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Original article

Access for whom? Inequality and inequity in multi-modal accessibility to large parks

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ABSTRACT

Large parks provide vital health, social, and environmental benefits, especially for low-income populations who face disproportionate exposure to environmental stressors and health challenges. While research has explored park access inequalities through walking and driving, less is known about access variations across different transport modes considering common travel sequences and shared mobility options. This study examines multi-modal accessibility to 58 large parks in Metro Vancouver, Canada, focusing on both spatial patterns of accessibility and underlying socioeconomic inequities. Using data from 3590 neighborhoods, we assess park accessibility through minimum distance, cumulative opportunities, and gravity models. Our findings reveal that driving provides the most equitable access distribution, while alternative modes, particularly shared mobility, show higher inequality and favor wealthier populations. The advanced gravity models accounting for travel time and park quality exposes greater disparities in shared mobility access compared to traditional approaches. These findings highlight the need for urban planners and policymakers to consider multimodal and equity-based approaches in green space planning. Ensuring that new and emerging transport options support rather than hinder equitable park access is critical for promoting inclusive urban environments and advancing environmental justice.

1. Introduction

Access to large parks and natural areas is critical for urban residents due to their role in delivering health, social, and environmental benefits. These spaces serve provide important ecosystem services such as air purification and urban heat mitigation (Bowler et al., 2010; Chang et al., 2007). They also attract longer visits and serve as hubs for physical activity, mental health restoration, and community engagement (Brown et al., 2014; Jansen et al., 2017; Wood et al., 2017). For low-income communities, who often lack access to private green spaces and recreational facilities, public parks serve as their primary venues for recreation and wellbeing (Huang et al., 2020; Abercrombie et al., 2008). These communities also face higher rates of chronic disease and psychological stress and are disproportionately exposed to urban environmental burdens such as air and noise pollution and extreme heat (Cohen et al., 2016; Wolch et al., 2014; Rigolon & Browning, 2021). This disparity is a core concern of environmental justice, which emphasizes the fair distribution of environmental benefits and burdens and the right of all communities to live in healthy, safe, and attractive environments (Bullard, 1993; Schlosberg, 2007). Therefore, disparities in park accessibility represent not only a planning challenge but also a pressing environmental and health equity issue.

Transportation systems play a crucial role in determining access to parks. In many urban areas, car-centric infrastructure dominates, creating a paradox: those who could benefit most from large parks often face the greatest barriers to reaching them due to lower vehicle ownership rates and limited transportation alternatives (Rigolon, 2016; Park et al., 2021; Byrne et al., 2009). This challenge is particularly acute for low-income communities, who predominantly rely on more affordable active transportation methods such as walking, cycling, and public transit, with constrained personal vehicle access (Glaeser et al., 2008; Yu, 2014). Addressing this inequity requires the development of robust multi-modal transportation networks that integrate public transit, cycling infrastructure, and shared mobility options. Such networks can reduce accessibility barriers, providing affordable and sustainable alternatives to car ownership while advancing goals of environmental

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justice and social inclusion (Chan et al., 2023; Park et al., 2021; Rigolon, 2016).

Quantifying and comparing levels of park accessibility across different transportation modes is a critical step in addressing these challenges. Accessibility evaluation methods in urban planning have relied on place-based approaches that assess the ease of reaching opportunities within defined spatial units (Delafontaine et al., 2012). Among these, the minimum distance method calculates travel cost or time to the closest destination, and cumulative opportunity methods measure the number of all accessible parks within a given time threshold (El-Geneidy & Levinson, 2006; Kelobonye et al., 2020). The gravity model accounts for both park attractiveness and distance decay, assuming accessibility decreases with distance but increases with higher demand at the origin and greater supply at the destination (Zhang et al., 2011; Wang et al., 2021).

Recent models such as the multi-modal network-based 2SFCA (MMN-2SFCA) method remain limited in their capacity to reflect ordered travel chains or incorporate shared mobility systems beyond first- and last-mile segments (Zhang et al., 2024). While efforts have been made to incorporate multi-modal travel through various advanced gravity models (e.g., floating catchment method variants), current approaches often omit these access and transfer stages and fail to reflect the complexity of real-world travel behavior by capturing the full sequence of mode transitions (Xing et al., 2018; Zhang et al., 2024; Oeschger et al., 2020). This study introduces a network-based trip-chain modeling framework that embeds logical mode sequences and transfer points within a multimodal network, enabling more behaviorally realistic evaluations of park accessibility.

Three critical gaps exist in current park accessibility research. First, despite growing recognition of multi-modal travel behaviour, most studies evaluate accessibility either through single travel modes, or creating integrated indices based on mode share data from surveys (Xing et al., 2018; Tao et al., 2020; Li et al., 2021; Zhang et al., 2024). This simplified approach fails to capture the complex trip chains considering common travel sequences and characterize actual park access patterns (e.g., transfer among different modes). Second, while shared mobility services (e.g., bikeshare and carshare) represent potentially transformative solutions for expanding park access, their role remains largely unexamined in accessibility literature. Third, existing research has focused primarily on neighborhood parks, neglecting large parks that serve broader populations and offer distinct recreational, cultural, and environmental benefits unattainable through smaller urban green spaces (Veitch et al., 2015; Czerniak et al., 2007; Markevych et al., 2017). This study is among the first to incorporate complex trip chains for shared mobility and transit access to large parks, including access/egress segments (e.g., walking to bikeshare and carshare stations) that reflect actual travel behaviour, rather than treating these as single-mode trips.

This study aims to evaluate the spatial and socioeconomic dimensions of multi-modal accessibility to large parks in Metro Vancouver, BC, Canada. We ask: (1) How does neighborhood-level accessibility to large parks vary across five transportation modes: driving, transit, biking, bikeshare, and carshare? (2) How do transportation modes differ in reinforcing or mitigating income-based inequities in large park access? By employing three place-based methods—minimum distance, cumulative opportunities, and gravity models—across five travel modes, we also show how methodological choices can alter equity conclusions, revealing, for example, that the apparent 'equity' in driving access can mask substantial exclusions (Hwang et al., 2025).

Applying this framework to large parks, we provide empirical evidence in a North American context of how shared mobility services affect park accessibility equity. Our results reveal that these services, often seen as democratizing technologies, may instead exacerbate inequalities. This framework is replicable to other types of destinations (e.g., workplace, hospitals, retails) and can be applied in other metropolitan areas to assess spatial equality and income-based equity across multiple travel modes.

2. Material and methods

2.1. Study area

Metro Vancouver, officially known as the Metro Vancouver Regional District (MVRD), is a governing body responsible for regional services and park management for 21 municipalities, one electoral area, and one Treaty First Nation within the Greater Vancouver area of British Columbia, Canada. It operates under the direction of 23 local authorities and serves a population of approximately 2.8 million residents. Metro Vancouver's regional parks experienced a 37 % increase in visitors between 2019 and 2021, reaching 16.3 million visits (Metro Vancouver Regional Parks, 2022). Automobile use dominates travel to these parks, with 74 % of visitors opting to drive, compared to 14 % walking, 9 % choosing cycling, and 3 % relying on public transit (Metro Vancouver, 2019). Metro Vancouver was selected as the study area to examine inequities in park accessibility across multiple transportation modes due to its extensive green spaces, diverse transportation infrastructure, and varied socio-economic composition.

This project focuses on large parks in Metro Vancouver (Fig. 1). We screened all publicly accessible urban green spaces located within the Metro Vancouver Urban Containment Area. The primary criterion for inclusion was size, with a minimum threshold of 30 ha. Green spaces designated as nature reserves or with large areas lacking public access were excluded. As stated in the Introduction, large parks tend to attract longer visits and function as significant hubs for both physical activity and social interaction (Brown et al., 2014; Jansen et al., 2017; Wood et al., 2017). This distinguishes them from smaller green spaces such as parklets, community gardens, and fragmented informal greeneries, which often offer limited ecosystem services, support more localized and short-duration use, and provide fewer recreational opportunities. Our final sample includes 58 parks: 5 provincial parks (managed by BC Parks), 22 regional parks (managed by Metro Vancouver), and 31 local parks (managed by municipalities). Details such as park size, number of entrances, and functional descriptions are provided in Appendix I.

Socio-economic disparities in Metro Vancouver underscore the equity challenges in park accessibility. Median household income, as used in Metro Vancouver's Social Equity and Regional Growth Study (2021), serves as a key indicator for evaluating and comparing economic well-being and living standards across neighborhoods. Among 3590 Dissemination Areas (DA) within Metro Vancouver Urban Containment Area, the average of the median household income is $99, 701 in 2021, ranging from $23,200 to $260,000 (Metro Vancouver, 2021). On average, 17 % of residents in each are classified as low-income, with poverty rates reaching as high as 66 % in certain neighborhoods (Metro Vancouver, 2021). Fig. 2 shows that low-income communities are concentrated around urban areas such as Vancouver East (center on the map), Richmond City Centre (south), Coquitlam City Centre (east), and Surrey City Centre (southeast). These geographic disparities, coupled with the region's heavy reliance on automobile travel for park access, raise critical equity concerns.

2.2. Data sources and processing

2.2.1. Data sources

Table 1 shows the key data categories and sources, including transportation network (car, transit, cycling, walking, bikeshare, and carshare), park locations and entrances, and neighborhood environment (location, socio-demographic information). Public transit refers to scheduled public transportation services, including buses, rail-based systems (SkyTrain), and ferries. Bikeshare refers to city bike systems where users can rent a bicycle through a mobile app for short periods and return it to designated stations. Carshare refers to short-term car rental services that allow users to access and return vehicles within predefined service areas, also typically managed through an app. These shared mobility services operate at different geographic scales, with

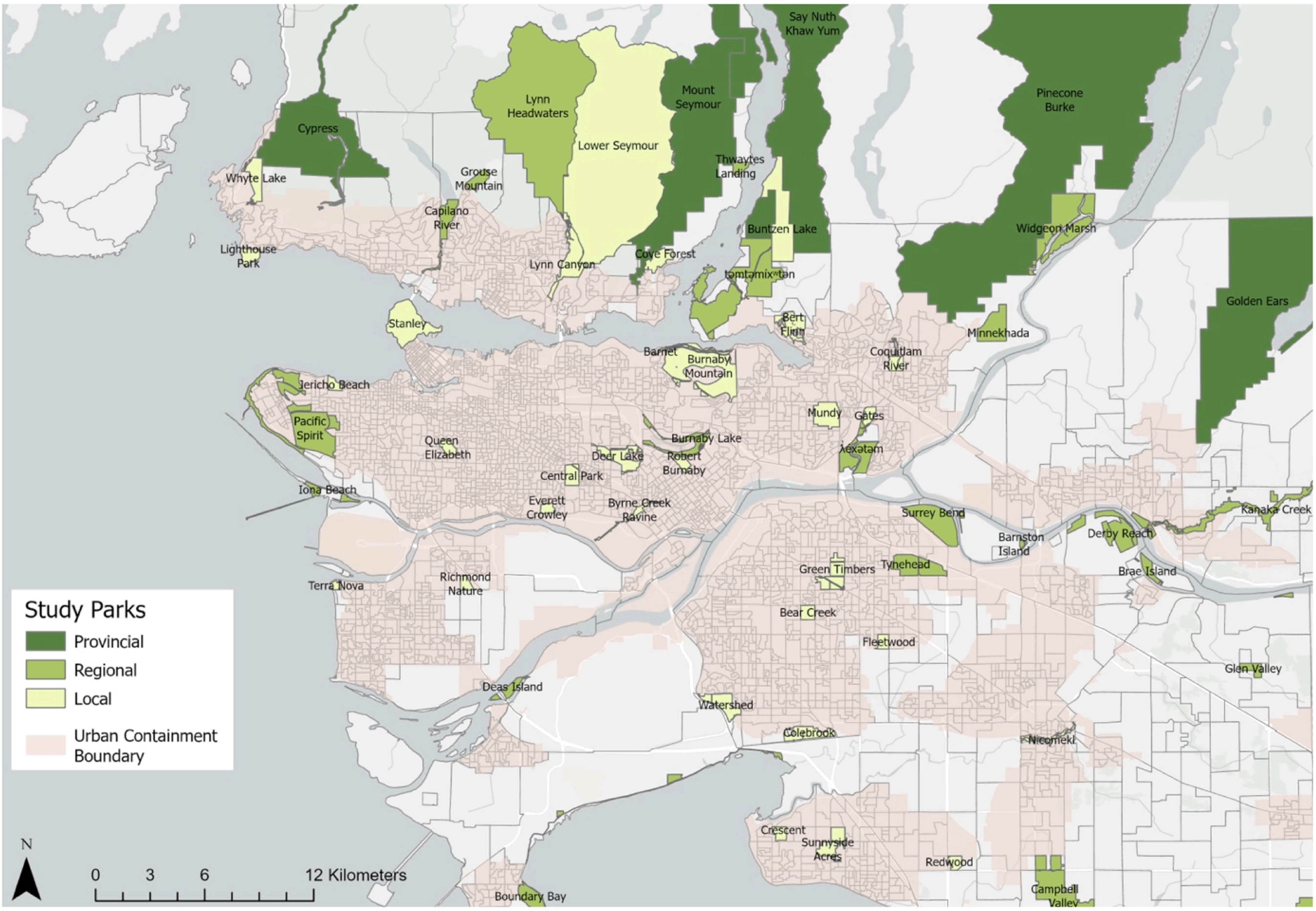

Fig. 1. Map of study parks.

some available regionally and others limited to specific cities (See Appendix II for service area of shared mobility). We used publicly available data and other spatial data provided by TransLink (the regional transportation authority), Metro Vancouver Regional District (MVRD), Provincial Government of British Columbia, Statistics Canada, and shared-mobility service providers (carshare: Evo, Modo; bikeshare: Lime, Mobi). Road centrelines and cycling and sidewalk networks are from OpenStreetMap (OSM), which we cross-validated against Google Maps and up-to-date transportation network data by regional and municipal government data to ensure data accuracy. In addition, our model allowed pedestrians to travel along roads when sidewalks were absent, which helps mitigate most routing issues associated with some incomplete data from OSM.

2.2.2. Network configuration for different modes and trip-chain scenarios

To simulate park access under realistic urban travel conditions, we constructed a multimodal network incorporating driving, biking, walking, transit, bikeshare, and carshare modes. Road network data were derived from OpenStreetMap, with traversable segments filtered by mode permissions. Mode-specific average travel speeds were assigned based on local traffic rules and urban norms (Table 2), with empirical support from Hassanpour & Bigazzi (2024) and Do et al. (2018). This base network was integrated with public transit routes and extended to include carshare and bikeshare systems by geolocating designated service stations, where users can enter and exit the respective systems. In this network dataset, the bikeshare system performs like a transit system while the bikeshare stations perform like bus stops.

Five trip-chain scenarios were constructed based on data availability, network integration feasibility, and behavioral plausibility, and mode share patterns observed in the Metro Vancouver Regional Parks Visitor Survey (Metro Vancouver, 2019). Each trip chains represents a distinct, realistic travel sequence used to access regional parks. We first included three individual modes most used by large park users, driving, biking, transit (Metro Vancouver, 2019). We excluded walking for this study because large regional parks are often located in remote areas which makes walking less practical (Gu et al., 2017). To capture emerging mobility options not represented in the travel survey, we also developed carshare and bikeshare scenarios by enabling a walking segment before and after. Referencing one of five transit-integrated bike trip chains identified by Lee et al. (2016), we constructed a bikeshare-to-park scenario that begins with walking, may include transit, and concludes with bikeshare. This scenario reflects observed patterns of bikeshare use for park access and recreation (Guo et al., 2022; Lee & Noland, 2021; Kim et al., 2012). Compared to traditional methods such as 2SFCA, which either assume single-mode travel or aggregate multiple modes post-analysis (Hu et al., 2020; Mao et al., 2023), this approach allows for integrated, continuous evaluation of trip chains with embedded sequencing and transfer logic. It also improves upon existing shared mobility models that typically only simulate access around docking stations or hubs (Oeschger et al., 2020).

To model multimodal trips involving bikeshare or carshare, we implemented a structured cost matrix-based approach in ArcGIS Pro that allows for automatic cost evaluator switching between walking, transit, and bikeshare or carshare. Given the complexity of this three-mode configuration, several restrictions were encoded into the network to preserve logical flow. Bikeshare cannot precede transit, ensuring shared micromobility functions as an end-leg solution rather than a feeder to major public transport. In suburban and rural contexts where direct

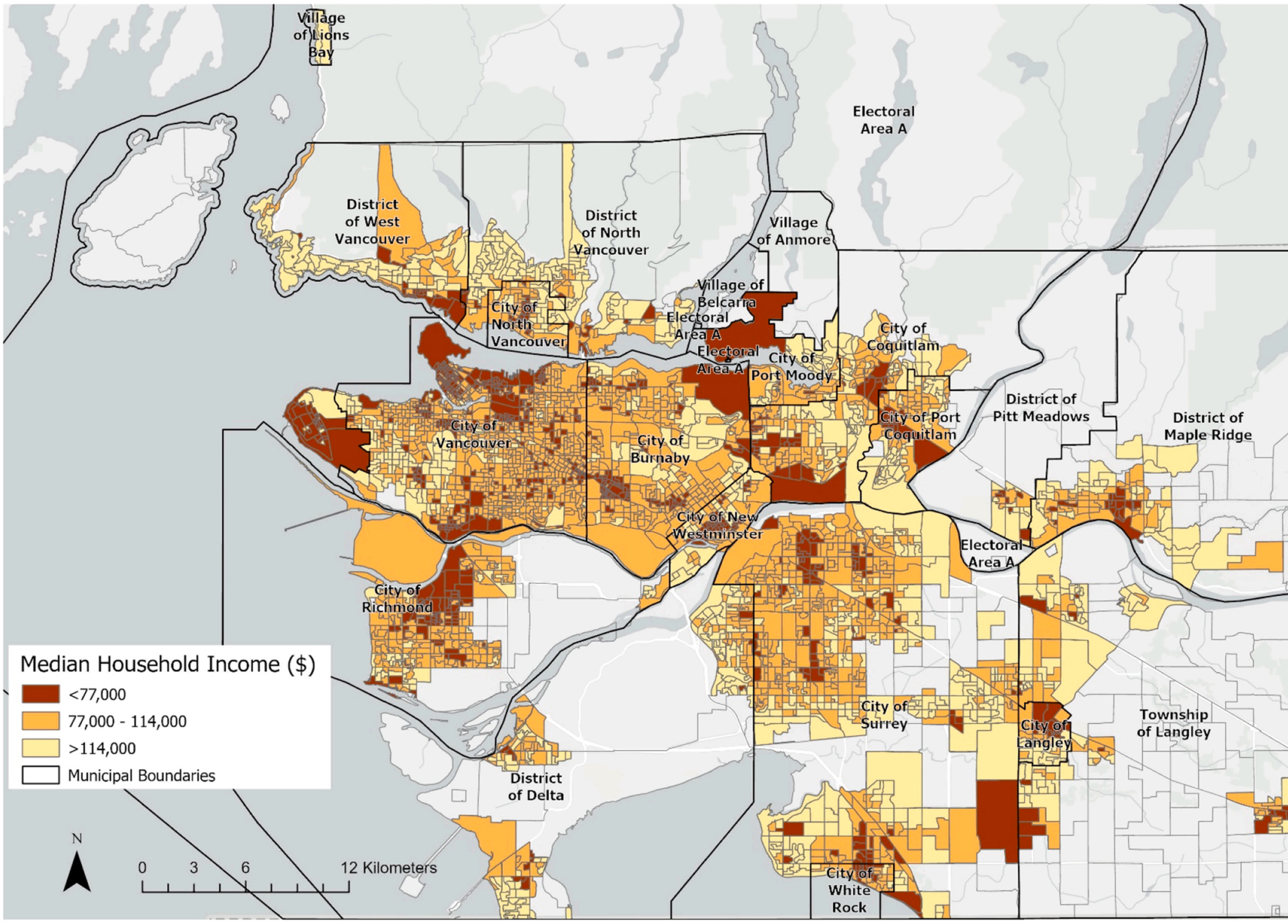

Fig. 2. Map showing distribution of median household income (in Canadian dollar) in Metro Vancouver.

walking provides shorter travel times to parks, the model prioritizes walking over bikeshare. Transfers between modes are permitted only at designated service stations, and the model automatically identifies the least-cost station pair to minimize total travel time. These constraints collectively ensure that the simulated trip chains closely approximate real-world multimodal travel behavior while maintaining internal consistency and analytical rigor.

2.2.3. Park accessibility measures

To measure accessibility to parks, three methods were used via ArcGIS Pro, including minimum distance method, cumulative opportunities, and gravity model with park quality. Following Geurs and van Wee's (2004) framework, this study focuses three components of accessibility: land use (parks and neighborhoods), transportation (multiple modes and scenarios), and individual (indirectly for aggregate-level neighborhood socio-demographics). As stated in previous section, each method is applied to five common travel scenarios by park visitors in the study region justified in previous section: driving, biking, transit (involving walking), carshare (involving walking), and bikeshare (involving walking and if necessary, transit). Population-weighted centroids of Dissemination Areas (DAs) were used as origin points. Rather than using park shape centroids to represent destinations, we identified 628 park entrances across 58 study parks, using regional government datasets and manually digitized entrance locations in ArcGIS based on official park maps, validated with Google Street View (see Table 1 and Appendix I for more details).

2.2.3.1. Minimum distance method. The minimum distance method measures the travel time from each neighborhood (DA centroids) to the nearest park entrance via each transportation mode. The outcome provides the shortest travel time (in minutes) to the closet park. We use the "closest facility analysis" tool in ArcGIS Pro to compute the trip chains of each DA-Park entrance pair.

2.2.3.2. Cumulative opportunities. The cumulative opportunities method accounts for the cumulative effects of accessing multiple regional parks within selected time thresholds. Using the "OD cost matrix analysis" tool in ArcGIS Pro, the results of each OD pair is generated with a 60 min cutoff. The "summary statistics" tool is then used to count the number of parks accessible, via the five selected travel modes at 15-, 30-, 45-, and 60-min thresholds, from each DA. Careful consideration of threshold values is essential, as destinations beyond the predetermined range are considered completely inaccessible (Fang et al., 2025). Therefore, through the sensitivity analysis with inequity measures at different time cutoffs (see Appendix III), we choose the 45-min scenario to represent the accessibility via cumulative opportunities method.

2.2.3.3. Gravity model with park quality. The gravity model method incorporates supply and demand factors into travel time analysis. It is useful as it considers both the attractiveness of a destination and the ease of access, allowing for a more nuanced understanding of how different populations might interact with multiple regional parks. The gravity model equation is presented below.

$$M2P\_mode(a)_i = \sum_{j=1}^{n} C_j d_{ij}^{-\beta}$$

where $M2P\_mode(a)_i$ indicates the DA i's regional park accessibility

Table 1
Data types and sources.

Data	Description	Source
Transportation		
Road Network	Metro Vancouver's Road network, with information such as street names, types, speed limits, and lane widths	OpenStreetMap
Cycling Network	Metro Vancouver's cycling network, with information such as route name, facility type, and paving/surface type	OpenStreetMap
Sidewalk Network	Metro Vancouver's sidewalk network	OpenStreetMap
GTFS	The public transit data from TransLink, with information such as transit routes, stops, and schedules	TransLink
Bikeshare Stations	The service locations of bikeshare systems, though the availability of bikes in these locations is not guaranteed	Lime & Mobi
Carshare Stations	The service locations of carshare systems, though the availability of vehicles in these locations is not guaranteed	Evo & Modo
Destinations (Parks)		
Regional Parks	The boundaries of Metro Vancouver Regional Parks	MVRD
Provincial Parks	The boundaries of BC Provincial Parks	Government of British Columbia
Local and Regional Greenspaces	Greenspaces in BC, differentiated by its primary use such as park, trail, and playground	Government of British Columbia
Park Entrances	A total of 628 entrances for 58 parks. 151 entrances provided by MVRD. Others digitized manually based on official park-level map data and intersection between major roads (validated by Google Streetview).	MVRD and official park maps
Origins (Places of Residency) and Administrative Boundaries		
Census Dissemination Areas	The geographic boundaries and representative points (population-weighted centroids) of Canada's dissemination areas, containing sociodemographic information	Statistics Canada
Administrative Boundaries	The administrative boundary of Dissemination Areas and the Urban Containment boundary of the Metro Vancouver Regional District	MVRD
Income level	Median household income (in Canadian dollar) is the median total income for households within a census unit, used in the Social Equity & Regional Growth Study (Metro Vancouver, 2021).	MVRD

Table 2
Travel mode and corresponding speed used in analysis.

Driving and carshare		Biking and bikeshare		Walking	
Highways	70 km/h	Bikeways	15 km/h	Roads	4 km/h
Arterials	40 km/h	Roads	10 km/h	Sidewalks	4 km/h
Residential Streets	30 km/h	Sidewalks	4 km/h		

for mode a (e.g., transit, bike); C_j is the quality index of the park j, which is set as its Google Review Star Rating value multiplied by the logarithmic function of its number of reviews (See Appendix I for the quality index for each park); and d_{ij}^{β} is the travel time (in minutes) via mode a between the centroid of the DA i and the entrance point of the park j. β is the travel friction coefficient and is set as 1, similar to previous studies (Park et al., 2021). We tested sensitivity to the distance decay parameter (β=1, 2, and 0.5). In addition, pairwise Pearson correlation coefficients were generated across scenarios per mode at DA-value (see Appendix IV for detailed results). We found minimal variation in inequality measures (Gini coefficient changes of different distance decay $<$0.03 for all modes; high Pearson correlation value), confirming the robustness of our findings.

Our final index values demonstrate the park quality accessible from each DA under a per-minute rate. In other words, the index calculates the travel time to multiple parks, moderated by the visitorships and recreational functions of each park, via the five selected modes of transportation. With a 60 min cutoff, the index values are summed up for all parks within each DA using the "summary statistics" tool.

2.3. Data analysis

This study employs two complementary analytical measures to evaluate the spatial and socioeconomic dimensions of park accessibility, focusing on equality and equity.

Equality focuses on the uniform distribution of accessibility benefits across the entire population, ensuring everyone has similar levels of access. Equity, on the other hand, addresses the need to prioritize disadvantaged groups by accounting for socioeconomic disparities and allocating resources based on varying levels of need (Hwang et al., 2025).

The Lorenz curve and Gini coefficient have been extensively used to measure transportation equality, evaluating how accessibility benefits are distributed across populations (Martin & Conway, 2025; Kaplan et al., 2014; Song et al., 2018). These methods align with egalitarian principles—that all individuals deserve equal treatment—by quantifying how evenly resources are distributed (Delbosc & Currie, 2011; van Wee & Mouter, 2021). The Gini Index ranges from 0 (perfect equality) to 1 (maximum inequality). The concentration index (CI) incorporates socioeconomic factors into the measurement of accessibility disparities. The CI evaluates whether accessibility benefits are systematically distributed in favor of or against specific groups based on income, education, or other socioeconomic factors (Chen et al., 2013; Karner et al., 2024). A positive CI suggests that higher-income communities enjoy better access than lower-income counterparts, while a negative CI suggests a pro-poor (i.e., more equitable) distribution. While both the CI and Lorenz curve display cumulative accessibility distribution, the CI distinctively arranges population data by socioeconomic variables, enabling the identification of relationships between accessibility and socioeconomic disparities.

We validated all indices using a DA-level nonparametric bootstrap: resample n = 3590 DAs with replacement, recompute the index, repeat 1000 times, and examine percentile 95 % CIs. The analytic Gini values closely matched the bootstrap point estimates. For example, under the Gravity model results, the absolute differences were small ($\approx$0.003–0.012, $\leq$3.3 % of the estimate): Drive 0.145 vs 0.149, Bike 0.307 vs 0.304, Transit 0.368 vs 0.370, Carshare 0.501 vs 0.506, Bikeshare 0.466 vs 0.474. All analytic estimates lay within their bootstrap 95 % CIs, with modest interval widths (e.g., Drive 0.133–0.168; Carshare 0.493–0.519). Concentration Index estimates showed the same pattern of coverage (e.g., Carshare 0.205 with 95 % CI 0.189–0.220).

Fig. 3 summarizes the methodological workflow of this study. To address the first research question, the Gini index quantifies the equality of park accessibility across the five travel modes, measuring the evenness of accessibility distribution across the regional population. This analysis is visualized through Lorenz curves, which illustrate the deviation of actual accessibility distribution from the line of perfect equality. To address the second question on equity, the CI examines the relationship between accessibility and median household income. Concentration curves plot the cumulative proportion of park accessibility against the cumulative proportion of the population ranked by income values. This allows to identify whether the transportation accessibility systematically favors or disadvantages specific socioeconomic groups.

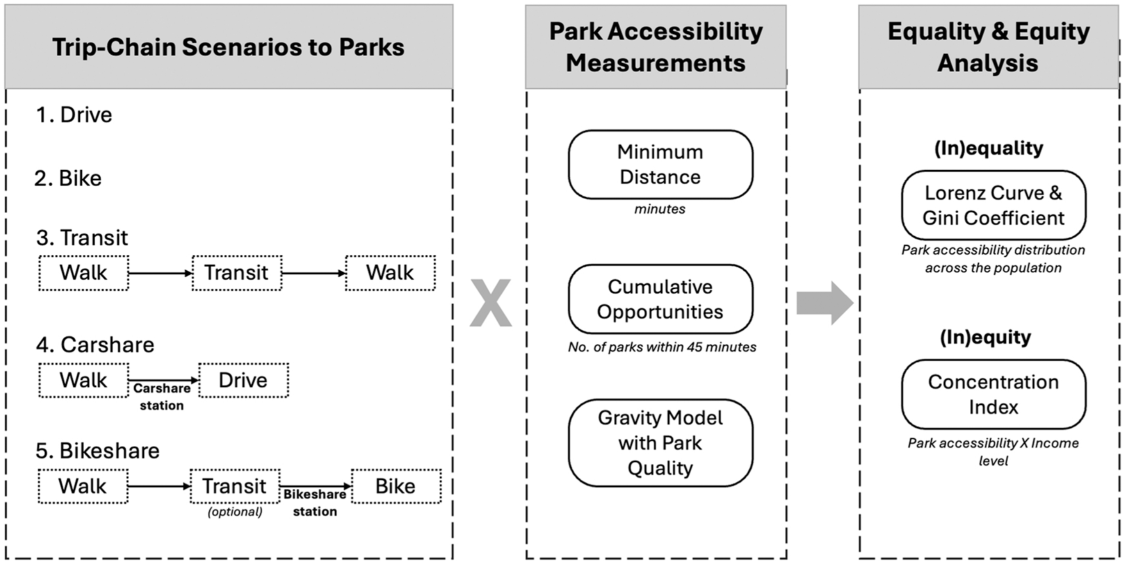

Fig. 3. Methodological workflow.

3. Results

3.1. Multi-modal accessibility to parks

Table 3 shows summary statistics of three park accessibility measures across five travel modes. Driving accessibility to parks is consistently the highest across the three evaluation methods. Using the minimum distance method, the average travel time from DAs to the nearest park is 4.38 min for driving, 13.47 min for biking, and 25.05 min for transit. Using bikeshare to get to a large park takes 30.41 min on average, more than double that of biking, while carshare requires 24.34 min, about six times longer than driving. Both share-mobility options demonstrate significantly lower accessibility scores, mainly due to the gap in service providers in suburban areas.

For the cumulative opportunities method, an average DA can reach 46 parks within 45 min by driving, followed by 23 parks by carshare, 5 parks by biking, 4 parks by transit, and 2 parks by bikeshare (Table 3). These results indicate that the access disparity between private vehicles (driving and carshare) and other alternative modes (biking, transit, and bikeshare) is more pronounced than the differences between driving and carshare or biking and bikeshare, underscoring the limited accessibility provided by non-driving options.

A similar pattern emerges when using the gravity model, which accounts for park quality and travel distances. The gravity index is highest for driving (39.02), followed by carshare (18.14). Accessibility values drop significantly for other modes, with biking at 6.12, transit at 3.64, and bikeshare at 2.84. Incorporating park quality into the analysis amplifies the disparity between driving and all other transportation options, highlighting the pronounced advantages of private vehicles in providing access to higher-quality parks.

Table 3
Summary statistics of accessibility to parks measured by three methods.

	Driving	Biking	Transit	Carshare	Bikeshare
Minimum distance method (minutes)					
Mean	4.38	13.47	25.05	24.34	30.41
Median	4.26	12.81	24.04	13.83	26.67
SD	2.27	7.31	11.97	24.8	18.2
Min	0.00	0.01	0.05	0.05	0.05
Max	15.22	61.10	75.21	244.47	98.63
Cumulative opportunities method (number of parks)					
Mean	46.97	5.98	4.16	23.62	2.61
Median	48	6	4	25	2
SD	6.90	2.55	2.79	21.26	2.26
Min	19	0	0	0	0
Max	57	12	15	55	12
Gravity model with park quality					
Mean	39.02	6.12	3.64	18.14	2.84
Median	37.43	5.99	3.29	17.2	2.39
SD	25.79	13.44	4.18	16.68	4.19
Min	12.62	0	0	0	0
Max	1001.66	764.66	204.03	203.52	203.52

Fig. 4 shows the spatial patterns of multi-modal access to parks using the gravity method. Access via driving is highest in central areas, including Burnaby, Coquitlam, and northern Surrey, where multiple parks are clustered. Carshare access, in contrast, peaks in Vancouver (western part on the map), where the concentration of service providers is significantly higher compared to suburban areas. A similar spatial trend is observed for biking and bikeshare: Biking access is higher in central areas, but bikeshare access is concentrated in areas where bikeshare providers operate, such as Vancouver and North Vancouver (northern part of the map). Fig. 5 illustrates disparities in park accessibility across municipalities by alternative travel modes. Several urban municipalities, including Electoral Area A, Coquitlam, Port Moody, Vancouver, North Vancouver, and New Westminster, have relatively high accessibility with small gaps among biking, bikeshare, carshare, and transit. In contrast, many suburban municipalities, such as Surrey, the Township of Langley, Delta, and White Rock, show consistently low accessibility across all alternative modes. The City of Langley shows notably higher bike accessibility relative to its other modes. Bikeshare accessibility is near zero in most municipalities, indicating limited service coverage outside core urban areas.

Transit access to parks is also concentrated in Vancouver and along major light rail (SkyTrain) corridors. These areas benefit from higher transit frequency and connectivity, providing residents with relatively better access to parks compared to regions farther from the transit network. These spatial patterns visually highlight the disparities in park access across different transportation modes, with driving consistently providing the broadest and most equitable coverage, while sustainable modes like bikeshare and transit remain highly localized and dependent on service availability.

3.2. Equality analysis among different travel modes

Fig. 6 through Fig. 8 presents the Lorenz Curves and Gini indices for the five travel modes across the three evaluation methods, respectively. Among the five modes, driving provides the most equitable accessibility

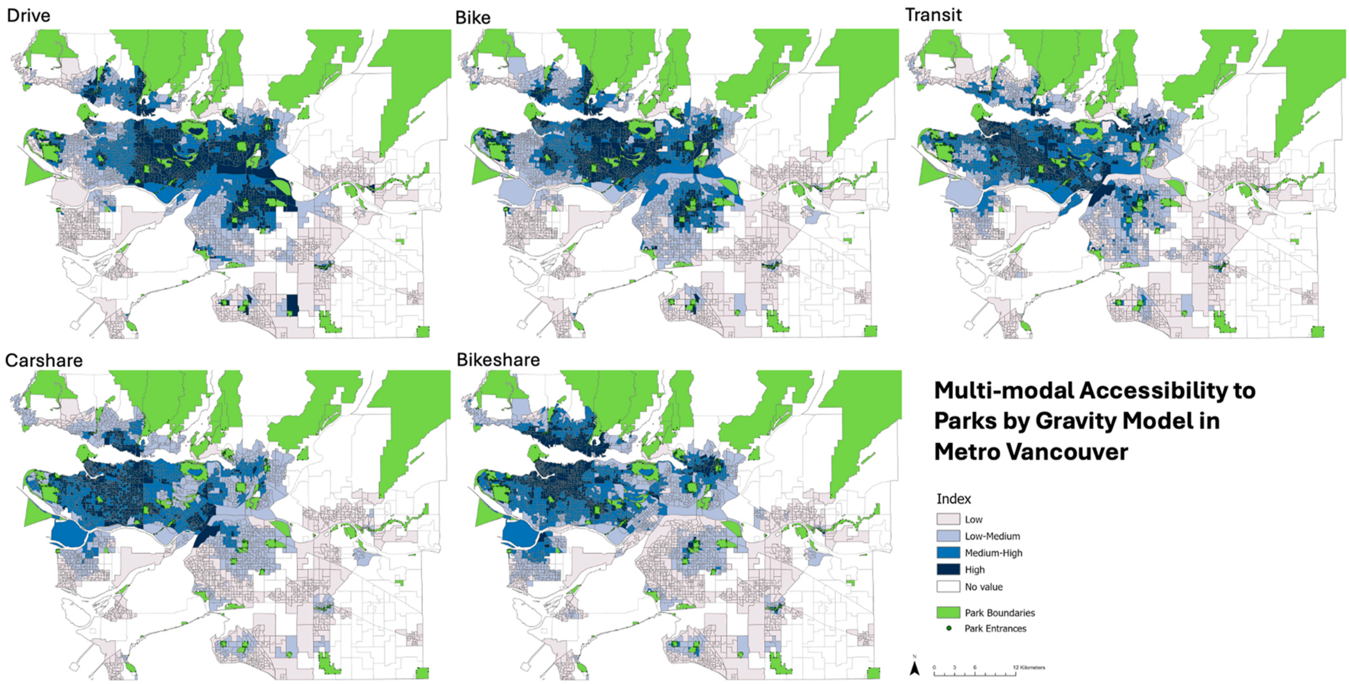

Fig. 4. Multi-modal access to parks of five transportation modes using the gravity method.

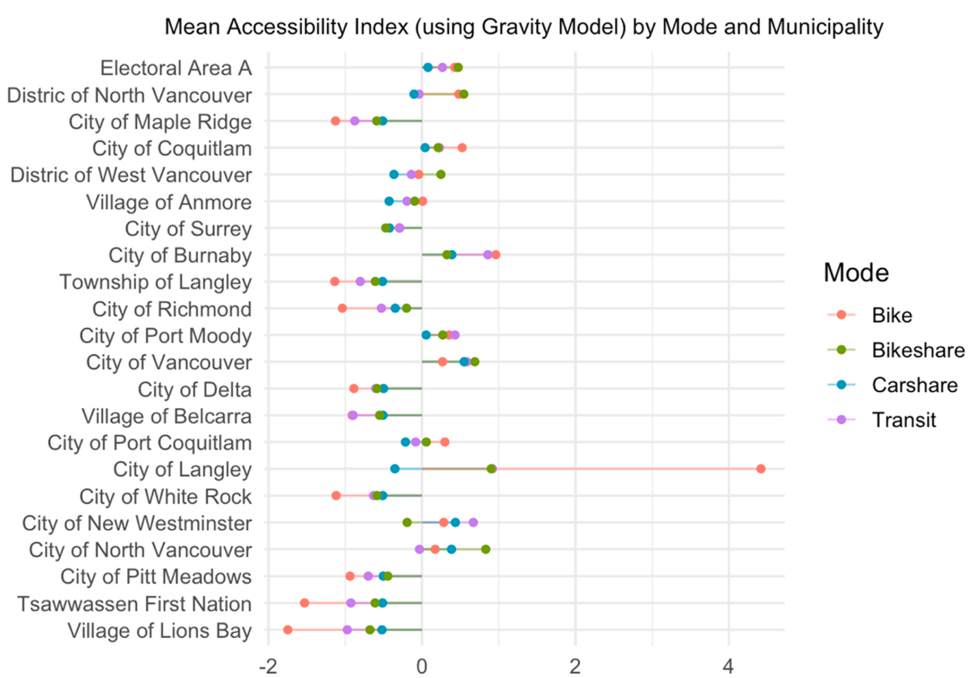

Fig. 5. Mean index by mode and city in Metro Vancouver.

to parks across the region. The Gini indices for driving are consistently low among the three methods (0.29, 0.08, and 0.15 for the minimum distance method, cumulative opportunities, and gravity models, respectively). These low values highlight driving as the mode with the most uniform accessibility distribution.

Transit and biking demonstrate similar equality levels across the three methods, though both are consistently less equitable than driving. Transit's Gini indices are 0.26, 0.38, and 0.37 for the three methods, respectively, while biking shows Gini indices of 0.30, 0.24, and 0.30 (Fig. 6 to Fig. 8). In contrast, the two share-mobility options have the highest Gini indices, ranging from 0.33 to 0.52 across all methods, implying the greatest inequality in park accessibility distributions (Fig. 6 to Fig. 8).

Notably, when accessibility is measured based solely on the nearest park (Fig. 6), the difference in equality between driving and the other four modes are not as distinctive. However, when multiple potential parks and park quality are factored into the analysis, the disparities become significantly wider (Fig. 7 and Fig. 8). This indicates that driving consistently provides more equitable access to both the quantity and quality of parks, while sustainable and shared mobility options reveal greater inequities under more comprehensive evaluations.

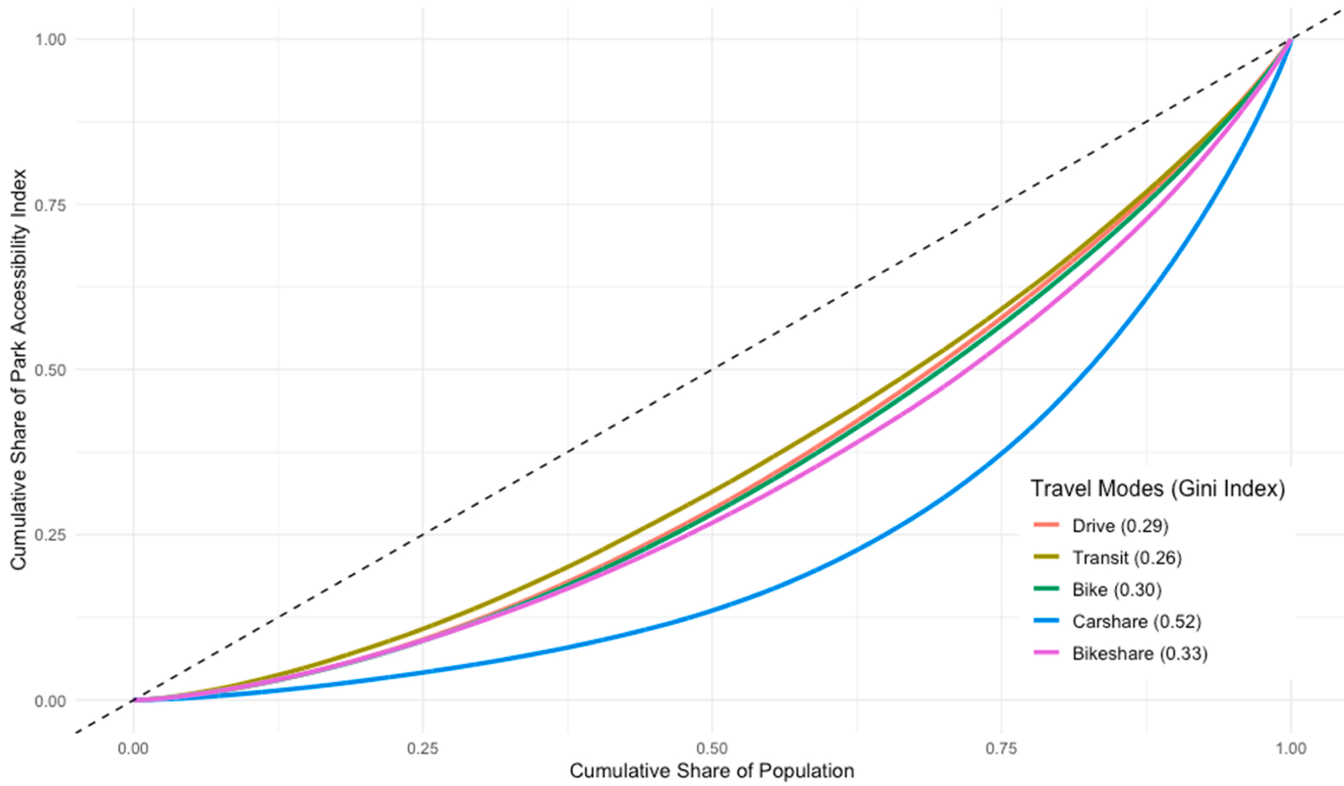

Fig. 6. Lorenz curves of accessibility by minimum distance method for five travel modes with Gini index values.

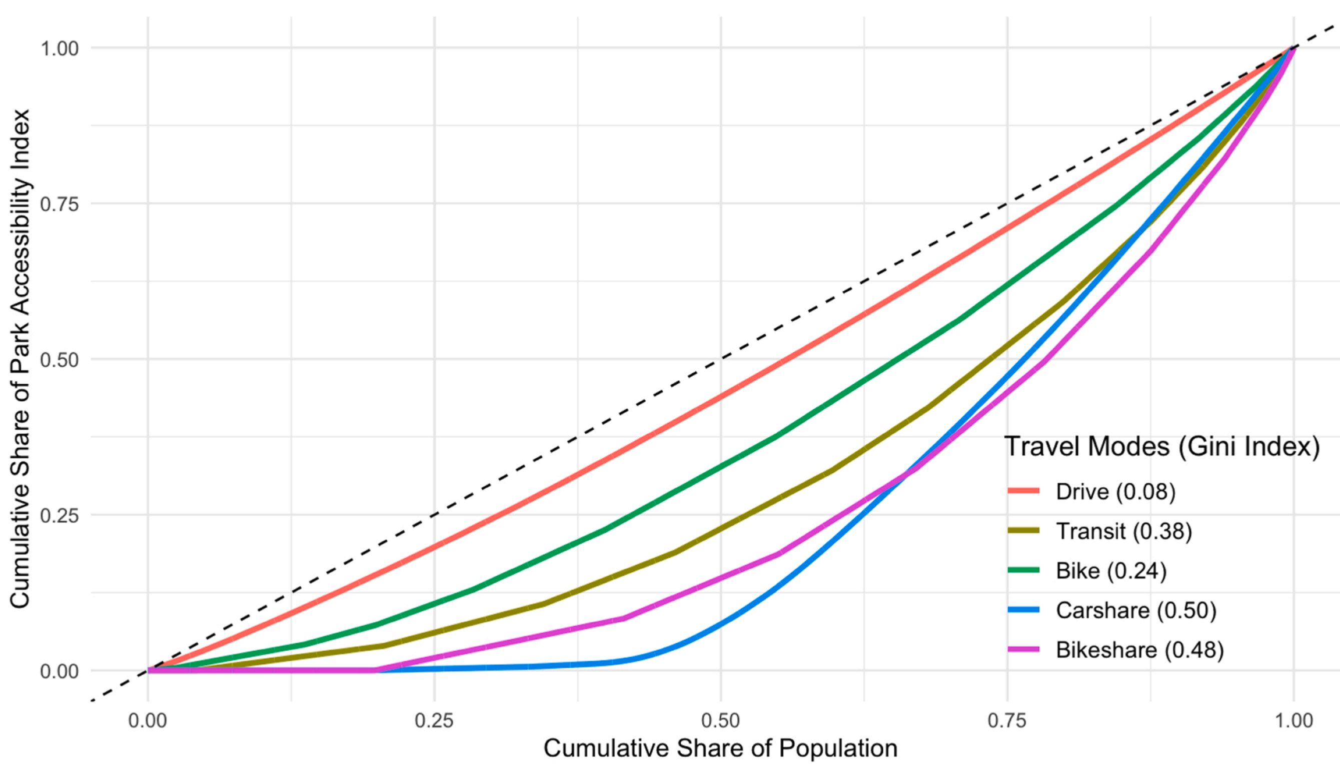

Fig. 7. Lorenz curves of accessibility by cumulative opportunities (45min-threshold) for five travel modes with Gini index values.

3.3. Equity analysis among different travel modes

Fig. 9 through Fig. 11 present the concentration curves and Concentration Indices (CI) for the five transportation models across the three evaluation methods, respectively. While the Gini Index captures the overall evenness of accessibility distribution, the CI evaluates whether transportation accessibility systematically favors or disadvantages certain groups—in this project, based on household income.

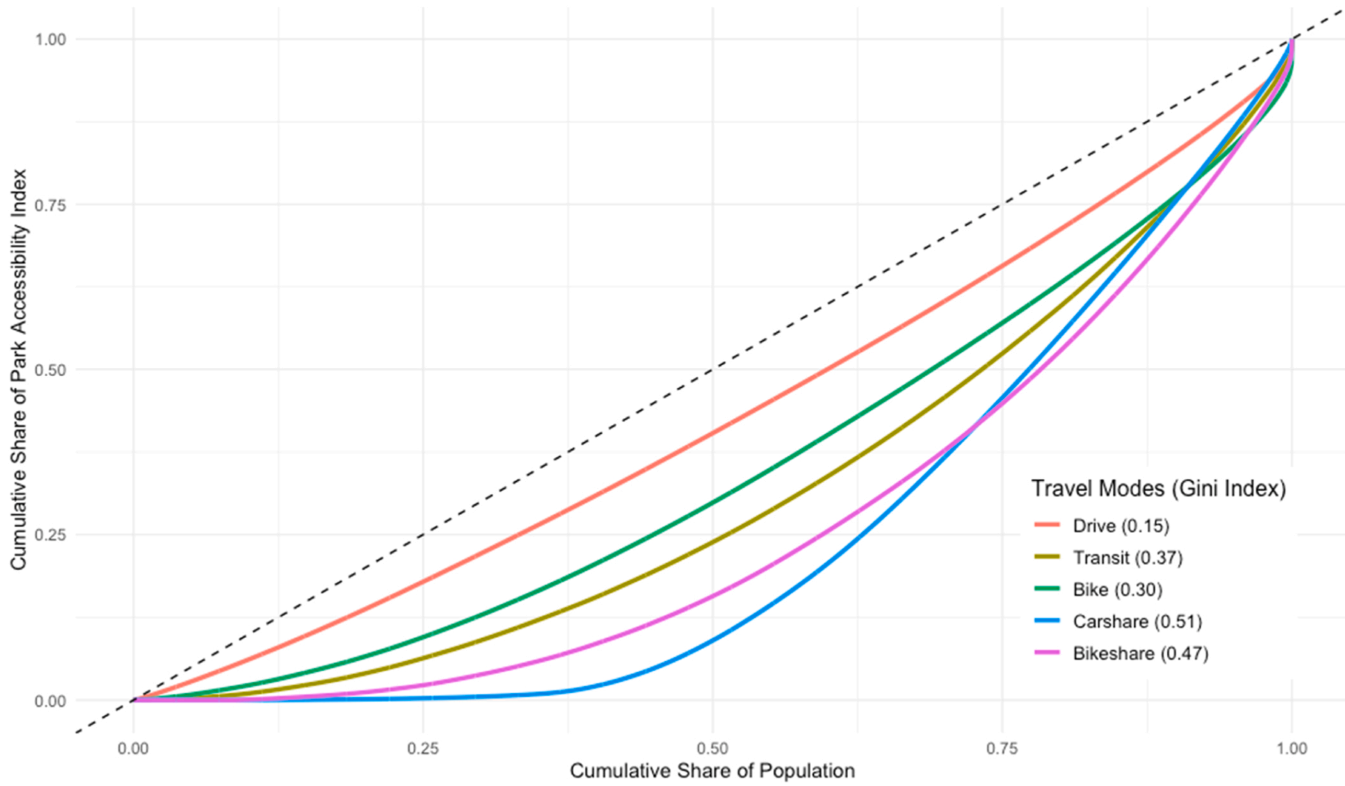

Fig. 8. Lorenz curves of accessibility by gravity model with park quality for five travel modes with Gini index values.

Fig. 9. Concentration curves of accessibility by minimum distance method for five travel modes with CI values.

Notable variations in income-related inequity are evident in access to large public parks across different modes. According to the minimum distance method, driving (-0.0079) and biking (-0.0012) slightly favor low-income populations, whereas transit (0.034), carshare (0.17), and bikeshare (0.057) disproportionately benefit higher-income groups (Fig. 9). The cumulative opportunities and gravity model methods show similar trends, showing that all five modes favor higher-income demographics. Driving accessibility is the closest to the line of perfect equity, with CI values of 0.008 and 0.017 respectively (Fig. 10 and Fig. 11). These findings highlight significant disparities in how different

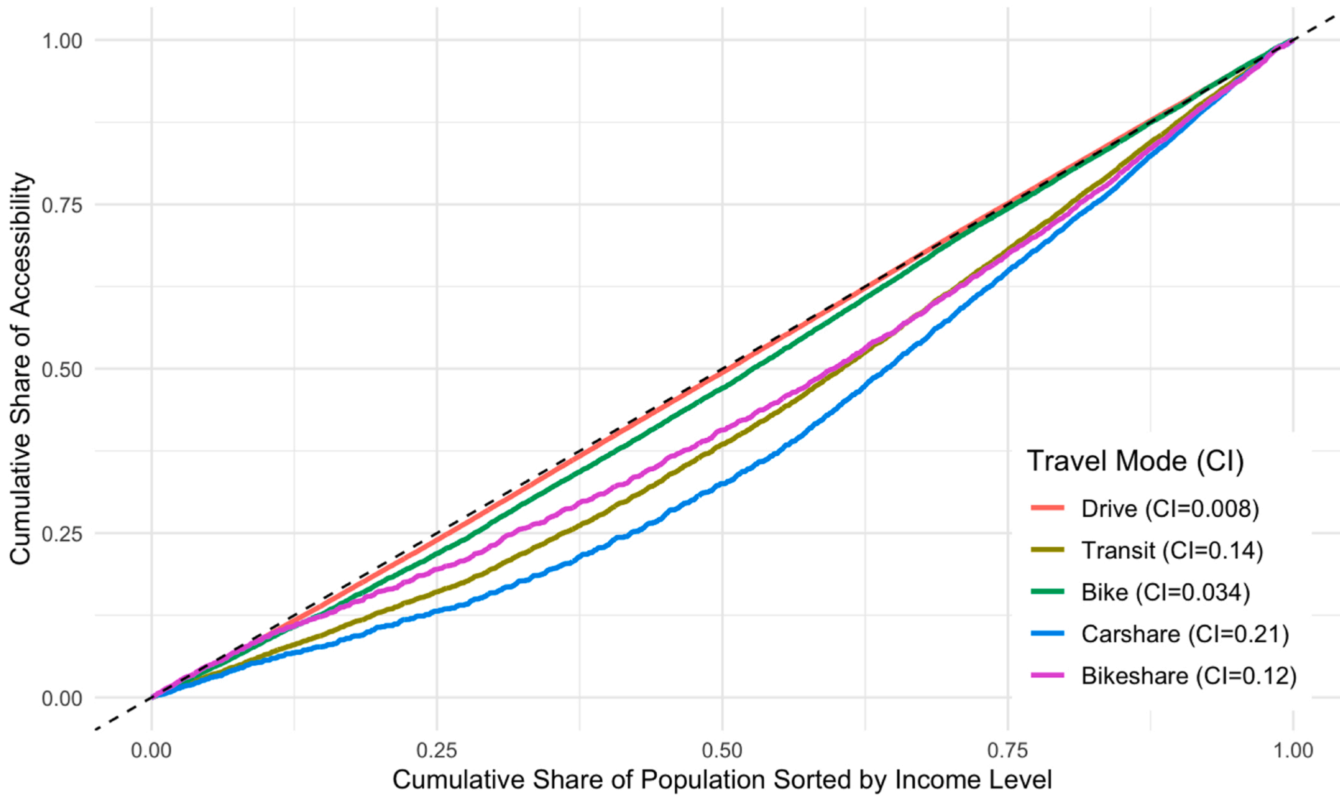

Fig. 10. Concentration curves of accessibility by cumulative opportunities (45min-threshold) for five travel modes with CI values.

Fig. 11. Concentration curves of accessibility by gravity model with park quality for five travel modes with CI values.

transportation modes serve populations of varying income levels.

Transit, bikeshare, and carshare consistently exhibit the higher levels of pro-rich bias across all three methods, with carshare showing the greatest inequity in park accessibility (Fig. 9 to Fig. 11). Similar to the inequality analysis, inequity becomes more pronounced when accounting for park quantity and quality rather than focusing solely on the nearest park. CI values are consistently higher when using the cumulative opportunities and gravity model methods compared to the minimum distance method, reflecting greater disparities in accessibility across income groups under more comprehensive evaluations of park accessibility.

4. Discussion

This study aims to evaluate the equality and equity of accessibility to large parks across multiple transportation modes in Metro Vancouver, BC, Canada. Our results demonstrate that driving provides the most equitable spatial distribution of park access across the region, while accessibility via alternative modes—including transit, biking, carshare, and bikeshare—is significantly less equitable. These findings are consistent with prior studies that emphasize the equity advantage of driving across different regions and methodological approaches. For instance, Wang et al. (2022) found that driving-based modes offer superior spatial equity in park access compared to transit-based modes. Similarly, Ni et al. (2024), using the Gini index, reported that driving yielded the most equitable outcomes among all modes for healthcare accessibility. Mahmut et al. (2024) also concluded that driving provides more equitable spatial accessibility than public transit or walking.

Our income-based analysis further indicates that driving approaches near-perfect equity and even shows a slight pro-poor tendency, while all other modes disproportionately benefit higher-income populations. This is striking given that alternative transportation modes are generally more affordable and often implemented to support low-income communities. The current pro-wealthy bias in park accessibility outcomes suggests a disconnect between equity-driven transportation goals and the realities of infrastructure and service provision (NABSA, 2022; Howland et al., 2017). Shaheen and Chan (2016) highlighted that, compared to private vehicles and traditional public transit, shared mobility services hold greater potential to deliver affordable and equitable access for disadvantaged communities. However, despite this promise, our findings reveal that shared mobility options (e.g., carshare and bikeshare) tend to reinforce rather than alleviate transportation inequities in the context of park access. This is largely due to limited service coverage in suburban and lower-income neighborhoods, where access needs are often greatest (Mouratidis et al., 2021; Sun et al., 2020). These outcomes may reflect the early-phase development of such services, underscoring a policy window to steer their expansion toward greater inclusivity in Metro Vancouver's transportation system.

Furthermore, our comparison across various accessibility measures demonstrates that simpler methods, such as proximity-based or cumulative counts, tend to obscure key disparities. By contrast, our gravity model, integrating actual travel time, park quality, and multiple destinations, reveals more pronounced and policy-relevant inequities. These findings underscore the analytical value of multi-dimensional frameworks, offering a more nuanced and realistic understanding of spatial equity and inequality in park access (Wang et al., 2022; Yu et al., 2020).

The following sections discuss the policy implications of these findings, acknowledge key limitations, and propose future research directions.

4.1. Policy implications

The findings of this study reveal significant disparities in park accessibility across transportation modes, particularly for non-driving options, with shared mobility services showing the highest levels of inequity. These results underscore the urgent need for equity-focused multimodal transportation planning that reduces reliance on private vehicles while expanding affordable and accessible alternatives for underserved populations. Addressing these disparities requires a holistic approach that considers not only spatial distribution but also socioeconomic barriers that inhibit access for marginalized communities, including older adults, immigrants, people of color, individuals with disabilities, and those without private vehicles (Bateman et al., 2021; Mcneil et al., 2020; Landis, 2022).

One key strategy is to improve transportation services for low-income and marginalized groups through targeted initiatives. Expanding shared mobility services into suburban and lower-income neighborhoods—where they are currently found underrepresented due to limited market potential and transportation infrastructures gaps—could address critical service gaps. As these services are typically profit-driven and rely heavily on existing transportation systems, Bai and Jiao (2024) argue that transportation agencies should move beyond revenue-maximization models and incorporate equity analyses when partnering with private mobility providers. Public-private partnerships and subsidies offer viable pathways to address these gaps. One example of these successful carsharing program is BlueLA in Los Angeles, which was launched as a public-private partnership between the City of LA and Bolloré Group, offering discounted memberships and vehicle access in underserved neighborhoods (Shaheen et al., 2019). In addition, public transit improvements, such as expanded service hours and increased frequency particularly transit-dependent neighborhoods, can also improve equity in parks accessibility. In North America, transit-to-parks programs (e.g., seasonal shuttles, dedicated bus lines to popular parks, and group trips for youth and seniors) have been implemented in several cities. Many of these initiatives are equity-driven and have demonstrated success by leveraging public funding and partnering with NGOs and local communities (Wang et al., 2024; Rigolon et al., 2024).

Our findings emphasize that improving park quality is as critical as enhancing transportation connections. Disadvantaged neighborhoods are often served by lower-quality or smaller parks (Rigolon, 2016; Xu et al., 2017), but traditional proximity-based metrics such as minimum distance or cumulative opportunity measures can miss such disparities. This highlights the need for municipalities, regional park agencies, and park advocates to prioritize both equitable distribution and quality enhancement of parks in disadvantaged areas. Investments should prioritize improving amenities, maintenance, programming, and safety in parks serving lower-income communities, while also developing new high-quality green spaces in underserved areas. Design and programming should intentionally address the needs of groups such as older adults, children, and people with disabilities, who often face both socio-economic and physical barriers to park access (Loukaitou-Sideris et al., 2016; Park et al., 2021). Furthermore, agencies should adopt multi-dimensional assessment frameworks like those presented in this study to holistically evaluate park accessibility, incorporating considerations of travel time, multiple destination options, and quality indicators. Such nuanced approaches can better guide resource allocation decisions and more accurately track progress toward environmental justice goals in urban green space planning.

Another priority is to integrate multimodal networks through investments in infrastructure that connects transit with active and shared transportation options. For example, placing shared mobility hubs near transit stations and constructing safe cycling and pedestrian pathways can help create seamless connections for first- and last-mile access. While improving transportation connections is essential, this should be balanced with residential planning strategies that bring people closer to parks. Transit-oriented development (TOD) that priotizes both park accessibility and affordable housing could ensure more equitable access across socioeconomic groups. Expanding greenways and recreational infrastructure to underserved regions would also enhance accessibility across modes (Pettersson & Hrelja, 2020; SFMTC, 2023).

Achieving equitable park access requires robust collaboration across government levels and sectors, bringing together transit authorities, municipalities, park agencies, shared mobility providers, and housing departments. These cross-sectoral partnerships are essential for creating integrated solutions that address multiple societal challenges. For instance, regional transportation authorities could partner with local governments to implement equitable mobility programs while park agencies coordinate with housing authorities on proximity-focused residential development. Such collaborative governance would better align transportation equity with broader social goals including public health, climate resilience, and environmental justice. By providing viable alternatives to private vehicles, these integrated policies can reduce greenhouse gas emissions, improve urban air quality, promote active lifestyles, and enhance community cohesion (Huang et al., 2024; Ha et al., 2023; Rigolon & Browning, 2021). Throughout this process, regular community engagement and policy co-creation with marginalized groups should guide implementation, ensuring that interventions address the unique needs of vulnerable populations. This holistic approach reinforces the importance of viewing transportation equity not as an isolated goal but as a fundamental component of creating just, healthy, and sustainable urban environments for all residents.

4.2. Limitations and future research

Several limitations of this study should be acknowledged. First, our analysis focuses exclusively on large public parks, omitting smaller greenspaces and other types of informal urban greeneries that may influence overall accessibility patterns. While large parks offer distinct benefits and warrant multiple access modes, future research should consider the complementary role of diverse greenspace types in accessibility assessments and specifically examine how access to smaller greenspaces and greeneries impacts equality and equity outcomes. Future studies could develop integrated accessibility metrics that combine access to various greenspace types, weighted by their size and amenities for comprehensive park quality assessment.

The study's cross-sectional nature presents another limitation, as it does not account for temporal variations in transportation systems and travel patterns. While we addressed three key components of accessibility—land use, transportation, and sociodemographic characteristics—the temporal component is also important (Geurs & van Wee, 2004). This includes factors such as the service hours and schedules of public transit and shared mobility services, as well as the available time for activities in parks, all of which can influence accessibility.

Our analysis did not incorporate real-time travel data from sources like the Google Maps API, which could improve the precision of travel time estimates by accounting for dynamic traffic conditions. Additionally, commercial datasets offering point-of-interest (POI) visitation records may help identify actual trip origins, reducing reliance on modeled assumptions. For shared mobility, our approach was limited to station locations and did not consider system characteristics such as vehicle availability, capacity, or operational zones—all of which influence real-world accessibility. Future research could address these uncertainties by integrating real-time usage data and partnering with mobility providers to better capture actual travel behavior and user patterns.

Finally, our equity analysis focused only on median household income, omitting factors like age and car ownership that also affect mobility. We also relied solely on objective measures, overlooking perceived accessibility—an important dimension, especially as marginalized groups often experience lower perceived access due to multiple barriers (Negm et al., 2025; Park, 2017; Zhang et al., 2025). Future research should adopt multivariate approaches (e.g., using other or a combination of relevant socio-indicators for inequity analysis) and incorporate participatory methods to better capture these intersecting dynamics. In addition, future studies could incorporate health-related factors—such as obesity, chronic illness, or disability—that may significantly affect individual mobility and access to parks. As this study is context-specific to a region in developed country with relatively high automobile reliance, future research should examine how accessibility and equity patterns differ in cities with varying development levels, particularly in the Global South.

5. Conclusion

Our multi-modal accessibility analysis of large public parks in Metro Vancouver, BC, Canada, reveals complex patterns of spatial and socioeconomic inequities that are often overlooked in conventional evaluations of park accessibiilty. Among the five transportation modes analyzed, driving shows the most equitable spatial distribution of park access at the neighbourhood level. Accessibility via other modes, including transit, biking, carshare, and bikeshare, is much less equitable, with shared mobility modes exhibiting the highest disparities. Incorporating park quality and travel time into the analysis reveals even larger disparities for shared mobility modes, likely reflecting service gaps in suburban and lower-income areas. While shared mobility services hold promise for broadening transportation access by providing flexible options that complement traditional modes, their current implementation in the region appears to reinforce existing inequities, underscoring opportunities for targeted policy intervention. Equitable park accessibility requires policies that improve sustainable mode options while reducing reliance on private vehicles, which, despite their measured equity in this study, present environmental and affordability challenges.

This study advances current knowledge by integrating shared mobility options into multi-modal park accessibility analysis, emphasizing large urban parks as vital urban resources, and applying different spatial method and comparing their equality and equity results. Our approach contributes to a growing body of literature that moves beyond single-mode assessments and highlights the role of non-traditional transportation in shaping equitable access. Building on this study, future research can explore more realistic trip chains, incorporate additional socio-economic dimensions, and leverage real-time travel data and perceived accessibility measures to better capture the lived experiences of underserved populations.

CRediT authorship contribution statement

Kai Hei Mau: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Yiyang Wang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Formal analysis, Conceptualization. **Keunhyun Park:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix I

Table A1
List of study parks included in the analysis

No.	Park Name	Type	No. of Reviews	Rating	Quality Index	Park Size (Hectare)	# of Entrances	Overview
1	Pinecone Burke Park	Provincial	354	4.5	11.47	37155.54	2	Wilderness; high biodiversity
2	Cypress Park	Provincial	3525	4.7	16.67	2868.61	1	Alpine recreation
3	Mount Seymour Park	Provincial	1485	4.6	14.59	3565.62	3	Ski-hiking; old-growth forests
4	Golden Ears Park	Provincial	4632	4.7	17.23	61590.31	2	Wilderness; lake-forest recreation
5	Say Nuth Khaw Yum Park [A.K.A. Indian Arm Park]	Provincial	187	4.6	10.45	6687.08	1	Fjord-shore conservation
6	Aldergrove Regional Park	Regional	1078	4.6	13.95	279.97	6	Meadow-wetland recreation
7	Barnston Island Regional Park	Regional	28	4.6	6.66	26.84	2	River-fringe cycling and hiking
8	təmtəmíxʷtən / Belcarra Regional Park	Regional	354	4.6	11.73	1034.37	13	Coastal forest; intertidal life
9	Boundary Bay Regional Park	Regional	561	4.6	12.65	193.45	12	Coastal wetland; migratory birds
10	Brae Island Regional Park	Regional	491	4.3	11.57	67.15	1	River island; recreation
11	Burnaby Lake Regional Park	Regional	2480	4.5	15.28	152.36	11	Wetland; birdwatching
12	Campbell Valley Regional Park	Regional	2129	4.7	15.64	555.21	23	Forest-meadow; equestrian trails
13	Capilano River Regional Park	Regional	1671	4.7	15.15	151.06	15	Canyon; salmon hatchery
14	ƛ̓éxətəm (tla-hut-um) (formerly known as Colony Farm) Regional Park	Regional	804	4.5	13.07	260.95	9	Wetland; bird habitat
15	Deas Island Regional Park	Regional	741	4.5	12.91	73.21	1	River island; riparian forest
16	Derby Reach Regional Park	Regional	1851	4.6	15.03	315.78	7	Fraser riverfront; heritage sites
17	Glen Valley Regional Park	Regional	294	4.4	10.86	77.31	1	Floodplain forest; wildlife
18	Grouse Mountain Regional Park	Regional	421	4.7	12.33	73.61	1	Recreation; ski
19	Iona Beach Regional Park	Regional	1984	4.6	15.17	811.15	1	Coastal wetland; bird habitat
20	Kanaka Creek Regional Park	Regional	1082	4.6	13.95	487.90	18	Creek canyon; salmon habitat
21	Lynn Headwaters Regional Park	Regional	712	4.7	6.66	3726.49	1	Rainforest; high biodiversity
22	Minnekhada Regional Park	Regional	918	4.8	11.73	228.29	6	Wetland-forest biodiversity
23	Pacific Spirit Regional Park	Regional	1818	4.7	12.65	860.91	66	Coastal forest; nature trails
24	Surrey Bend Regional Park	Regional	784	4.3	11.57	353.98	3	Floodplain wetlands biodiversity
25	Thwaytes Landing Regional Park	Regional	5	4.4	15.28	48.20	1	Remote shoreline; boat access
26	Tynehead Regional Park	Regional	2188	4.6	15.64	259.27	15	Serpentine river; salmon habitat
27	Widgeon Marsh Regional Park	Regional	7	4	15.15	638.52	1	Marsh wetlands; rich wildlife
28	Sunnyside Acres Urban Forest Park	Local	423	4.6	13.07	143.04	17	Urban forest; biodiversity
29	Barnet Marine Park	Local	3012	4.6	12.91	101.85	5	Waterfront; picnic beach
30	Bear Creek Park / Surrey Arts Centre	Local	5491	4.6	17.20	62.00	12	Gardens; playground; arts
31	Bert Flinn Park	Local	371	4.7	12.08	154.28	30	Forested trails; cycling
32	Burnaby Mountain Conservation Area	Local	3854	4.7	16.85	607.59	25	Forest park; mountain views
33	Byrne Creek Ravine Park	Local	654	4.5	12.67	48.93	22	Ravine forest; salmon stream
34	Robert Burnaby Park	Local	862	4.5	13.21	47.92	11	Forested urban park
35	Central Park	Local	6323	4.6	17.48	86.36	18	Urban forest; sports fields
36	Colebrook Park	Local	51	4.7	8.026	146.08	4	Riparian corridor; wetlands
37	Coquitlam River Park	Local	609	4.7	13.09	69.78	29	Riverside forest trails
38	Cove Forest	Local	1091	4.6	13.98	117.95	1	Coastal forest; hiking
39	Crescent Park	Local	79	4.7	8.92	51.96	16	Forested park; gardens
40	Deer Lake Park	Local	7766	4.6	17.89	183.29	25	Wetland-lake; birdwatching
41	Stanley Park	Local	49041	4.8	22.51	417.95	20	Iconic urban forest
42	Everett Crowley Park	Local	737	4.4	12.62	38.17	7	Forested former landfill
43	Fleetwood Park	Local	1398	4.5	14.15	49.70	11	Urban park; sports field
44	Gates Park	Local	1071	4.6	13.94	51.91	5	Sports fields; riverfront
45	Green Timbers Urban Forest Park	Local	1226	4.6	14.21	170.53	29	Urban forest; fishing lake
46	Jericho Beach Park	Local	5140	4.7	17.44	48.20	18	Beach; recreation focus
47	Mundy Park	Local	3468	4.7	16.64	178.97	22	Forest trails; urban wildlife
48	Nicomekl Park	Local	242	4.1	9.77	59.38	21	River corridor; wetland
49	Queen Elizabeth Park	Local	15411	4.7	19.68	53.24	6	Botanical gardens; city views

(*continued on next page*)

Table A1 (*continued*)

No.	Park Name	Type	No. of Reviews	Rating	Quality Index	Park Size (Hectare)	# of Entrances	Overview
50	Redwood Park	Local	1636	4.7	15.10	50.21	5	Unique exotic trees
51	Richmond Nature Park	Local	1165	4.4	13.49	42.94	1	Peat bog; interpretive centre
52	Terra Nova Rural Park	Local	2473	4.7	15.95	26.24	10	Farmland; bird habitat
53	Lighthouse Park	Local	5223	4.7	17.47	76.51	1	Coastal forest; old growth
54	Watershed Park	Local	1095	4.7	14.29	145.44	8	Forest; groundwater protection
55	Whyte Lake Park	Local	332	4.6	11.60	159.85	3	Forest lake trails
56	Lynn Canyon Park	Local	9859	4.8	19.17	264.27	14	Canyon; suspension bridge
57	Lower Seymour Conservation Reserve	Local	469	4.8	12.82	5668.50	7	Watershed; high biodiversity
58	Buntzen Lake Recreation Area	Local	3078	4.7	16.39	541.63	2	Lake; hiking recreation

Appendix II

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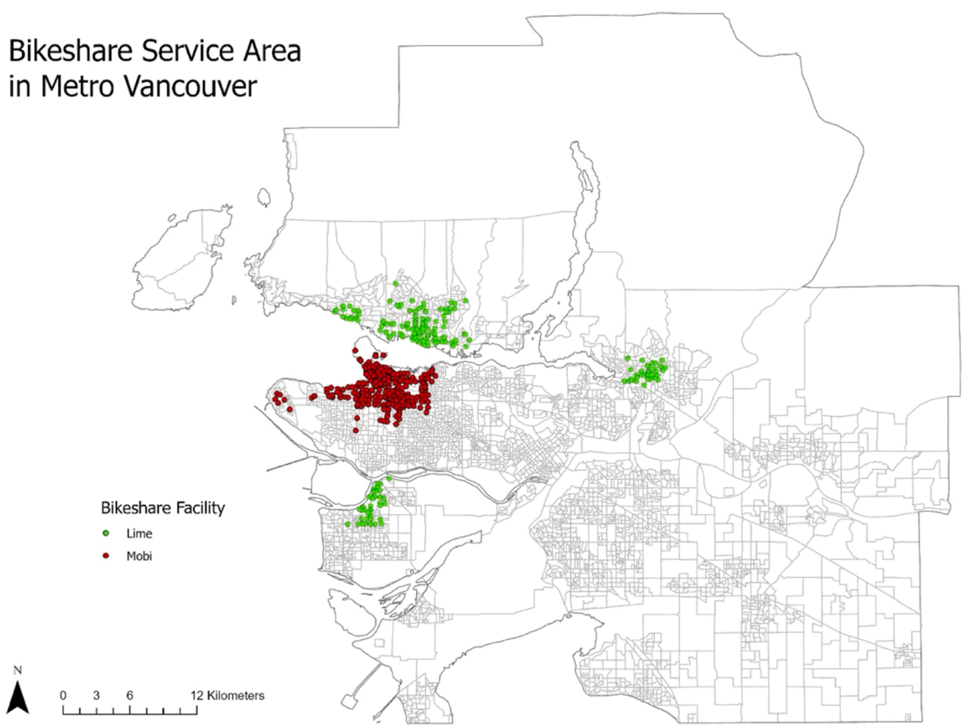

Fig. 12. Bikeshare station locations of two bikeshare service providers—Lime and Mobi—in Metro Vancouver

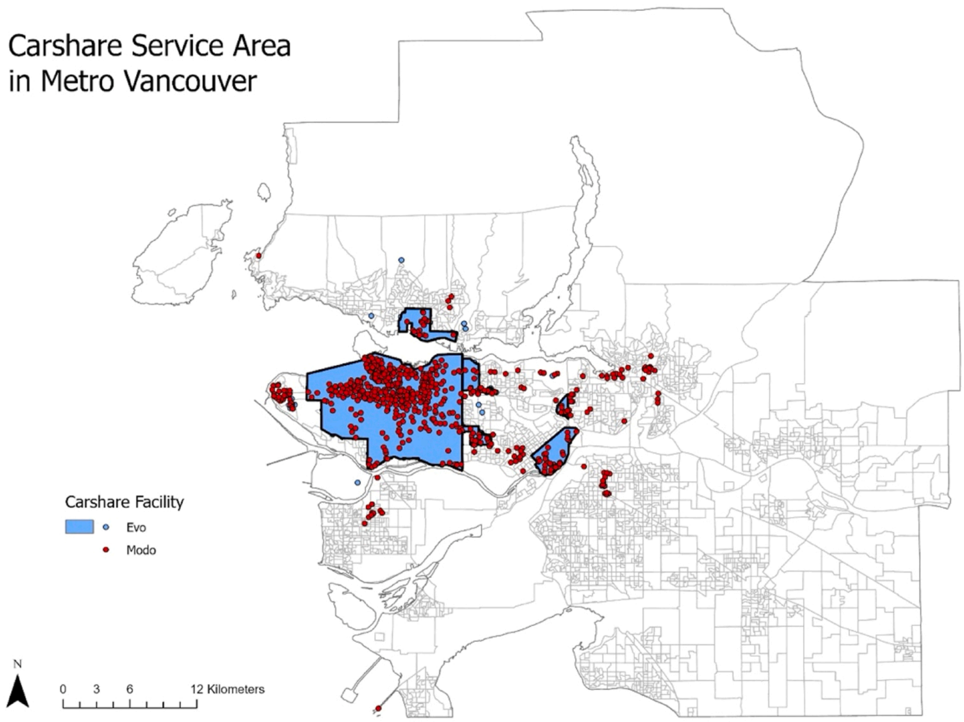

Fig. 13. Carshare station locations of two carshare service providers—Evo and Modo—in Metro Vancouver

Appendix III

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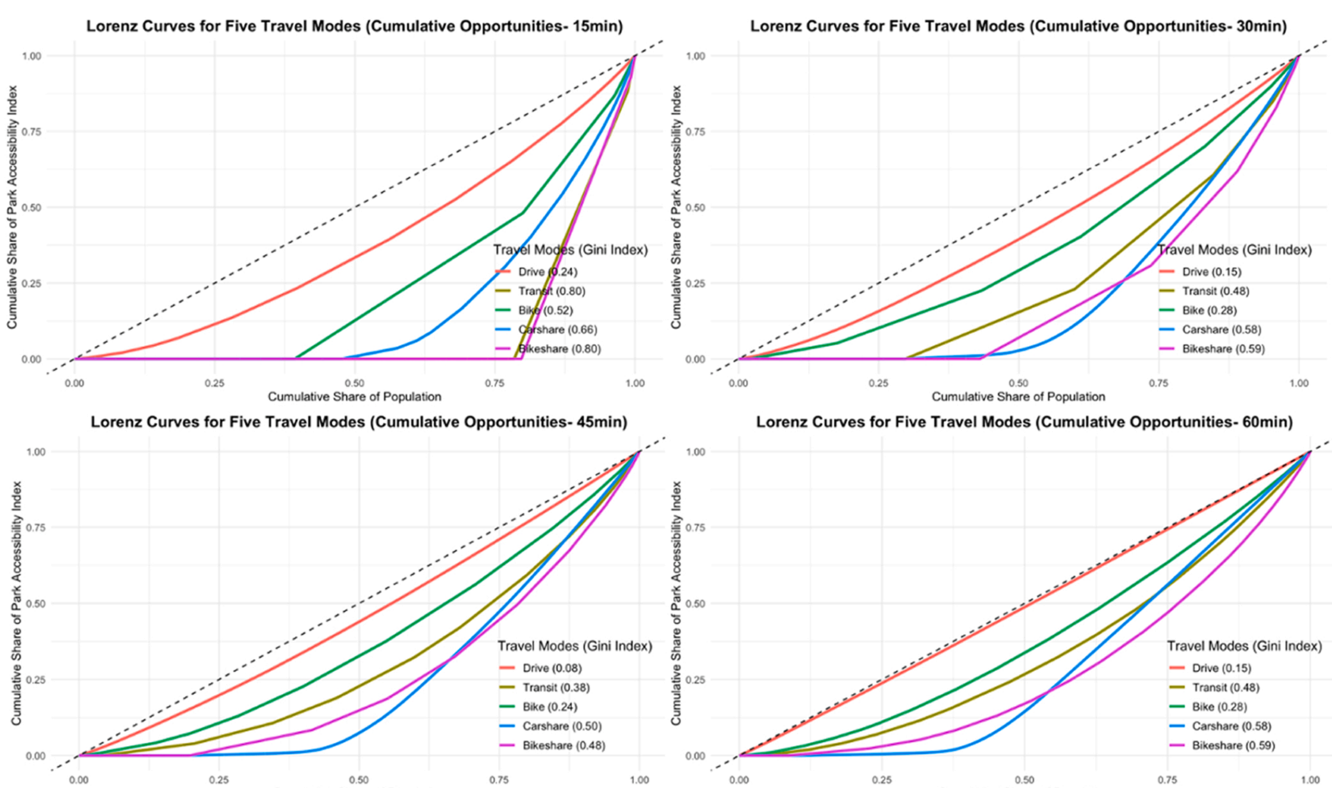

Fig. 14. Sensitivity analysis of Lorenz Curves and Gini indices based on results of Cumulative Opportunities at different time cutoff

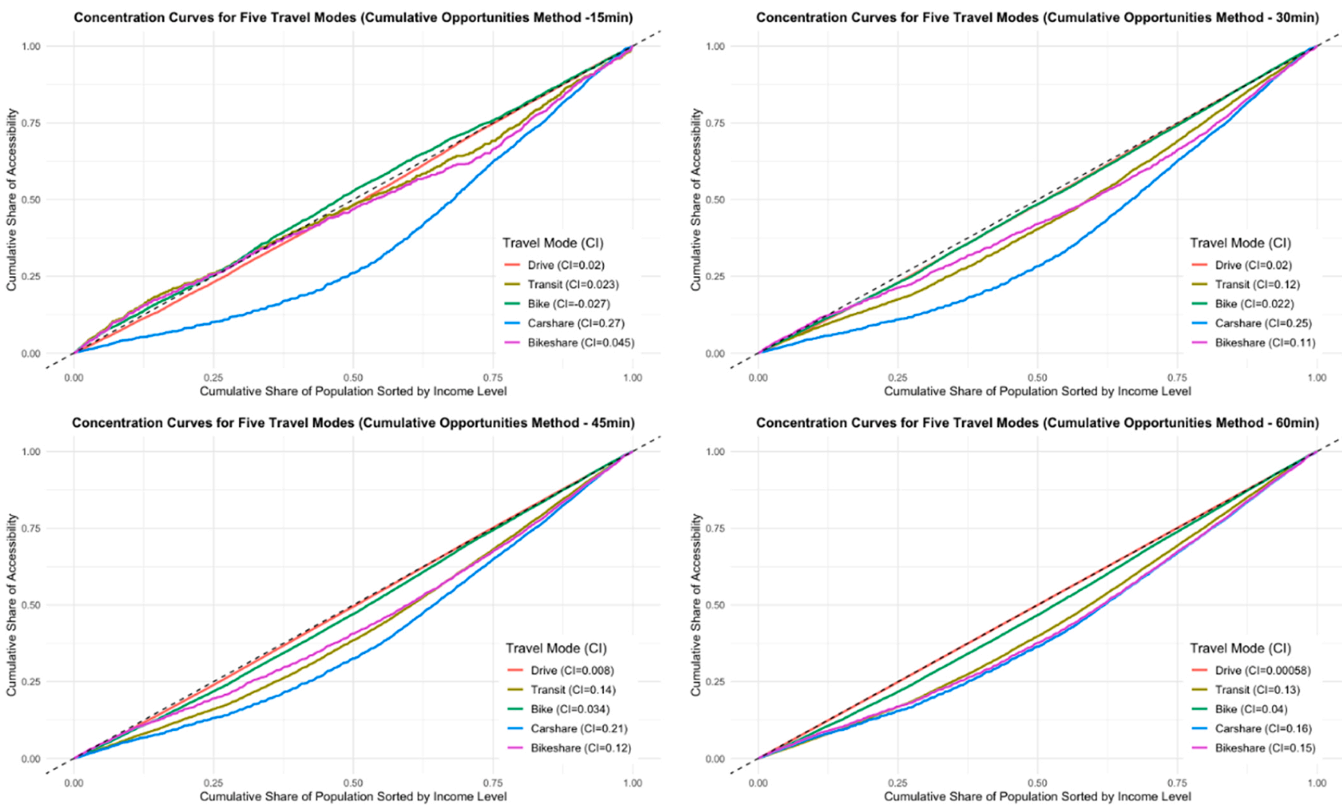

Fig. 15. Sensitivity analysis of Concentration Indices based on results of Cumulative Opportunities at different time cutoff

Appendix IV

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Table A2
Sensitivity analysis and correlation results of gravity model with park quality for different modes. S1 (baseline, the analysis used in this paper; β=1 and C_j as star rating * ln[reviews]); S2 (β =2), S3 (β =0.5). Pairwise Pearson correlation coefficients were generated across scenarios per mode at DA-value

Mode	Scenario (X)	Beta	Gini	Scenario (Y)	Pearson correlation coefficient
Driving	S1	1 (baseline)	0.1454	S2	0.9796
	S2	2	0.1502	S3	0.9474
	S3	0.5	0.1462	S1	0.9923
Biking	S1	1 (baseline)	0.3070	S2	0.9981
	S2	2	0.3297	S3	0.9942
	S3	0.5	0.3029	S1	0.9990
Transit	S1	1 (baseline)	0.3680	S2	0.9882
	S2	2	0.3476	S3	0.9666
	S3	0.5	0.3566	S1	0.9944
Carshare	S1	1 (baseline)	0.5104	S2	0.9851
	S2	2	0.4351	S3	0.9704
	S3	0.5	0.4424	S1	0.9975
Bikeshare	S1	1 (baseline)	0.4659	S2	0.9892
	S2	2	0.4151	S3	0.9946
	S3	0.5	0.4185	S1	0.9786

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