone-based measures.

Moreover, the statistical approach does not consider differences in the mode of transport and in travel behavior. It assumes that all the residents within a unit are equally accessible, whether on foot or by car. Doing so, statistical measures often overlook actual conditions of accessibility and provide a general picture of patterns of park distribution and equity. Recent comparative studies have found that the statistical measure of park access is poor compared to the network measure of access, especially in its ability to predict equity in park use in the United States context (Collins et al. 2025). Administrative-boundary measures overestimate and underestimate access, depending on the park's local geography (Collins et al. 2025).

2.2. Spatial Proximity Approach

The spatial proximity approach is a method of measuring accessibility by travel distance or travel cost from residential locations to parks. This involves parameters like distance to the closest park and number of parks within a certain radius (Wang 2012). This is more direct than statistical measures, which only take into account the location of the facilities. A significant recent advancement in this approach is the integration of network-based distance, rather than Euclidean distance, to better approximate how people travel in the real world through transportation networks (Xiao et al. 2017). Network-based measures take into consideration actual travel pathways and restrictions and are more representative of real-world access (Xiao et al. 2017). Network-based routing has been shown to significantly alter accessibility outcomes compared with straight-line buffers, especially in cities with non-rectangular street layouts or a lack of pedestrian facilities (Spangler et al. 2023).

Another key consideration for proximity-based analysis is transport modes. Walking and driving have different levels of accessibility. Access to nearby parks is generally restricted to walking, and driving provides access to parks over a more extensive area (Xing, Liu, and Liu 2018). Thus, integrating several modes of transportation and related distance cut-offs is crucial to correctly reflect accessibility patterns (Xing, Liu, and Liu 2018). Mode differentiation is particularly critical for underserved groups, such as children, the elderly, and households with low income and no private cars, who are disproportionately dependent on walking or public transport for access to parks (Rigolon 2016; Cheng, Liao, and Zhu 2021)

This method has drawbacks, though. It assumes people will select the closest park, but this does not necessarily align with people's preferences. The quality, facilities, and size of the park could also be the determining factors (Zhang, Lu, and Holt 2011). Another factor is the representation of parks in the analysis. It is important to note that the estimation of accessibility may be skewed by simplifying parks to single points (e.g., centroids), particularly in large parks (Wang, Wang, and Liu 2021).

Recent research has shown the need to apply more realistic representations, such as park entrances, which are more representative of the actual access conditions (Wang, Wang, and Liu 2021; Collins et al. 2025). In Massachusetts, the choice of entrance-based versus centroid-based representations meaningfully altered population-level estimates of park access; this difference was particularly pronounced for large and irregularly shaped parks (Collins et al. 2025).

2.3. Spatial Interaction (Gravity-Based) Approach

The spatial interaction approach is a development of the accessibility approach, which also considers park supply and population demand. It is based on gravity models, which state that access to a park will be greater if the park is more attractive and/or bigger and less if the distance between the origin and the destination is greater (Joseph and Bantock 1982).

An advantage of this method is that it documents competition for park resources and more fully represents accessibility. The size is also a factor affecting the number of people using them; larger parks are likely to see more use, and more densely populated areas are likely to see higher demand, thereby affecting overall accessibility (Wang 2012). Administrative boundaries do not limit gravity-based models and have the potential to describe access at finer spatial resolutions than statistical models.

The method, however, is more complicated. Choices of distance decay parameters, which set how accessibility decreases with increasing distance, can dramatically influence the outcome and can vary from one context to another. Furthermore, the model is also dependent on assumptions as to the modes of transport, travel thresholds, and definitions of the destination, as with proximity-based methods.

Recent comparative studies on the basis of US census microdata have suggested that gravity-based methods, coupled with network distance and entrance-based destinations, should be preferred for park equity mapping tools, with the caveat that this is tailored to areas with sufficient park provisioning and a well-connected road network (Collins et al. 2025). It is also interesting to note that the two-step floating catchment area (2SFCA) method, which

is based on the gravity model and explicitly considers the ratio between supply and demand within the overlapping catchment area, has received much attention in recent literature on park accessibility (Luo and Wang 2003; Dai 2011; Hu et al. 2020). To examine the performance characteristics of the three approaches in particular, in this automobile-dependent urban context with a low number of parks, this study refers to the three basic approaches: statistical, network, and gravity-based.

2.4. Research Gaps

Even with these developments, there are still research gaps regarding the relationship between the various approaches to accessibility and methodological choices and differences affecting the accessibility results in various urban settings. Wang, Wang, and Liu (2021) studied the combined effects of transport modes, distance thresholds, and park access points in the cities of Ipswich, Australia, and Enschede, the Netherlands, which both have relatively planned urban forms and good pedestrian and bicycle networks. The results do not necessarily transfer to other mid-sized cities in the United States where car dependence is great, pedestrian facilities are inconsistent, and there is a shortage of parks.

This concern is supported by the literature on accessibility in general. Comparative analyses across cities in the United States have demonstrated that the accessibility-sociodemographic equity relationship is not consistent across cities (Rigolon 2016; Collins et al. 2025). Accessibility measures can substantially change which areas are identified as underserved, depending on the way they are measured (Rigolon 2016; Collins et al. 2025). In addition, the research has so far proven that network-based and entrance-based methods are more successful than centroid-based methods in well-supplied urban areas, but there is little evidence to support the use of these methods in low park-supply, auto-oriented mid-sized cities in the United States.

This research aims to fill this gap by utilizing a comparative GIS-based approach for a low park-supply and automobile-dependent mid-sized US city, Quincy. It examines the methodological conclusions of the well-supplied, pedestrianized cities that still hold under different urban situations. It also explores the influence of methodological choices on planning decisions in cities that have limited parks and an unconnected road network.

3. Study Area

Quincy is a municipality in the United States that is situated in the western part of Illinois on the eastern side of the Mississippi River in Adams County. The population of Quincy was 39,463, with a land area of about 41 square kilometers (U.S. Census Bureau 2020). Quincy Park District manages parks, playgrounds, recreational facilities, and

open spaces, and maintains over 900 acres of parks and 21 parks to serve the public for recreational and leisure activities (City of Quincy 2025).

Quincy has been chosen as the study area due to its urban form and the availability of urban parks, which are well-suited to test GIS-based measures of park accessibility. It has a historic Central Business District and dense suburban areas, leading to differences in accessibility depending on mode and network characteristics. Its small size enables fine-scale GIS analysis of the city and its neighborhoods while still showing important spatial variations. The city is big enough that driving access exhibits noticeably different distributions, but small enough that walking thresholds are analytically sensitive. Quincy's compact land area ($\sim 41 \text{ km}^2$, roughly 6–7 km across) means a 5 km driving threshold approaches the scale of the city itself. This is treated as a feature of the design rather than a limitation. It allows the analysis to test whether automobile access closes the accessibility gap even under a near-maximal assumption of driving reach.

Additionally, Quincy's comparatively low park density serves as a model for the several mid-sized US cities that fall short of suggested benchmarks for green space availability, yet are still understudied in the literature on park accessibility. Quincy's combination of walkable and automobile-dependent

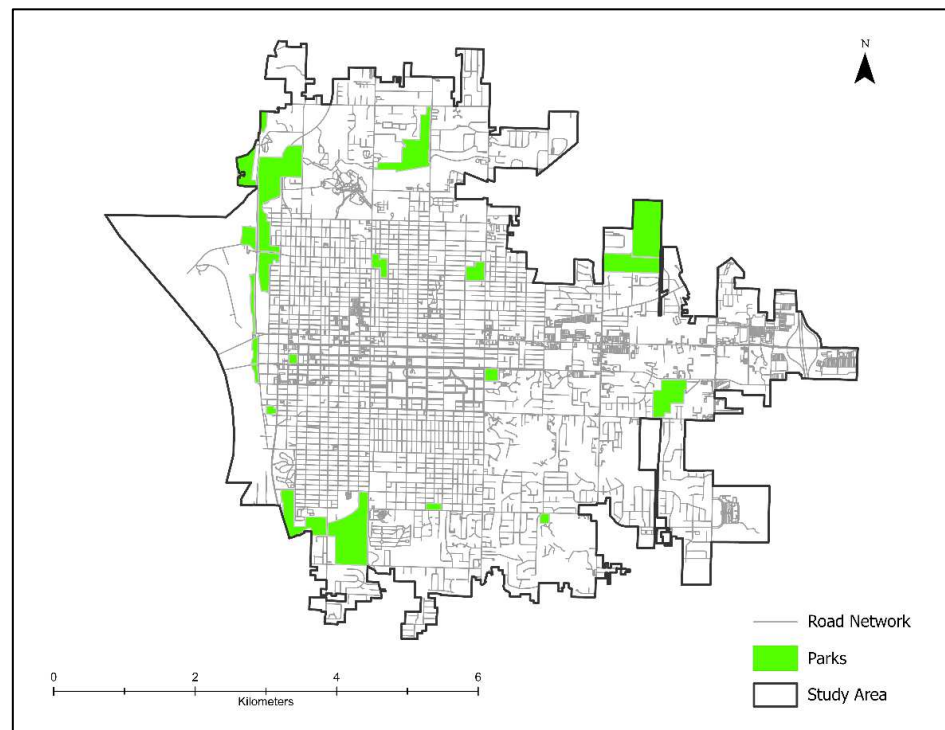


Fig. 1 Study Area (Quincy, Illinois) and its urban parks

neighborhoods makes it ideal for examining statistical, network, and gravity-based measures to reflect differences in access to neighborhood parks and outlying green spaces.

4. Data

4.1. Urban Park Polygons

The data on urban parks were obtained from ParkServe®, a national standard database created by the Trust for Public Land (TPL). The dataset is a compilation of park boundaries from municipal and county agencies, public land inventories, and other authoritative local data sources, and has been used to ensure that publicly accessible parks are always covered.

The dataset covers municipal, neighborhood, and community parks, but not the private or restricted-access facilities. The important attributes are Park ID and park area (based on geometry). Based on park polygon data, centroids, edges, and entrance points are derived for accessibility analysis. Park area values are used as the supply variable in the gravity model and statistical-based calculations. This data was chosen for its national uniformity, public-access focus, and suitability for spatial analysis.

4.2. Road Network Data

The data on the road networks were obtained through Geofabrik, which provides OpenStreetMap (OSM) data in GIS-ready formats. The data consist of polyline features that represent the centerlines of roads and a functional classification attribute.

To facilitate realistic accessibility modeling, the roads were filtered into two networks: a walking network (footways and cycleways) and a driving network (motorways, primary, secondary, and residential roads).

The dataset facilitates network-based computations, including service area generation and origin-destination (OD) cost matrices. It was selected because of its routable format, extensive classification framework, and applicability to transportation analysis at urban scales.

4.3. Census Block Group Population Data

Population data were obtained from the 2020 U.S. Census via the Esri Living Atlas. Small area polygon units are known as census block groups, with an approximate range of 600-3,000 people. For clarity, this study uses "census block group" to refer to the specific statistical polygon unit analyzed throughout the methodology and results. The term "neighborhood" is used elsewhere in the text only in an informal, descriptive sense to refer generally to areas of the city and does not imply that block group boundaries correspond to residents' perceived or administratively defined neighborhoods.

The major attributes are total population, FIPS codes, and geometry-based polygon area. Population data are the demand aspect of the analysis and are applied to park-area per capita, network-based analysis, and gravity modeling. This dataset was chosen for its large spatial scale and applicability to neighborhood-level accessibility evaluation.

4.4. Data Standardization and Limitations

Each dataset was trimmed to the Quincy boundary and checked for geometric and attribute consistency to give a sound analysis. All datasets are authoritative but have limitations. ParkServe® boundaries can be inaccurate, and more recent parks can be missing. There may be classification inconsistencies in OpenStreetMap data. Recent changes might not be reflected in population data released in the 2020 Census. Also, census block groups and neighborhoods are not equivalent spatial units. Nevertheless, standardization and quality control of all datasets were ensured to guarantee quality analysis.

5. Methodology

5.1. Methodological Framework

The main purpose of the study is to evaluate various methodological approaches of GIS for measuring the accessibility of urban parks in Quincy, Illinois. It assesses three widely used approaches: zone-based statistical measures, network-based accessibility, and gravity-based spatial interaction. The study applies these methods under different assumptions, such as travel modes, distance, and park destination definitions, to determine which methods capture the most accurate access conditions.

Accessibility in cities is complex, influenced by the distribution of parks, population, and transport conditions. Using one method alone may not provide a comprehensive picture. Thus, this study employs three approaches. The first applies statistical measures using spatial overlay, computing park area per census block, and providing a basic spatial distribution. The second applies network analysis to measure accessibility through service areas, determining parks accessible within walking and driving distances based on real road networks. The third uses a gravity-based spatial interaction model, accounting for park size (supply), population (demand), and distance decay to produce more detailed accessibility maps.

Collectively, these methods reveal methodological decisions on park accessibility and spatial disparities. Thematic mapping is used as the main approach to spatial pattern comparison in this study.

5.2. Analytical Workflow

The analytical workflow consists of four main stages: defining park destination representations, calculating statistical measures, measuring network-based accessibility, and modeling gravity-based (spatial interaction) accessibility. Statistical, network, and gravity approaches were applied to generate 14 measures (Table 1), based on which accessibility outputs were prepared.

5.2.1. Defining Park Destination Representations

An important methodological element of the study is the definition of park destinations (Fig. 2) that are applied in the accessibility analysis. Since parks are represented spatially as opposed to points, varying forms of park access locations may influence calculated travel distances.

Park centroids represent parks as a point in the geometric center of the park polygon. This simplistic model is commonly applied in accessibility studies because of its computational efficiency. However, it may misrepresent the real access requirements of large or irregularly shaped parks because the geometric center can be far from the actual points.

Park edge points provide a more spatially distributed representation of park access. Regular intervals (60 m) are used to generate points along park boundaries to estimate possible access points. A spacing of 60 m was chosen to match the spatial resolution of the urban street network. In Quincy, the average length of urban blocks is between 80 and 120 m. Thus, by having a 60 m separation, at least one possible access point is covered by a block face. This method is more appropriate for reflecting the area covered by parks, but assumes the availability of access along the entire boundary. Park entrance points are possible entry points where transportation networks meet the park boundary.

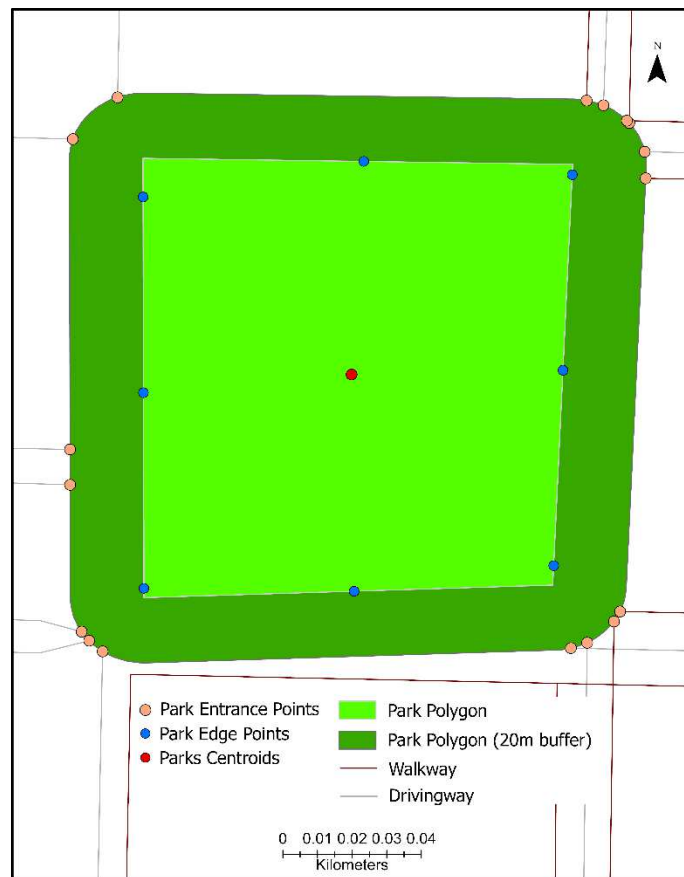


Fig. 2 Illustration of three park destination choices

These points are close to the real entrances that are used by pedestrians and vehicles (nearby parking lots) and thus give the most accurate idea about the accessibility of the park. Each park boundary is extended to a 20-meter area to capture the offset between the park edges and surrounding road centerlines. The extended park areas were then overlaid with the walking and driving road network to determine the potential access points to the park.

5.2.2. Statistical Accessibility

The initial analytical element is an assessment of park accessibility through a zone-based statistical measure. The spatially intersected polygons of the park and census block group are created in such a way that the park areas that cross the census block group boundaries are cut into fragments that can be linked to each census block group. The size of each park fragment is computed and summed up to compute the overall park size in each census block group. Each census block group has two indicators calculated. The first one is the park percentage, which is the ratio of park area to the total area of the census block group. The second indicator is the park area per capita, which is the measure of the size of park space that can be utilized by residents by dividing the total area of the parks by the population of the census block group. These indicators evaluate the access to park resources in each census block group, but do not consider access to parks that are located beyond the census block groups.

5.2.3. Network-based Accessibility

The second analytical element evaluates accessibility according to the travel thresholds through the transportation system. This measure is cumulative accessibility, which is defined as the count of access points to parks within a specified distance limit of travel. In the analysis, two travel thresholds were used, which were based on previous green space accessibility studies and the WHO recommendations (Wang, Wang, and Liu 2021; OECD 2014). The 1 km walking distance represents an average 8-10 minute walk to green space, and the 5 km driving distance represents a short drive to reach a green space anywhere across Quincy. The two distance thresholds are not meant to be equal or directly comparable. The 1 km walking threshold represents a short distance that people can realistically walk, where even small changes in distance can affect whether a park is accessible on foot. The 5 km driving threshold represents a best-case scenario for car travel. Because Quincy is relatively small (about 41 km², or roughly 6–7 km across), a 5 km driving distance can reach most of the city. This outcome is expected and was part of the study design. The purpose of using different thresholds is to compare travel modes and park access, not to find the ideal driving distance. A single driving threshold from the literature is enough to show whether access by car reduces or removes the accessibility gap seen with walking. Testing several shorter driving distances would

answer a different question: how quickly accessibility improves as driving distance increases, which is outside the scope of this study. Service areas are created at park access points to reflect access to network distances, each at a threshold. The residential census block groups that overlap these service areas are deemed to have access to these parks. These indicators are the number of accessible parks within realistic travel ranges.

5.2.4. Gravity-based Spatial Interaction Accessibility

The third analytical element measures accessibility with the gravity-based spatial interaction model (Wang 2012). Origin points are the centroids of census block groups, which represent population units, and destination points are park centroids, edge points, and entrance points.

This approach incorporates three key variables:

- Park size (representing supply),
- Census block group population (representing demand),
- Network distance between origins and destinations.

Park Accessibility (A_i) for each census block group is made using the following gravity model:

$$A_i = \sum \frac{S_j \times P_i}{d_{ij}^2}$$

Where:

S_j = Park Area

P_i = Population of the census block group

d_{ij} = Network distance between the census block group and park access points

The inverse-square (d^{-2}) distance decay function has been used. This means accessibility drops off quickly as distance increases. This is chosen because visiting a park is usually optional, unlike going to a hospital or grocery store. So, people are likely to lose interest fast once a closer option is available. Other decay functions, like negative exponential or Gaussian, are also common in the literature, and they differ mainly in how gradually they reduce accessibility with distance (Zhang, Lu, and Holt 2011; Hu et al. 2020). Those methods usually work best when trip-distance data are available to fit the decay curve to real behavior. Since that kind of data is not available for Quincy, the inverse-square form was chosen because it is simple, requires no additional parameters, and is consistent with

the method used in the comparative study on which the analysis is based. Future work could test other decay functions if travel-behavior data becomes available.

The model assumes that accessibility increases with park size and decreases with increasing travel distance. The gravity scores are computed for all parks within the specified walking and driving distances and then summed to generate a single accessibility score for each census block group. This methodology offers a more detailed portrayal of accessibility, as it considers both the supply of parks, the population demand, and the travel distance.

Table 1. Specification of 14 accessibility measures using three different approaches

Approaches	Distance thresholds by transport mode	Destination Choices
Park Percentage	N/A	N/A
Park per Capita	N/A	N/A
Spatial Proximity/ Network-based Accessibility (Cumulative Proximity)	Walking distance 1 km	Centroid Edge Entrance
	Driving distance 5 km	Centroid Edge Entrance
Spatial Interaction (Gravity Model)	Walking distance 1 km	Centroid Edge Entrance
	Driving distance 5 km	Centroid Edge Entrance

It should be noted that this specification treats census block group population as a numerator term alongside park size, both discounted by distance. This differs from demand-competition formulations such as the two-step floating catchment area (2SFCA) method, in which population functions as a denominator representing competing demand at the destination, structured to reduce accessibility scores as competition for a given park increases (Luo and Wang 2003). In the formulation used here, higher-population census block groups will receive higher accessibility scores at a given park size and distance, all else equal (Wang 2012; Wang, Wang, and Liu 2021). This specification has been retained for consistency with prior comparative work on this topic, and the resulting scores are interpreted as a

demand-weighted gravitational exposure index, reflecting the joint magnitude of population and nearby park supply, rather than a strictly per-resident measure of ease of access.

5.2.5. *Quantitative Agreement Among Measures*

In addition to comparing accessibility patterns through thematic mapping, the degree of agreement among the 14 accessibility measures was assessed statistically. Spearman's rank correlation coefficient (ρ) was calculated for all 91 pairwise combinations of the 14 measures across the 43 census block groups. Spearman's ρ was selected over Pearson's r because the accessibility measures differ in scale and units across the statistical, network-based, and gravity-based approaches, and the analytical interest lies in whether block groups are ranked consistently across methods rather than in the linear association between raw values. This analysis provides a quantitative complement to the visual comparison of accessibility patterns, allowing the relative influence of travel mode, model type, and destination representation on measurement agreement to be evaluated directly (Table 2).

5.3. Analytical Tools

Polygon intersection algorithms were used to perform spatial overlay to combine the park and census block group geometries. This operation divides park polygons across census block group boundaries, enabling a careful computation of the amount of park area that occurs in each unit. The outcomes advocate proportional allocation and allow such metrics as park coverage and per capita availability. Service area analysis uses network traversal algorithms to find all accessible locations within a specified travel distance using the road network (both walking and driving), where park access points, such as the centroid, edge, and entrance, are used as facilities. It uses real connected routes rather than straight-line buffers, creating catchment areas that represent realistic accessibility at walking and driving thresholds. These areas are then used to evaluate cumulative access to park locations. OD cost matrix analysis computes the minimum travel cost between multiple origins (census block group centroids) and destinations (park access points) using shortest-path algorithms. It calculates network distances based on all the origin-destination pairs systematically to model travel relationships and enable gravity-based accessibility calculations.

Regarding map classification, all choropleth maps were symbolized using a five-class scheme (Very High to Very Low). Fig. 3-13, which compare accessibility patterns across travel modes, destination types, and models, use the Natural Breaks (Jenks) method, which identifies natural groupings in the data and minimizes within-class variance while maximizing between-class variance. This method was chosen because it adapts class breaks to the actual

distribution of each accessibility measure, avoiding artificial groupings when values are unevenly distributed across the study area. Fig. 14 and 15, which directly compare network-based and gravity-based accessibility for entrance-based destinations, use a Quantile classification instead, ensuring an equal number of census block groups fall into each class. This allows the two models to be compared on a common visual basis, since quantile breaks are determined by the rank order of observations rather than by the absolute values of each accessibility measure, which differ in scale and units between the two models.

A generative AI tool (Claude, Anthropic) was used only for formatting, reference checks, and assistance in drafting administrative sections, not for data analysis or interpretation.

6. Results

6.1. Spatial Patterns of Statistical Accessibility

A large part of the city has low accessibility, especially in the central and southern parts of the study area, where the area of parks is relatively small compared with the area of census block groups (Fig. 3). Areas with higher park percentage and park per capita values are found in some northern, western, and a few eastern areas (Fig. 3). The comparison of these two statistical indicators highlights that park percentage reflects the spatial distribution of parkland, whereas park per capita captures the relationship between park supply and population demand.

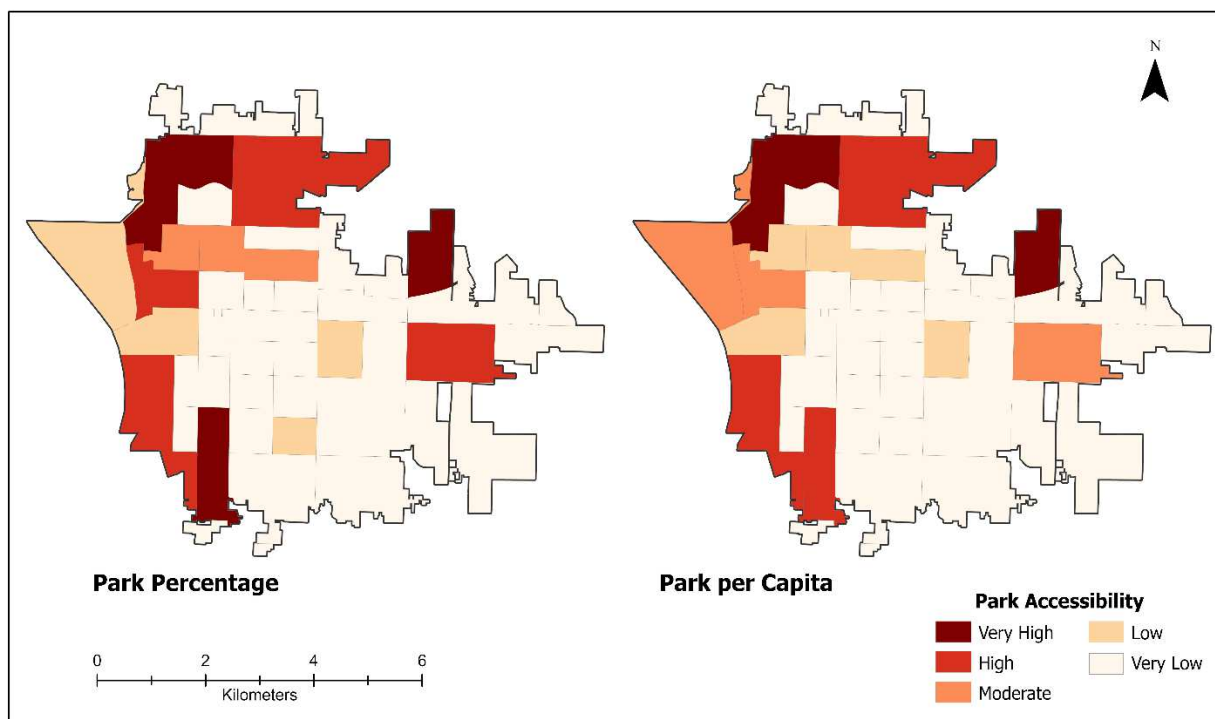


Fig. 3 Spatial Patterns of Statistical Accessibility Measures in Quincy, Illinois

Altogether, the findings indicate spatial disparities in park provision across census block groups and the shortcomings of zone-based statistical indicators, which consider park provision within administrative areas and do not account for residents' ability to visit parks beyond their administrative boundaries.

6.2. Spatial Patterns of Network-Based Accessibility

6.2.1. Walking (1 km Distance) vs. Driving (5 km Distance)

The network-based accessibility analysis shows contrasting patterns with walking and driving in the study area, using park centroids, park edges, or park entry points to represent destinations. Using the 1 km walking threshold, accessibility is generally low and highly concentrated in a few west-central, northern, and southwest areas where parks are located in proximity to residential areas (Fig. 4-6, 1 km walking distance). However, many peripheral and eastern areas have either very limited or no accessibility, due to more limited short-range walking accessibility. The 5 km threshold for driving drastically increases accessibility in most census block groups, with almost the entire western and central parts of the study area having high or very high accessibility, showing that cars help overcome the distance barrier and increase accessibility to a greater number of parks in the road network (Fig. 4-6, 5 km driving distance). This is consistent with expectations, as a 5 km driving threshold in a compact city like Quincy can reach most locations. As a result, the key comparison is between walking and driving access, rather than differences within the driving-access results themselves.

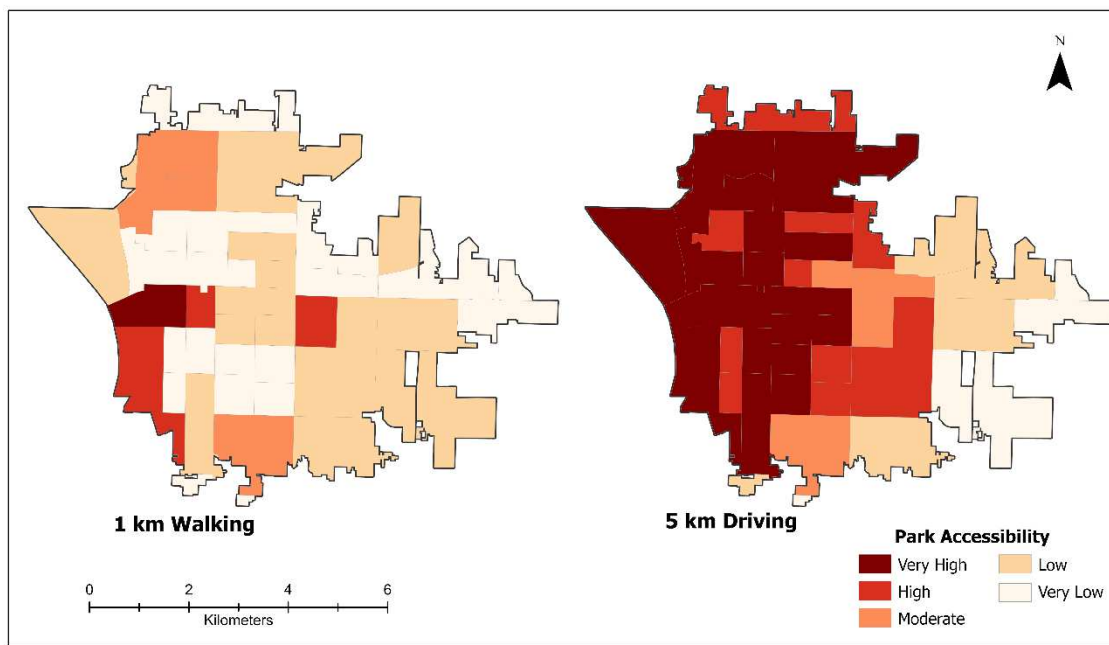


Fig. 4 Walking vs Driving (park centroid-based measure in Quincy, Illinois)

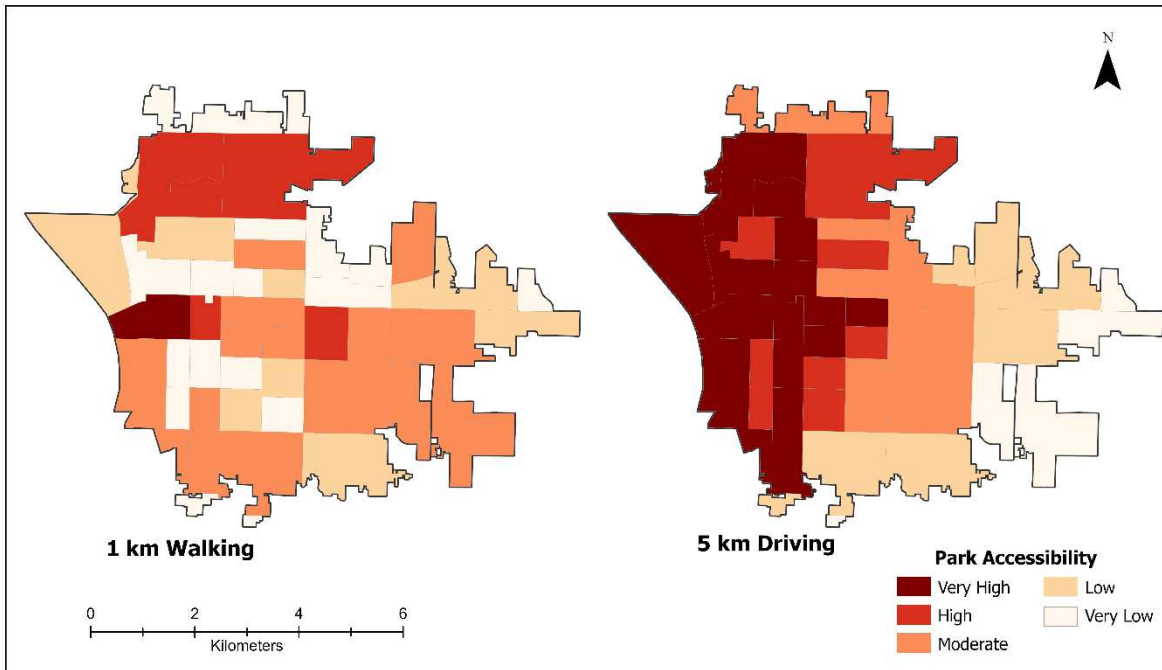


Fig. 5 Walking vs Driving (park edge point-based measure in Quincy, Illinois)

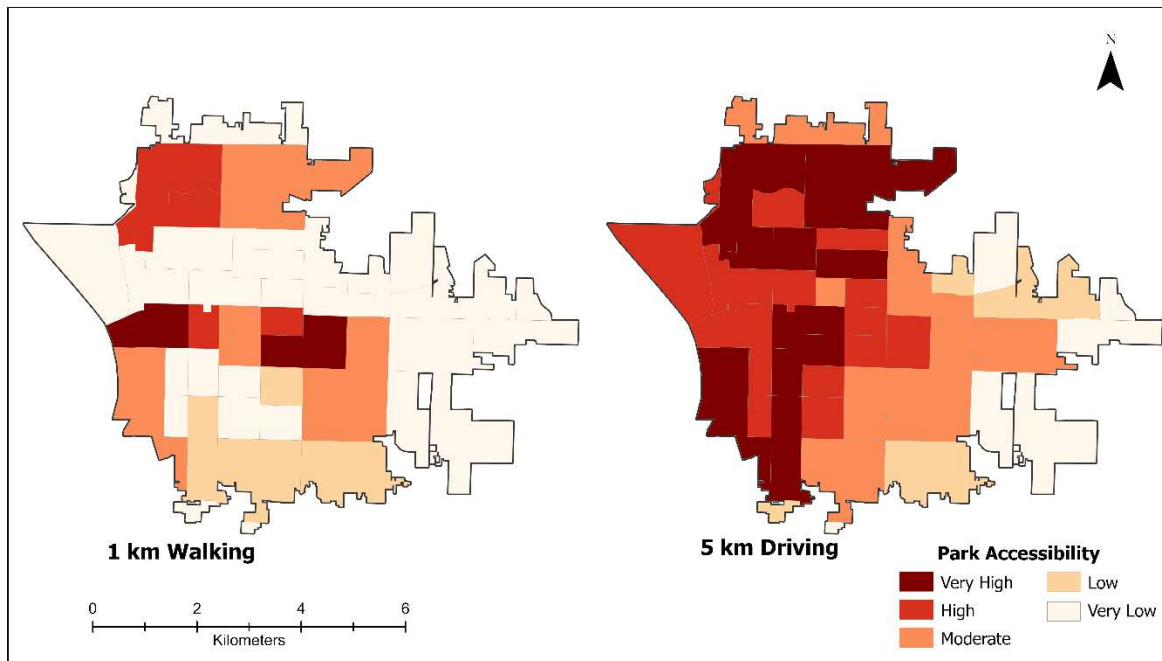


Fig. 6 Walking vs Driving (park entrance point-based measure in Quincy, Illinois)

6.2.2. Park Centroid vs. Park Edge vs. Park Entrance

Network-based accessibility varies significantly based on park representation (centroid, edge, or entrance) in both walking and driving scenarios. For the walking scenario, accessibility is generally low because of the short travel distance and the lack of pedestrian infrastructure. The centroid-based measure results in lower accessibility than the edge-based measure because it assumes access from the middle of parks, which may not be near streets. The edge-based measure marginally boosts accessibility in the northern and western parts of the study area (Fig. 7), which considers park edges closer to the street network.

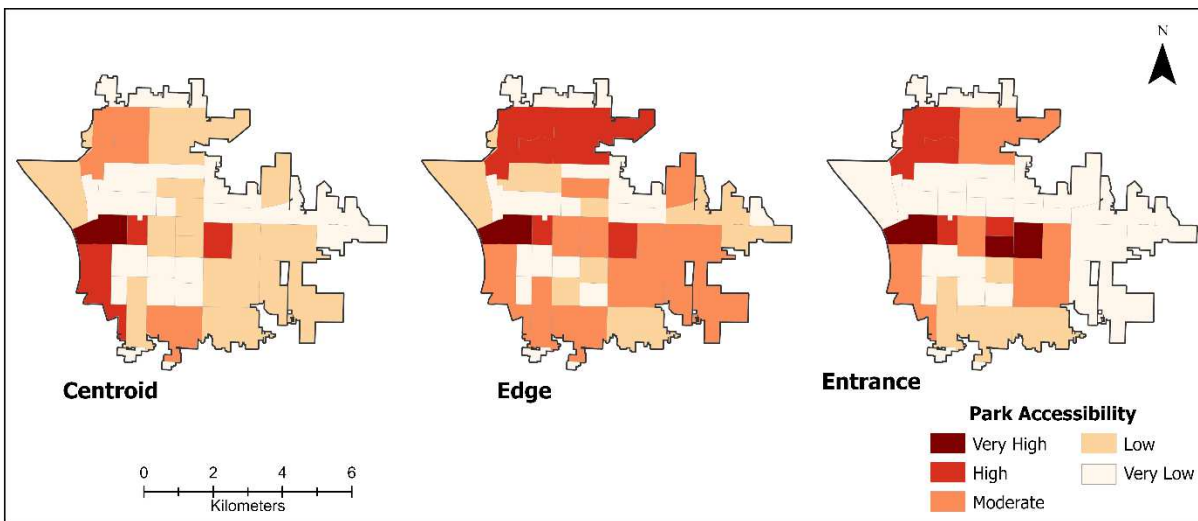


Fig. 7 Centroid vs Edge vs Entrance (network-based accessibility for walking in Quincy, Illinois)

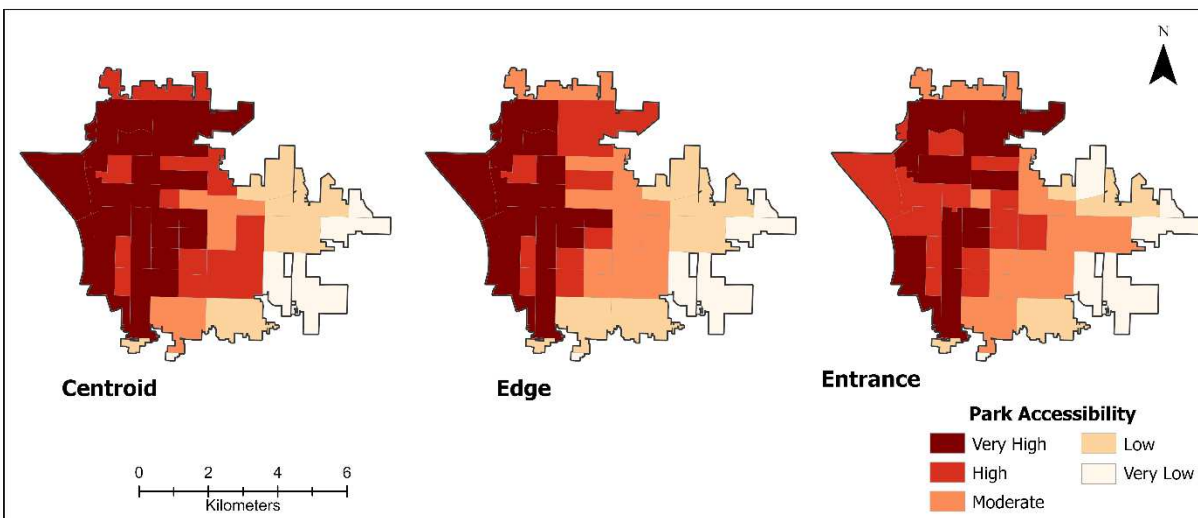


Fig. 8 Centroid vs Edge vs Entrance (network-based accessibility for driving in Quincy, Illinois)

However, the entrance-based measure produces more plausible accessibility patterns because it accounts for actual entrance points to parks along with pedestrian pathways. In the driving scenario, accessibility is significantly higher due to the high speed, large catchment area, and dense road network. The differences between the centroid and the edge narrow. However, the entrance-based measures better reflect accessibility because greater accessibility is perceived where the park has entry points connected to the driving network (Fig. 9), leading to more realistic access to the park entrance.

6.3. Spatial Patterns of Gravity-Based Accessibility

6.3.1. Walking (1 km Distance) vs. Driving (5 km Distance)

Gravity-based accessibility differs between walking and driving conditions in terms of distance decay, park size, and population demand. For the 1 km walking threshold, accessibility values are low throughout most census block groups because the gravity model takes into account both distance decay and population demand, restricting accessibility to very nearby parks. Only a small number of northwestern, northern, and southern areas with larger parks show relatively higher accessibility levels (Fig. 9–11, 1 km walking distance). Under the 5 km driving threshold, there is a shift in the accessibility pattern rather than a spread, as the longer distance reduces accessibility in some areas while increasing it in others, and the original sparse pattern remains (Fig. 9–11, 5 km driving distance).

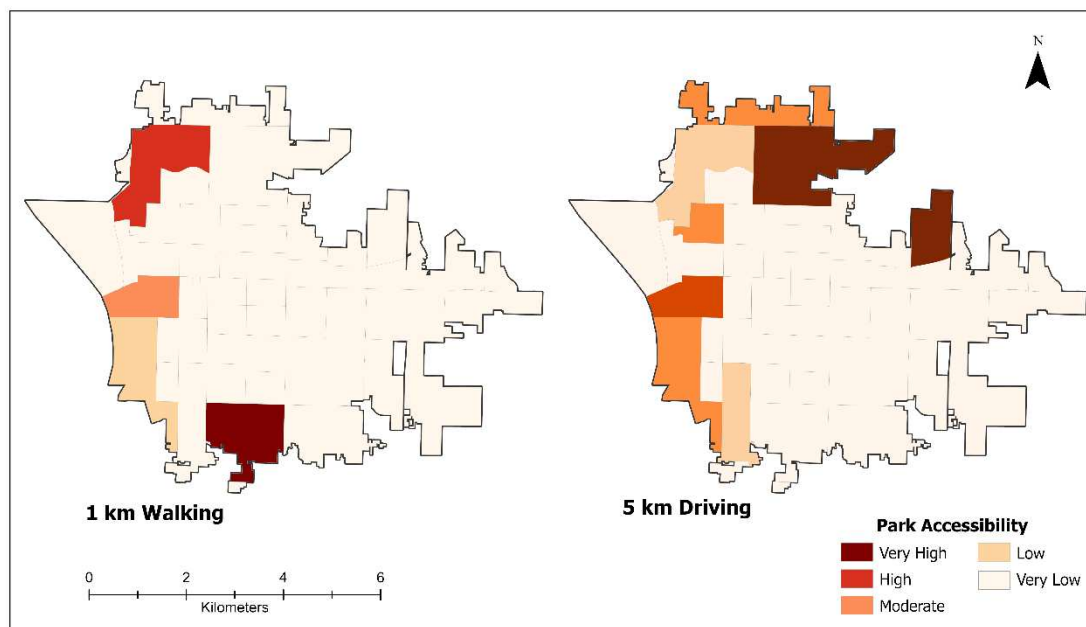


Fig. 9 Walking vs Driving (park centroid-based measure in Quincy, Illinois)

Overall, the findings show that gravity-based accessibility to parks is moderately affected by the use of driving, but the spatial difference between walking and driving is less distinct than with the network-based measures. However, this model still exhibits low levels of accessibility because higher accessibility is based on the number and size of the parks, and the study area has a relatively low supply of parks, despite the larger park sizes.

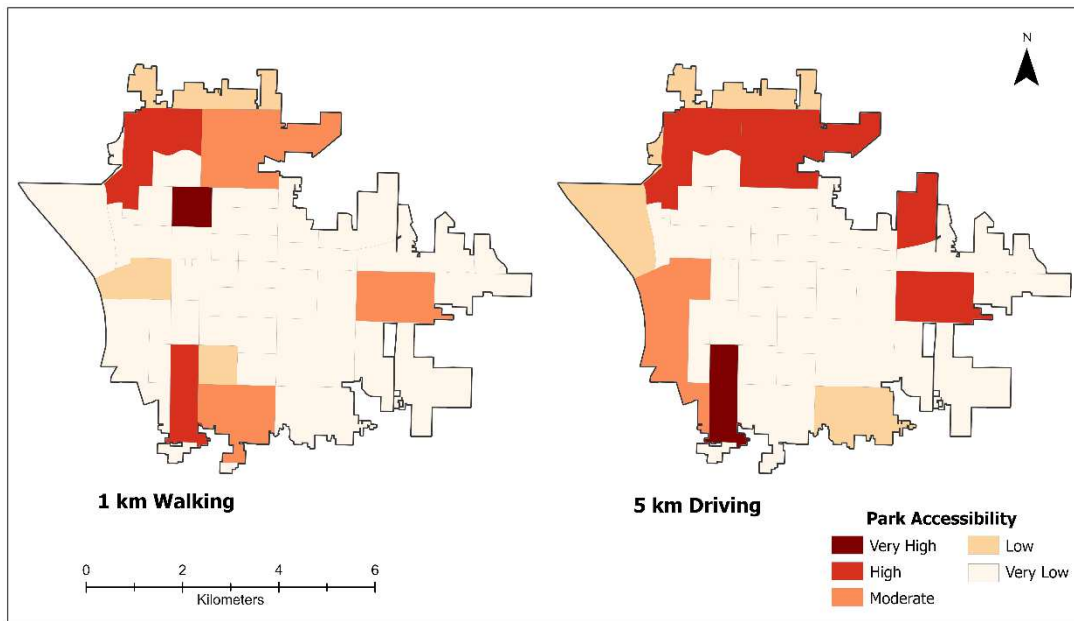


Fig. 10 Walking vs Driving (park edge point-based measure in Quincy, Illinois)

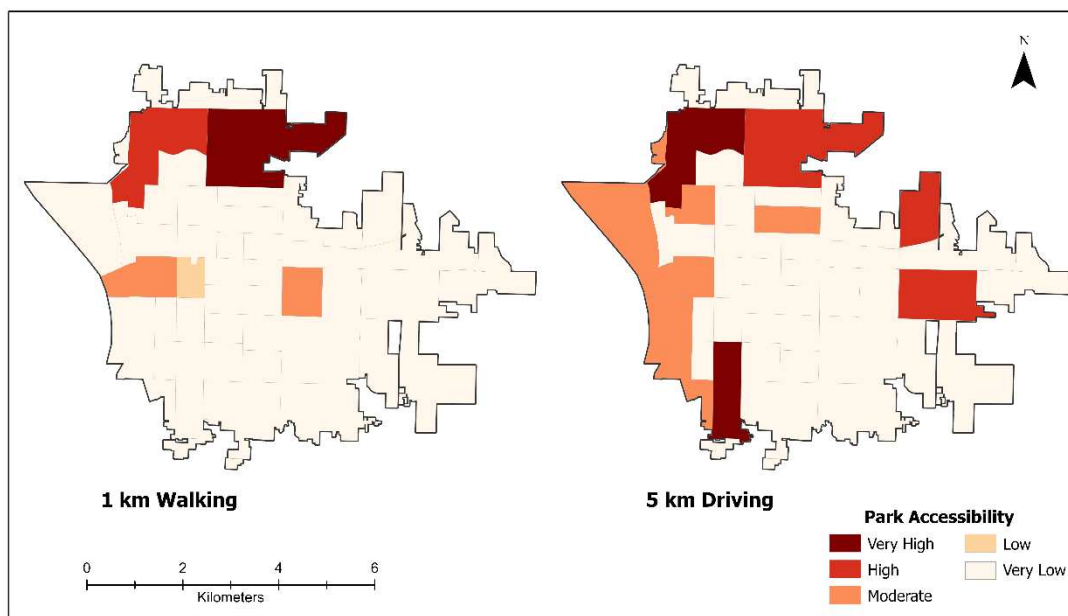


Fig. 11 Walking vs Driving (park entrance point-based measure in Quincy, Illinois)

6.3.2. Park Centroid vs. Park Edge vs. Park Entrance

The gravity-based accessibility measures show distinct patterns among centroid, edge, and entrance representations, driven by distance decay, park scale, and population needs. The walking scenario shows that the centroid-based representation results in high accessibility values in the southern area (Fig. 12), indicating closeness to large parks but misrepresentation of park entry points. The edge-based measure redistributes high accessibility to the north-central area, as it combines proximity to park boundaries and the street network. The entrance-based measure shifts very high accessibility toward the northern area, more accurately considering the interactions between the surrounding population and actual park entry points. The driving scenario redistributes accessibility instead of expanding the area (Fig. 13).

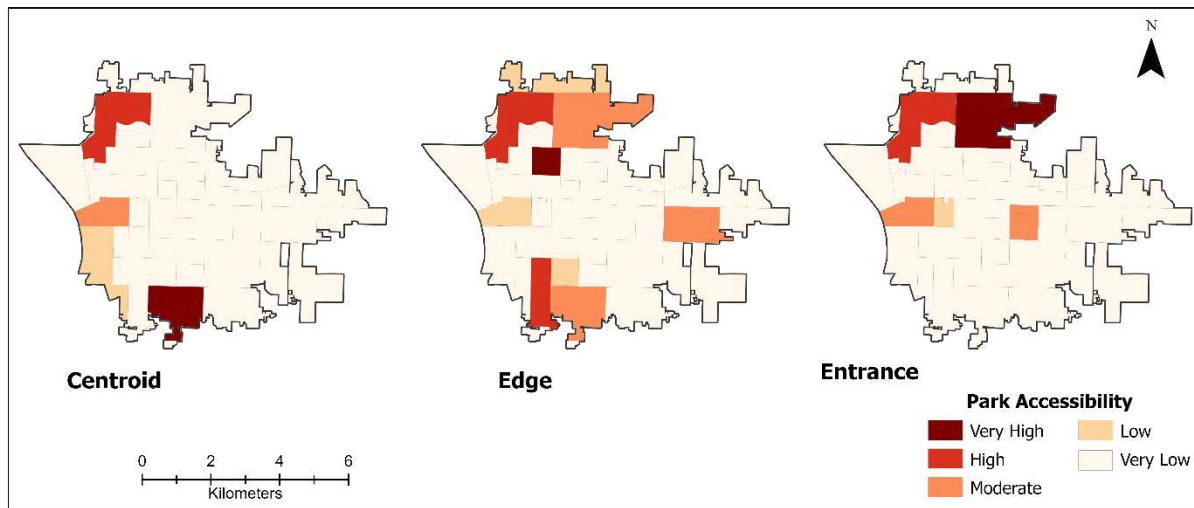


Fig. 12 Centroid vs Edge vs Entrance (gravity-based accessibility for walking in Quincy, Illinois)

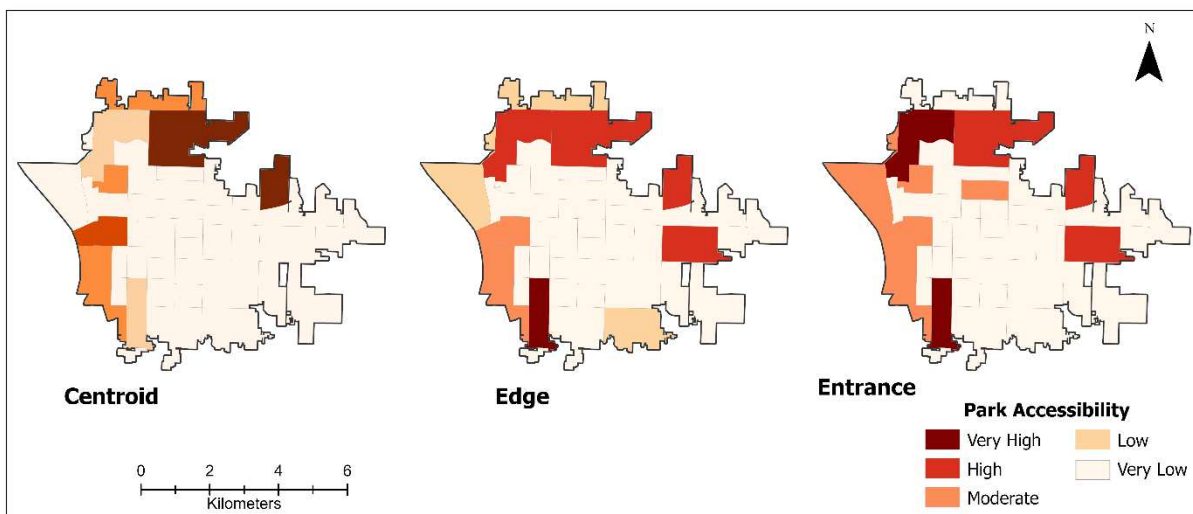


Fig. 13 Centroid vs Edge vs Entrance (gravity-based accessibility for driving in Quincy, Illinois)

The centroid-based method integrates very high values in the north-central zone, while the edge-based measure shifts the very high zone to the south. The entrance-based measure spreads very high accessibility values across the northern area and the southern area, reflecting realistic park accessibility where entrances are connected with the street network. Under both scenarios, the three methods all produce sparse and fragmented accessibility patterns typical of gravity models in regions with low park supply.

6.4. Comparison of Entrance-Based Accessibility: Network vs Gravity Models

The comparison of entrance-based accessibility reveals clear differences between network and gravity models under both walking and driving conditions. In the 1 km walk scenario, the network model reveals very high, well-spread accessibility across the central, northern, and western zones (Fig. 14), corresponding to the pedestrian network coverage within the travel threshold. The gravity model shows more concentrated high accessibility in the northern area near larger parks and low accessibility in other areas, reflecting the influence of park size and population demand. With a 5 km driving distance, both models show increased accessibility, with the network model covering more areas in central and western zones but leaving several eastern areas unserved (Fig. 15).

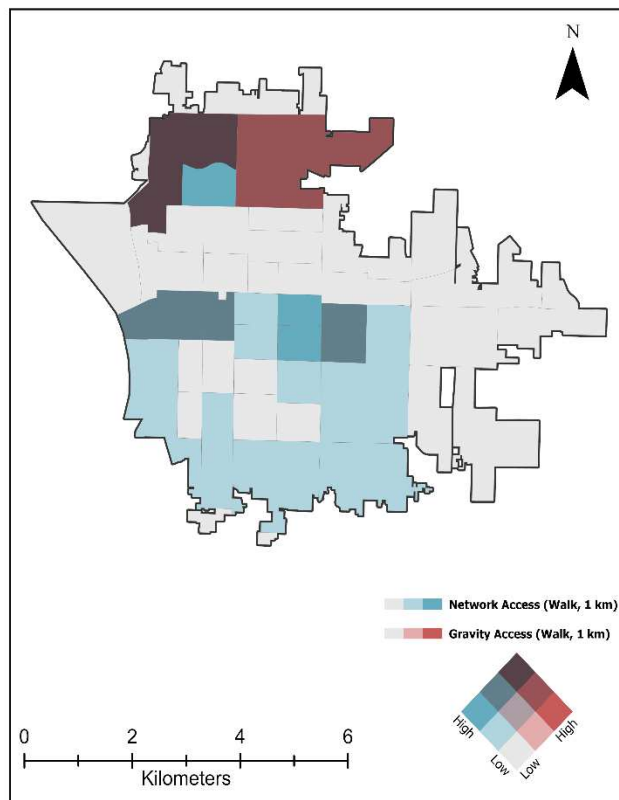


Fig. 14 Entrance-Based Accessibility under Network and Gravity Models for Walking in Quincy, Illinois

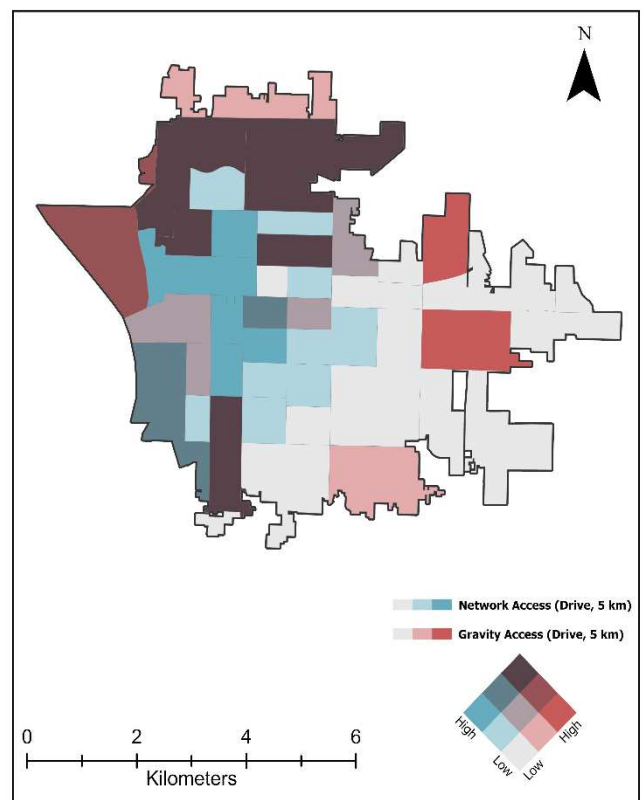


Fig. 15 Entrance-Based Accessibility under Network and Gravity Models for Driving in Quincy, Illinois

The gravity model still shows many localized zones of high accessibility near large parks in the eastern zone.

Notably, dark brown zones in both maps (Fig. 14 and 15) indicate where both network and gravity models agree on high accessibility. In summary, the network model covers a wider area, while the gravity model highlights demand-based variability near large park resources.

6.5. Quantitative Agreement Among the Fourteen Accessibility Measures

To assess the degree to which the fourteen accessibility measures agree in their relative ranking of block groups, Spearman's rank correlation (ρ) was calculated for all 91 pairwise combinations across the 43 census block groups (Table 2). Agreement was strongest among measures sharing both a travel mode and a destination representation: within the driving-based network measures, centroid, edge, and entrance variants correlated at $\rho = 0.89\text{--}0.94$, and within the driving-based gravity measures, correlations ranged from $\rho = 0.70\text{--}0.91$. This indicates that once travel mode and model type are held constant, the choice of destination representation (centroid, edge, or entrance) has a comparatively modest effect on the ranking of block groups.

The agreement weakened substantially when travel mode was allowed to vary within the same model type. Walking- and driving-based network measures correlated only weakly with one another ($\rho = 0.28\text{--}0.44$), indicating that travel mode, rather than destination representation, is the primary source of divergence among the network-based measures.

The weakest correlations overall occurred between the statistical measures and the walking-based network measure for the entrance variant ($\rho = 0.14\text{--}0.17$), the lowest values in the matrix. Gravity-based driving measures showed comparatively stronger agreement with the statistical measures ($\rho = 0.55\text{--}0.71$) than their walking-based counterparts ($\rho = 0.29\text{--}0.47$) did. This pattern shows that statistical measures can give very different results from measures based on real travel routes, especially for walking. The size of this difference also depends on the travel mode (walking or driving) and the accessibility method being compared.

Overall, these results show that the fourteen accessibility measures do not produce the same results. The choice of method, especially whether walking or driving is used, changes which block groups are identified as having the highest or lowest park accessibility. This highlights the importance of comparing accessibility measures that consider different travel modes and destination representations, as done in this study.

Table 2. Spearman Rank Correlation Matrix

	Stat: Park % of BG area	Stat: Park m2 per capita	Net: Walk-Centroid	Net: Walk-Edge	Net: Walk-Entrance	Net: Drive-Centroid	Net: Drive-Edge	Net: Drive-Entrance	Grav: Walk-Centroid	Grav: Walk-Edge	Grav: Walk-Entrance	Grav: Drive-Centroid	Grav: Drive-Edge	Grav: Drive-Entrance
Stat: Park % of BG area	1.00	0.99	0.38	0.37	0.14	0.29	0.30	0.36	0.29	0.46	0.34	0.55	0.66	0.70
Stat: Park m2 per capita	0.99	1.00	0.42	0.40	0.17	0.30	0.31	0.34	0.32	0.47	0.39	0.56	0.68	0.71
Net: Walk-Centroid	0.38	0.42	1.00	0.89	0.77	0.28	0.35	0.31	0.51	0.36	0.52	0.32	0.41	0.38
Net: Walk-Edge	0.37	0.40	0.89	1.00	0.82	0.30	0.36	0.38	0.38	0.40	0.55	0.37	0.39	0.35
Net: Walk-Entrance	0.14	0.17	0.77	0.82	1.00	0.38	0.44	0.42	0.41	0.27	0.56	0.27	0.28	0.16
Net: Drive-Centroid	0.29	0.30	0.28	0.30	0.38	1.00	0.94	0.89	0.20	0.33	0.20	0.28	0.27	0.28
Net: Drive-Edge	0.30	0.31	0.35	0.36	0.44	0.94	1.00	0.92	0.20	0.29	0.28	0.30	0.30	0.27
Net: Drive-Entrance	0.36	0.34	0.31	0.38	0.42	0.89	0.92	1.00	0.20	0.39	0.31	0.32	0.27	0.30
Grav: Walk-Centroid	0.29	0.32	0.51	0.38	0.41	0.20	0.20	0.20	1.00	0.53	0.39	0.40	0.32	0.27
Grav: Walk-Edge	0.46	0.47	0.36	0.40	0.27	0.33	0.29	0.39	0.53	1.00	0.45	0.48	0.50	0.42
Grav: Walk-Entrance	0.34	0.39	0.52	0.55	0.56	0.20	0.28	0.31	0.39	0.45	1.00	0.40	0.31	0.26
Grav: Drive-Centroid	0.55	0.56	0.32	0.37	0.27	0.28	0.30	0.32	0.40	0.48	0.40	1.00	0.78	0.70
Grav: Drive-Edge	0.66	0.68	0.41	0.39	0.28	0.27	0.30	0.27	0.32	0.50	0.31	0.78	1.00	0.91
Grav: Drive-Entrance	0.70	0.71	0.38	0.35	0.16	0.28	0.27	0.30	0.27	0.42	0.26	0.70	0.91	1.00

Notes:

- Values are Spearman's rho, computed across all 43 census block groups.
- Stat = statistical accessibility (park area / per-capita supply); Net = network-based service-area accessibility; Grav = gravity-based accessibility; BG= block group.
- Walk = 1 km walking threshold; Drive = 5 km driving threshold.
- Centroid/edge/entrance = park destination representation (centroid, edge point, entrance point).
- Green color = strong agreement near +1, yellow color = weak/no relationship near 0.

7. Discussions

7.1. Low-Supply, Automobile-Dependent Cities as a Distinct Accessibility Context

Before comparing the three methods in detail, it is necessary to state explicitly why a low-park-supply, automobile-dependent city constitutes a different analytical setting rather than a smaller-scale version of the well-supplied, pedestrian-oriented cities that dominate the accessibility literature. Existing comparative work, including Wang, Wang, and Liu's (2021) study of Ipswich and Enschede, was conducted in cities with dense, evenly distributed park networks and mature pedestrian infrastructure. Under those conditions, two assumptions embedded in standard accessibility methods generally hold: first, that park supply varies enough across space to produce meaningful differentiation between census block groups; and second, that distance decay operates consistently under a single dominant travel mode, typically walking. Quincy violates both conditions simultaneously. Park supply is sparse and unevenly distributed relative to the population base, and travel is split between a limited pedestrian network and a road network that overwhelmingly favors driving. This combination produces a different accessibility regime rather than a scaled-down version of the same one. With few parks, small differences in individual park size or location come to dominate supply-sensitive measures, while the shift toward driving collapses distance decay across most of the study area, making mode itself a primary driver of accessibility rather than a secondary refinement. Treating Quincy simply as a smaller or less-developed Ipswich would overlook important differences in accessibility, as the results show that the methods respond differently when park supply is limited, and driving is the dominant travel mode.

7.2. Evaluating methodological approaches to measuring park accessibility

Each analytical approach produces spatially distinct accessibility patterns and captures a different conceptual dimension of access, demonstrating that methodological choices carry direct consequences for planning outcomes. The statistical approach, operationalized through park percentage and park area per capita, offers a computationally efficient baseline of parkland distribution, with northern, western, and some eastern areas exhibiting relatively higher provision due to greater coverage or lower population densities. These measures serve as useful first-order equity indicators but are structurally constrained by their reliance on fixed administrative boundaries. By assuming residents access only parks within their own block group, they systematically underestimate accessibility where adjacent park provision is high and overestimate it where parks are nominally present but physically disconnected

from the road network. Statistical measures are therefore best understood as indicators of supply distribution rather than realized access and must be complemented by travel-informed approaches in applied planning contexts.

The network-based approach advances measurement realism by grounding travel in actual road network structure and differentiating access by mode and distance threshold. Under the 1 km walking threshold, accessibility is concentrated in a limited set of west-central, northern, and southwestern areas. In contrast, large peripheral and eastern areas exhibit little to no walkable access, reflecting both uneven park distribution and pedestrian infrastructure gaps. Under the 5 km driving threshold, accessibility increases significantly, demonstrating how motorized travel lessens the impact of distance. Network-based measures are consequently less sensitive to administrative boundary delineation and provide a more transferable and interactively valid framework for accessibility assessment. It should be noted, however, that both the network-based and gravity-based analyses use population-weighted block-group centroids. Although this reduces the effects of zone aggregation, they are still not completely free from the modifiable areal unit problem (MAUP), because the choice of block-group boundaries can influence the estimated travel distances and gravity scores.

In contrast to the other two methods, the gravity-based technique assesses accessibility by accounting for park size, population demand, and distance. Under the walking threshold, values are low and spatially fragmented, concentrated near larger parks, reflecting strong distance decay that makes the measure more sensitive to park size than to network connectivity. Under the driving threshold, accessibility is redistributed instead of increasing uniformly over all locations. The entrance-based gravity access produces more geographically differentiated patterns, though the model's structural sensitivity to park size and population magnitude limits its general applicability. Large parks can have too much influence on the results, even if they are not well-connected by roads. At the same time, areas with high population density can affect accessibility scores, even though park resources are shared among many users. The gravity approach is most appropriately deployed to evaluate supply–demand balance or service capacity, serving as a complement to, rather than a substitute for, network-based measures.

This study confirms that transport mode and distance threshold exert a stronger influence on accessibility patterns than the choice of destination point, consistent with prior comparative work. This is clearly shown by the pairwise rank-correlation analysis (Table 2): measures sharing both travel mode and model type correlated strongly ($\rho = 0.89\text{--}0.94$ for driving-based network measures; $\rho = 0.70\text{--}0.91$ for driving-based gravity measures), whereas measures that shared a model type but differed in travel mode agreed only weakly ($\rho = 0.28\text{--}0.44$ between walking-

and driving-based network measures). Destination representation, therefore, accounts for comparatively little of the divergence among measures relative to travel mode. However, an important difference emerges in how the gravity-based measure responds to low park supply. In Ipswich, where parks are numerous and well-distributed, gravity indices produced spatially coherent zones of high accessibility because supply variation across the study area was large enough to generate stable, interpretable gradients (Wang, Wang, and Liu 2021). In Quincy, the same model produces fragmented, park-size-driven patterns that do not correspond to any coherent underlying spatial structure. This is not a case of the gravity model performing somewhat worse in a harder environment. It reveals a boundary condition in the method itself. The gravity model works best when there is enough variation in park supply across space. When park supply is uniformly low, the model can exaggerate small differences in park size or nearby population, creating accessibility "hot spots" that may not reflect actual access conditions. A similar issue affects the statistical approach. Its reliability depends on having enough parks within each area so that errors related to a single park have only a limited impact. In low-supply settings, however, one park can significantly change an area's accessibility classification. These findings suggest that supply-sensitive methods are not simply less effective in such contexts; rather, they rely on conditions that low-supply, automobile-dependent cities often do not meet. By contrast, network-based measures are less affected because they depend primarily on transportation connectivity rather than the density of park supply.

7.3. Identifying the representation theoretically most consistent with everyday park access

One of the key elements influencing accessibility is the mode of transportation. Walking is constrained by pedestrian infrastructure and limited to short distances. Accessibility is still low in many areas of Quincy under the 1 km criterion, indicating gaps in park distribution and pedestrian network coverage. Driving, on the other hand, makes a lot more parks accessible and lowers distance barriers. This disparity has significant implications for equity for those without private vehicles, including children, the elderly, and low-income households, who are restricted to considerably smaller, walkable regions. Walkable accessibility thus becomes particularly crucial for planning regulations intended to assist vulnerable populations. Distance thresholds are inseparably linked to mode and must reflect empirically reasonable travel behavior. The 1 km walking threshold aligns with WHO guidance on access to green space within an 8- to 10-minute walk (OECD 2014). The 5 km driving threshold reflects short automotive trips in a compact city (Wang, Wang, and Liu 2021). Because the driving threshold was set deliberately high relative to the city's extent, its purpose is to establish an upper bound on automobile-based access rather than to resolve fine-

grained spatial variation in driving accessibility. The absence of such variation is therefore expected and does not undermine the walking–driving comparison, which is the analytically meaningful contrast in a compact, low-supply city. When using a driving criterion for pedestrian analysis, travel difficulty is misrepresented, which can result in misleading conclusions about equity.

Defining park destinations as entrance points produces measurable improvements in accessibility realism. Large or uneven parks may have centroids that are far from any road, which causes accessibility scores to drop and trip distances to be overestimated. Edge points distribute destinations around the perimeter, but treat all boundary locations as accessible regardless of road connectivity. In Quincy, these limitations are empirically evident. Centroid-based measures undercount reachable parks, while edge-based measures distribute accessibility without regard for whether access points are functional. Entrance-based measures, defined as network-to-boundary intersections within a 20 m buffer, corresponding to gates, formal pathways, and parking access points, identify where people actually enter parks. The findings demonstrate that entrance-based measurements produce more internally consistent accessibility patterns, which are theoretically more likely to approximate real access conditions. In the walking scenario, where the precise location of access points has a significant impact on distance calculations, the improvement is particularly evident. In general, network-based approaches outperform statistical and gravity-based ones, while entrance-based network measures outperform edge- and centroid-based techniques. This highlights the need to go beyond boundary-based measures and employ strategies that more accurately represent how people truly access parks, particularly when it comes to organizing equitable and efficient investments.

Beyond the choice of destination, these findings reveal a broader pattern that characterizes low-supply, automobile-dependent cities. In well-supplied, pedestrian-oriented settings, most residents can access a similar set of parks regardless of travel mode, making mode a secondary influence on accessibility. In Quincy, however, accessibility depends less on proximity to the nearest park and more on whether residents have access to a car. Driving does not simply increase the number of reachable parks; it fundamentally changes which parks are realistically accessible. As a result, the difference between walking and driving accessibility is qualitative rather than merely quantitative. This has important equity implications. Children, older adults, and low-income households without private vehicles are not experiencing a reduced version of the accessibility available to drivers; instead, they face a much more limited set of park opportunities. Consequently, accessibility measures developed in cities where travel mode plays a

secondary role may underestimate the importance of transportation choice in low-supply, automobile-dependent cities, where access to a vehicle is often a prerequisite for meaningful park access.

8. Conclusion

Urban park accessibility measurement is highly sensitive to methodological choices, including the analytical framework, transport mode, distance threshold, and destination representation. Different choices can produce substantially different results even when applied to the same underlying spatial data. This was confirmed by the pairwise rank-correlation analysis, which showed that measures agree closely when travel mode is held constant but diverge sharply when it varies, identifying travel mode as the dominant source of disagreement among the 14 measures. This sensitivity is not consistent across urban contexts, however. Although the gravity-based approach accounts for supply, demand, and distance, its performance depends on having sufficient variation in park supply across space. In low-supply, automobile-dependent cities, where this condition is not met, the method can produce fragmented and unstable patterns that may not reflect actual accessibility. The statistical approach faces a similar limitation because its reliability depends on having enough parks within each spatial unit so that individual omissions or classification errors do not disproportionately affect the results. By contrast, the network-based approach, particularly when using park entrances as destinations, is more robust because it relies on transportation connectivity rather than the density of park supply. It also more closely reflects how residents actually access parks in this setting.

These findings suggest a broader guideline that extends beyond Quincy. In cities with limited park supply and high automobile dependence, network-based, mode-specific, entrance-based measures should be the primary tool for identifying underserved areas. Gravity-based measures remain valuable, but are better suited to assessing supply–demand imbalances than to representing realized accessibility. This recommendation is likely applicable to many mid-sized, car-dependent U.S. cities that share Quincy's combination of sparse park provision and incomplete pedestrian infrastructure, a type of urban environment that remains underrepresented in the accessibility literature compared with the dense, pedestrian-oriented cities that have been the focus of most previous studies.

Beyond methodological implications, the identified spatial disparities have significant implications for urban planning. Eastern and peripheral neighborhoods with persistently low walking-distance accessibility represent the most acute areas of need and should be prioritized for new park development or targeted pedestrian infrastructure

investment. Notably, the entrance-based analysis reveals that some parks in underserved areas are nominally present but functionally disconnected from the road network. Improving entrance connectivity through formal access paths, signage, or parking provision could produce meaningful gains at a lower cost than new construction. The analysis is cross-sectional and cannot account for temporal variability in park use, time-of-day network fluctuations, or population shifts. As a result, it might not accurately depict how accessibility varies over time or under various daily and seasonal circumstances. Also, only walking and driving (specifically for cars) are modeled, excluding public transit modes critical for transit-dependent and low-income populations. The driving threshold was set at 5 km based on previous research and was not varied in this study. Because Quincy is relatively compact, a 5 km driving distance can reach most of the city. Therefore, the driving-access results should be viewed as representing near-maximum automobile access rather than a detailed measure of spatial differences in driving accessibility. Future studies could examine a range of driving distances to explore how quickly the gap between walking and driving access narrows, but this was beyond the scope of the current analysis.

A further limitation concerns the structure of the gravity-based measure itself. Because census block group population enters the model as a numerator term rather than as a competition-based denominator, the resulting scores partly reflect local population size rather than purely reflecting proximity to park supply. This is a recognized property of gravity-based accessibility models more broadly (Wang 2012) and is consistent with the pattern observed in Section 7, where gravity scores in Quincy were sensitive to population magnitude as well as park size. Future work could adopt a two-step floating catchment area approach (Luo and Wang 2003), in which population functions as a demand-competition term at the destination rather than a multiplier at the origin, to more cleanly isolate per-capita accessibility from aggregate demand exposure.

Future research should extend the framework to include transit-based and multi-modal routing, time-sensitive travel impedance, and socioeconomic variables, such as car ownership, age, and income, to enable an explicit environmental justice analysis. The evidence base for more equitable planning decisions would be strengthened by longitudinal analysis that connects changes in land use and infrastructure investments to changes in accessibility. Planners can better understand the forces behind accessibility advancements and enduring gaps by looking at how accessibility changes over time in response to new roadways, enhanced pedestrian networks, or shifting urban development patterns. In a broader sense, this study emphasizes the need for methodological transparency in generating reliable and useful accessibility research.

This study examines only geographical accessibility based on the geographic distribution of urban parks; it does not account for social, cultural, or economic aspects. Future studies should take a more comprehensive approach, considering factors such as park types, user perceptions, affordability, and service capacity. The multifaceted nature of park accessibility would be better captured by combining GIS analysis with social survey data.

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Clinical Trial Number

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Ethics, Consent to Participate, and Consent to Publish

Ethics, Consent to Participate, and Consent to Publish declarations: not applicable.

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