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Original article

How good is your basket of parks? A combined index of park quality and accessibility for youth

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ABSTRACT

Parks and green spaces are essential components of urban areas as they provide ecological, economic, health and social functions. Their positive outcomes are closely linked with both the quality of the parks as well as their accessibility, especially via walking and cycling. This is particularly relevant for youth who largely depend on active modes for independent travel. To date, most studies have focused on a single component (quality or accessibility). To our knowledge, no study has measured the quality of a group of parks accessible to an individual. This study, therefore, proposes a methodology to generate an index that combines accessibility and quality: the Combined Index of Parks Quality and Accessibility for Youth (CIPQAY). The index is designed by combining a recently developed quality index, the "QUality Index of Parks for Youth" (QUINPY) with cumulative-opportunity accessibility measures, and is then applied to the city of Montreal, Canada. The QUINPY variables and scores are adapted to reflect the combined quality of accessible parks, based on five criteria: structured play diversity, nature, park size, safety, and maintenance. Using open-source data, the CIPQAY is then operationalized based on the study context and data availability. The final index contains 17 variables and is computed for each residential lot (n = 374,599). Findings show a low correlation between the CIPQAY index and the number of parks accessible, highlighting the relevance of this composite index. This research provides researchers and planners with a systematic methodology, transferable to other contexts, to measure the quality of parks accessible to individuals.

1. Introduction

With an increasing part of the population living in urbanized areas (Nabielek et al., 2016), parks and green spaces are of strategic importance for the quality of life of individuals (Chiesura, 2004). The presence of parks in a neighborhood is associated with social (Seaman et al., 2010), health (Cohen et al., 2007; Lachowycz and Jones, 2011), economic (Nicholls, 2004; Loch et al., 2024) and environmental (Feyisa et al., 2014) benefits. Children (2–18 years old) experience significant improvements in well-being when they spend time in parks, especially when it comes to their physical and mental health (Chawla, 2015; Maas et al., 2009). The positive outcomes are closely linked with the quality of the parks, which includes features such as the presence of well-maintained amenities (e.g., playgrounds, pools, sports fields) (Veitch et al., 2021), the possibility to conduct a variety of leisure and outdoor activities, and the provision of a safe environment. In addition to the quality of parks, their accessibility, especially via walking and cycling, contributes to a greater use of these public spaces (Giles-Corti et al., 2005), and in turn, to greater associated outcomes (Xie et al., 2018; Macfarlane et al., 2020). Access by active modes is essential for youth, due to their inability to use private motor vehicles.

To support planning and decision-making, several studies have developed methodologies to measure park quality and accessibility. To date, most of these studies have focused on a single component, either park quality (Cavnar et al., 2004; Byrne et al., 2005; Rigolon and Németh, 2018) or park accessibility (Fan et al., 2017; Guo et al., 2019; Reyes et al., 2014; Semenzato et al., 2023; Zhang and Chen, 2024). Park quality indices are typically developed from a landscape planning perspective, whereas measures of accessibility to parks relate more closely to land use and transport planning. Yet, from the individuals' perspective, it is likely the quality of the combined park spaces and amenities that are accessible to them that influences their interest and ability to conduct activities in parks. In other words, what matters to individuals is the set of amenities and activities that are accessible to

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them, regardless of whether they are in the same park.

This study proposes a methodology to generate an index that combines accessibility with the quality of (accessible) parks, with a focus on youth (in this study referring to children between 2 and 18 years old). More specifically, the proposed methodology merges cumulative-opportunity accessibility measures with a recently developed quality of park index for youth (QUINPY) (Rigolon and Németh, 2018) into a single index: the Combined Index of Parks Quality and Accessibility for Youth (CIPQAY). Fig. 1 illustrates the conceptual differences between the QUINPY and the CIPQAY: whereas the QUINPY is computed for each park A, B and C (park-based indicator), the CIPQAY is computed based on a specific origin (here the residential lot, representing home locations) and is a function of the features of all parks accessible under a travel time or distance threshold (parks B and C here). In doing so, the study integrates this established measure on the quality and features of parks (QUINPY) with a well-known and commonly used accessibility indicator. It allows for the consideration of all parks accessible from a location when measuring the quality of parks.

The method is applied to the city of Montreal, which displays important discrepancies in spatial accessibility to parks and activities (Reyes et al., 2014; El-Murr et al., 2021). First, the QUINPY variables and scores are adapted to reflect the combined quality of surrounding parks. Second, the newly developed CIPQAY variables and scores are operationalized based on the study context and data availability. Using open-source data, the CIPQAY index is then generated for each residential lot, thereby demonstrating the applicability of the methodology. The designed output is a unique score for each origin (residential lot) that represents the quality of the parks individuals have access to. This research provides researchers, planners and decision-makers with a systematic methodology to specifically measure the quality of park spaces and amenities accessible to individuals. While the methodology is applied to the city of Montreal, the approach is transferable to other contexts, all depending on data availability regarding park characteristics and transport networks.

2. Literature review

2.1. Quantifying park quality

Researchers have demonstrated a positive and significant association between park quality and park use among adults (Leslie et al., 2010; Knapp et al., 2019; Kaczynski et al., 2014) and youth (McCormack et al., 2010; Loukaitou-Sideris and Stieglitz, 2002). More specifically, the positive relationships to physical activity (Roemmich et al., 2006; Tucker et al., 2009) and lower obesity rates (Cohen et al., 2014; Hughey et al., 2017) for youth have been demonstrated.

Measures of a park's quality and attractiveness are based on a series of features considering the park's physical composition and condition, and the features available (Rigolon and Németh, 2018; Van Herzele and Wiedemann, 2003). These features are generally classified into park infrastructure, amenities, safety, aesthetic, nature and landscape (Ahn et al., 2020). Some researchers (Bird et al., 2015) have used children-specific activities, environmental quality, and service components. Building on these attributes, researchers have developed quantitative approaches to measure park quality to inform decision-making. Quantitative indicators, which are often context-dependent, have been developed in different urban regions around the world. These indicators are mainly designed for on-site observations of parks, where field raters assign quality scores based on a series of park features (Bird et al., 2015; Gidlow et al., 2012; Kaczynski et al., 2012). Other methods have also been put forward such as remote sensing including satellite, aerial imagery (Edwards et al., 2013), and geospatial open-source data (Rigolon and Németh, 2018).

Noteworthy to the present study is that the indicators found in the literature are designed to quantify the quality of a *single* park. An individual will likely have *access to multiple* parks. Those parks may have different characteristics such as a sports field in one and a community garden in another. A measure of just one park would not give an accurate measure of the joint quality of all parks accessible to the individual. To the authors' knowledge, no quality index has been set up for a group of parks (e.g., parks in a neighborhood, parks accessible from individuals' place of residence) to consider them as a combined environment.

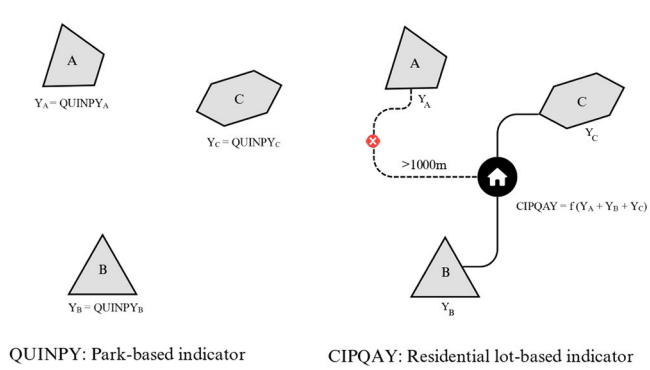

Fig. 1. Conceptual representation of the QUINPY and the CIPQAY.

2.2. Measuring accessibility to parks

The notion of accessibility is used in a wide range of research and planning applications, including the field of land use and transport (Hansen, 1959). Scholars generally measure access to a specific type of service considering accessibility, broadly defined as the ease of reaching destinations (El-Geneidy and Levinson, 2006). Accessibility studies are often based on counting the number of opportunities that can be reached from an origin point within a specified threshold (time or distance) and using a specific mode. This measure is known as the cumulative-opportunity accessibility and is by far the most widely used metric for accessibility (Boisjoly and El-Geneidy, 2017a).

Accessibility to parks specifically was measured previously in several case studies using a wide range of accessibility measures with differences in operational methods (Reyes et al., 2014; Zhang and Chen, 2024; Apparicio et al., 2010; Comber et al., 2008; Robillard et al., 2023; Liu et al., 2024; Wu and Zheng, 2023). For example, Reyes, et al (Reyes et al., 2014). measured children's walking accessibility to parks in Montreal considering the accessible surface area. This study is based on a cumulative-opportunity measure that sums rasterized park areas, whereas Comber, et al (Comber et al., 2008). measured greenspace access by counting the number of accessible parks in a city. Regardless of their type and method, accessibility measures are typically based on either the number or surface area of parks, thereby neglecting the quality/amenity aspects.

A few studies have considered parks amenities directly, mainly playgrounds (De Alvarenga et al., 2018). De Alvarenga, et al (De Alvarenga et al., 2018). measured accessibility to playgrounds within parks using proximity (closest playground) and availability (supply and demand) from an equity perspective. Other studies have accounted for multiple types of amenities. Dony, et al (Dony et al., 2015). considered nine amenities representing park quality (e.g., playgrounds, picnic areas), while Xing, et al (Xing et al., 2020). considered eight youth preferences for park quality (e.g., number of playgrounds, tree coverage). These studies incorporate park features, measured for each park separately, in a floating catchment area accessibility method in order to consider park attraction as a weighting term for the supply side (coefficient).

A recent study integrated park quality in the generation of an accessibility measure. Zhang, et al (Zhang et al., 2021). measured accessibility to peri-urban parks, defined as parks located on city outskirts, by combining a quality index of peri-urban parks, park size, and

travel time to parks. The researchers first designed a peri-urban park quality index (PPQI) based on 23 variables. Second, PPQI was calculated for each peri-urban park of the case study. Finally, the PPQI scores were used to weight the parks in the calculation of the accessibility measures, in this case based on the improved two-step floating catchment area (H-2SFCA). The comprehensive supply coefficient, park size, was therefore weighted based on the PPQI scores. While this approach does consider both park quality and accessibility, the index is first generated for each single park and then incorporated into the accessibility calculations. Accordingly, this method could still result in an accessibility score that does not reflect children's needs if certain park features are not present in every park, even though these features might be accessible across the group of parks as a whole. For instance, in some cases, what matters is the presence of one amenity (e.g., a splash park) in the surrounding parks, and not the number of splash parks per park. Similarly, the total number of features (for example playgrounds) is more directly related to children's needs than the average number of playgrounds per park.

To the authors' knowledge, no study has jointly measured the quality of a group of accessible parks within walking distance by simultaneously assessing all accessible park environment and features. Studies have measured individual park-by-park quality and then calculated a weighted measure of quality of all parks accessible from an origin (Xing et al., 2020; Zhang et al., 2021), without considering the joint quality of a group of accessible parks as one entity. Park-level indicators do not consider access or distances, including how far a child might be willing to walk, and common accessibility indicators (see for example (Reyes et al., 2014); Comber et al., 2008) tend to overlook children's specific needs and characteristics by only considering the number or surface area of parks accessible. Yet, to better reflect the level of accessibility to diverse amenities that are accessible to individuals within a reasonable distance, it is essential to jointly consider all amenities and spaces together when developing the quality index. This study directly addresses this research gap and contributes to integrate park quality in the measurement of accessibility. In doing so, it brings together the literature on park quality and accessibility. The study also contributes to testing and demonstrating the transferability of the QUINPY features.

3. Data and methods

Accessibility can be measured in different ways and from different perspectives: infrastructure-based, location-based, person-based, and utility-based (Geurs and Van Wee, 2004). In this study, we adopt a land use and transport perspective and focus on location-based accessibility, which provides an indication of the level of accessibility at a specific location (e.g., from a residential lot). These measures are well suited to provide a spatial diagnosis of accessibility and can in turn be combined with socio-demographic characteristics to include individual and equity components (Boisjoly and El-Geneidy, 2017b).

This study builds on the commonly used cumulative-opportunity accessibility measures. These measures have been proven to be highly correlated with a "more complex" and theoretically-sound measure, the gravity-based measure (Boisjoly and El-Geneidy, 2016). Given the complexity already associated with the scaling-up of the QUINPY index (as will be discussed in the next sections) and the number of variables included in our measure, we opted for the cumulative-opportunity approach. This measure avoids unreadability of the results and ensures adequate ease of interpretation and communication of the accessibility measures incorporated in the designed quality index discussed in the next sections. Similarly, while different thresholds might yield different results, only one distance threshold was applied in this study.

The study area is the city of Montreal, Canada. A diversity of park types exists in Montreal: more than 1175 urban and neighborhood parks managed by the 19 boroughs of the City, and 19 "Nature-parks" (*Parc-natures*) which are equivalent to metropolitan parks and are managed by the City of Montreal. A total of 3078 activities, considered as a major reason for individuals to visit green spaces and parks (Chen and Jim, 2008), are distributed across 1075 parks located in the city and are divided by the City into five different types: playgrounds, leisure, recreational, sports and open-air activities.

Fig. 2 presents the methodological framework developed for this study. Two categories of open-source geographic data are needed: park quality data (parks and park features), and data on public roads, including pedestrian infrastructure. Park data includes geospatial polygons and features such as playgrounds, community gardens, and maintenance standards, among other variables. Using these datasets, the score for each variable in every park is measured, whereas the pedestrian infrastructure data is used as the network to identify all parks and features accessible within a 1000 m threshold from each residential lot. A residential lot represents the smallest spatial unit of residential land use, referring to a "home", which can be a house, a duplex, or an apartment building. Then, based on the parks and park features accessible from each residential lot, an accessibility result is computed for each variable. Several scoring approaches are then used to assign a score to the residential lots, based on the distribution of the accessibility results. The result (CIPQAY) is obtained by summing all the variables scores.

The remainder of this section first briefly describes the QUINPY index and then presents how it is adapted to reflect the quality of a group of parks and thereby develop our combined index of parks quality and accessibility for youth (CIPQAY). It then presents the data sources and preparation required to generate the index for Montreal. Finally, we conclude with the specific methods used to generate the CIPQAY index.

3.1. QUINPY Index

The QUINPY (QUality INdex of Parks for Youth) (Rigolon and Németh, 2018) was selected as a starting point for this study. It is an assessment tool for the quality of parks for youth developed in 2018 in the United States. QUINPY measures the quality of a single park based

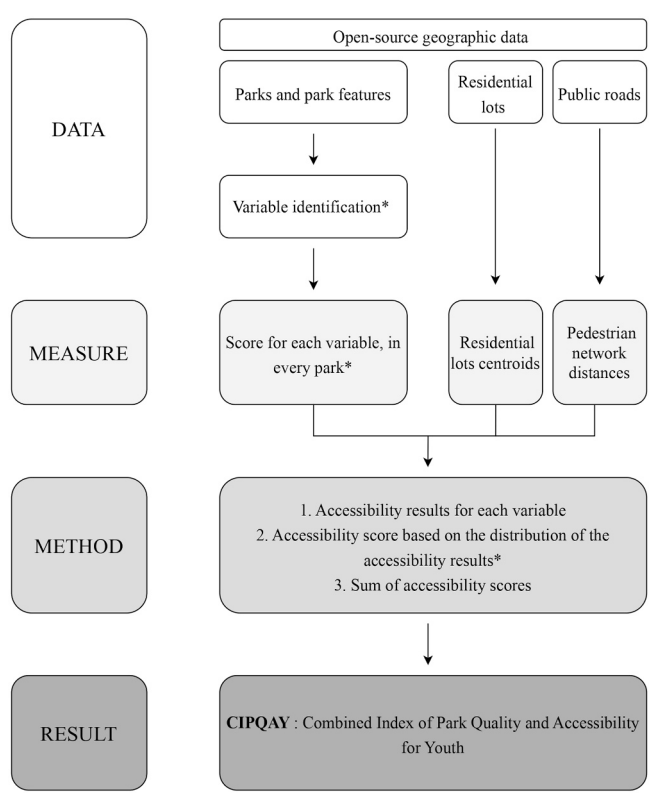

Fig. 2. Methodological framework for the development of the CIPQAY index (* steps needed to adapt the QUINPY to the CIPQAY).

on geospatial open-source data that can be analyzed using a geographic information system (GIS) software. In detail, the QUINPY includes 18 variables that are distributed into five weighted categories: structured play diversity, nature, park size, maintenance and safety. For each variable, scores (mainly between 0 and 3) are assigned (more details regarding the QUINPY index can be found in Rigolon and Németh (Rigolon and Németh, 2018)).

The main rationale for selecting the QUINPY is its double validation process since variables are chosen and categories weighted following a detailed literature review (youth "2–18 years old" and parks) with variables then validated by experts. The authors (Rigolon and Németh, 2018) reviewed 80 works which supported the weighting of the five categories, as a category would get its weight proportionally to the number of papers considering this aspect. For the validation process, experts from different countries were asked to rank six Denver parks, and findings show that the experts' rankings were equivalent to the ones obtained based on the QUINPY. Further, the QUINPY is easy to generate (relying on open-source geospatial data) and provides a comprehensive assessment of the parks' features and quality (18 variables). This allows for better replicability if the necessary data is available online. Therefore, after conducting an extensive review of the literature, the QUINPY index was considered as the most suitable for this study's purpose, taking into account its broad scope (five categories of park features, activities, and characteristics), its replicability, and its validation process.

3.2. CIPQAY: Scaling-up the QUINPY variables and scores

The proposed CIPQAY index relies on the same five categories and weights. As for the variables, when possible, the exact same variables were used. In some cases, minor adaptations were necessary given the data available for Montreal. In fact, particularity exists for the following variables: tree canopy, violent crime density and park maintenance standards. Given the nature of these variables, it is not possible to directly count the features. The definitions and their operationalization, as presented in the QUINPY, were thus adapted. First, the tree canopy ratio is now the sum of the tree canopy in the accessible parks over the surface area of these accessible parks. Second, the violent crime density variable is now the total number of violent crimes that occurred during the last year within accessible parks and in a 100 m buffer around them divided by the combined surface of the accessible parks (including the 100 m buffers). Finally, park maintenance standards are calculated by a weighted mean based on the surface area of accessible parks of each maintenance level. Further, to ensure that the CIPQAY adequately captures the quality of a group of parks, two modifications were necessary: (i) modifying the variable definitions and operationalization, and (ii) adapting the scoring approach.

Since the aim is to simultaneously assess the quality of all parks accessible considering the features of accessible parks, the variables are computed for all parks (and features) accessible at the same time, rather than for each park separately. The choice of variables depends on the data availability as presented in the next section.

Modifications to the scoring approach are essential to scale up the index and make it relevant for a group of parks. The idea is to determine a quality score that will closely reflect the options provided to individuals. In the absence of normative guidelines, most studies select thresholds either in an arbitrary manner, based on the local context, or based on planning standards or objectives.

The scoring framework developed consists of five scoring approaches: binary scoring, categorical scoring, number scoring, rank scoring, and standardized scoring. First, binary scoring is used when access to at least one opportunity (amenity/activity) is the objective. This approach is typically used in accessibility studies concerned with whether individuals have access at all to a specific service (e.g., pharmacy, post office) and when access to more than one opportunity of this type does not matter (Lucas et al., 2016). It can also be used to implement normative standards (for example, access to a minimum surface area). These standards are, however, almost non-existent for park amenities. Accordingly, the scoring approach will often be based on the area of study, to identify access to scarcely distributed features. For example, community gardens are not common in Montreal in terms of number per residential lots (41 gardens for 374599 residential lots), thus binary scoring fits well the context.

Second, categorical scoring (and/or) is used when the scoring approach depends simply on the variable's definition. It is applicable for variables that are divided into multiple categories.

Third, number scoring can be used for amenities available in limited numbers (example: number of playgrounds), when normative guidelines are provided.

Fourth, rank scoring (generally relative to the whole region of analysis) is considered. Assigning a rank score (e.g., quartiles, terciles, median) is most appropriate when accessibility results have a wide distribution and high variation. Variables are assigned a score based on their ranking relative to the rest of the region, as typically done in accessibility research (Widener et al., 2015; Widener, 2017).

Lastly, standardized scoring normalizes the values based on the maximum value. This scoring approach is also relative to the whole region but based on the maximum value. It is especially relevant for smaller distributions, mainly reflecting a variety of choices.

3.3. Data sources and preparation

This study is conducted using available open-source geographic data (Ville de Montreal, 2022). Since this study combines accessibility and park quality measurements, data management is divided into two parts: (i) parks and park features data, and (ii) residential lots and public road network data. The parks data availability check is done in order to design the final CIPQAY for Montreal, while residential lots and public road network preparation (namely extracting the pedestrian network) is required for the calculation of the accessibility measures.

With respect to parks and park features, Table 1 presents the datasets available for this study in relation to the 18 QUINPY variables. Two land-use datasets were used for the majority of the variables: (i) parks and green spaces (parks) and (ii) outdoor recreational, cultural and sport amenities at parks (park features). Parks and green spaces are geospatial polygons with features for each park (namely type of the park). Note that the terms parks and green spaces do not refer to distinct concepts in the database of the City and are, therefore, used interchangeably in this paper. The second dataset contains points for each activity located in parks, with features for each activity (namely type of activity, subtype of activity).

Additional datasets were obtained to cover variables that were not captured by the previous datasets: "community gardens", "tree canopy", "trails", "water fountain", "natural areas protected or under protection" and "criminal acts".

Finally, for this case study, two variables have no available data: (i) organized sport activities and (ii) playground surface. Conversely, a variable was added in relation to the splash parks, for a total of 17 variables instead of 18. A "splash parks" variable was added, while the "organized sport activities" was removed. Organized sports in QUINPY refers to afterschool programs and community centers. In the context of Montreal, these are located principally at schools and in buildings distinct from parks respectively. A decision was made to exclude those as they are not available freely to the public. Other green areas such as golf courses were also excluded for the same reason. Splash parks and paddling/play pools (total of 248 in Montreal) are important components of parks and largely visited by youth in Montreal. These splash parks are generally enjoyed by children with an added play value (Lewis, 2005).

Finally, park maintenance standards were not available: the variable was replaced with the type of park as a proxy for the maintenance standards based on consultation with the parks department of the City:

Table 1
Data availability, sources and preparation for the case study of Montreal.

QUINPY Variable	Availability	Dataset and geometry	Data manipulation and modifications to the QUINPY variable if needed
Playground number	√	Park features (POINTS)	
Playground surface	NA		
Sports-fields (by type)	√	Park features (POINTS)	
Sports-courts (by type)	√	Park features (POINTS)	
Walking/bike paths and hiking/ horseback trail	√	Park features (POINTS) "trails" (POLYGONS)	Each trail was converted from polygon data to points separated by an average distance of 65 m since a trail's linearity makes it accessible from any location (point) along it.
Public swimming pool	√ (Pools and splash parks*)	Park features (POINTS)	Two variables instead of one.
Supporting facilities (picnic areas, benches, BBQ, bathrooms/ water fountain)	√ (not all features – only picnic areas and water fountains available)	Park features (POINTS) Water fountain (POINTS)	Only picnic areas and water fountain are considered.
Organized sport activities (after school programs or recreation centers)	NA		
Water as visual amenity	√	Park features (POINTS) Wetlands (POINTS)	
Access to water for recreation	√	Park features (POINTS)	
Tree canopy ratio	√	Tree canopy (POLYGONS)	
Vegetation/ shading around behavior settings	√	Park features (POINTS) Tree canopy (POLYGONS)	Shaded behavior settings are located by extracting playgrounds and sport activities where 50 % of their 30 radial lines of a length of 15 m and 60 m respectively intersect with tree canopy polygons.
Natural areas, nature preserves, or nature centers	√	Natural areas protected or under protection (POLYGONS)	
Community gardens	√	Community gardens (POINTS)	
Distant views (from waterfront or hills)	√	Park features (POINTS) Parks (POLYGONS)	Parks with waterfront are extracted by selecting parks where their perimeters are up to 100 m away from a waterfront (using buffers).
Park acreage	√	Parks (POLYGONS)	
Park maintenance standards	√	Parks (POLYGONS)	The variable was replaced with the type of park as a proxy for the maintenance standards based on consultation with the parks department of the City.
Violent crime density	√	Criminal acts (POINTS) Parks (POLYGONS)	

*) The "splash parks" variable is not present in the QUINPY index. It was added specifically for the case study context of Montreal

green islands and promenades (low maintenance), neighborhood parks (mid-low maintenance), urban parks (mid-high maintenance) and metropolitan and large parks (high maintenance). This scoring approach assumes that larger parks typically have higher maintenance standards based on the governance structure, while fewer resources are allocated to the maintenance of small neighborhood parks.

3.4. Generation of the measures

Once the data were prepared, the measures were generated at the residential lot level using a configurable tool developed by the research team on ArcGIS. This tool determines the parks or park features that can be reached from each residential lot within a specific pedestrian network distance. The pedestrian network is generated from the public road network data: it includes all pedestrian links as well as the streets with sidewalks. For the threshold, a 1000 m pedestrian network distance is fixed which is considered a reasonable distance for children to walk (Waygood et al., 2017). Older youth may have a longer reasonable walking distance, but the lower threshold was used to be more inclusive. This method also accounts for the possibility that children access parks by bicycle, an important mode of transport for them since they are unable to drive.

The pedestrian network distance is calculated from each destination point to each residential lot centroid. The tool identifies all parks and features that are within the 1000 m threshold of each residential lot, as shown in Fig. 1. Park access is inspired by an Apparicio, et al (Apparicio et al., 2010). study by considering multiple access (destination) points along the perimeter of the park, while park features are simply represented by points. Access is considered by snapping the access point or the feature point to the closest street segment.

Accessibility is then computed for each variable (or feature) for each of the 17 variables. The most appropriate scoring approach is selected based on the accessibility results and criteria presented in the section above. The scores are then computed for each variable and residential lot. As such, the CIPQAY index was calculated for the 374,599 residential lots in Montreal. The accessibility results, the scoring approach and scores, as well as the index results are presented in the next section.

3.5. Statistical and spatial analysis

Following the generation of the CIPQAY measure, statistical analysis is performed by: (i) calculating the CIPQAY distribution with quintiles, (ii) comparing the CIPQAY quintiles results with commonly used

accessibility measures (number of parks, and park surface area), and (iii) calculating Z-scores for each category of the CIPQAY and analyzing these results against the CIPQAY quintiles

Within the accessibility literature, there are few guidelines on thresholds to use as minimum levels of access, thus the results are presented using a rank approach (quintiles). Then, the average number of parks accessible and the park surface area accessible are compared across the CIPQAY quintiles using ANOVA to identify any significant differences with the "stats" package from R (Development Core Team, 2010). The Tukey's range test is then used to confirm the results and identify differences between pairs of quintiles. Furthermore, the results for the five categories contributing to the CIPQAY are assessed by comparing, for each category, their average Z-scores across the CIPQAY quintiles. Results are again assessed using the ANOVA and Tukey's range tests.

In addition to the statistical analysis, spatial differences are assessed by: (i) mapping the CIPQAY scores at the residential lot levels based on the quintiles values, (ii) assessing the spatial autocorrelation by calculating Global and Local Moran's I with the "spdep" package in R (Bivand et al., 2013), and (iii) comparing the spatial distribution of the scores obtained for the five categories of the CIPQAY and the number of parks with six distinct maps. In addition, on each of these maps, the clusters of Low-Low CIPQAY scores identified in the previous step are highlighted.

This second analysis phase sheds light on the spatial distribution of the index, of its five categories and of the common measures of accessibility based on the number of parks. The spatial autocorrelation analysis first considers the Global Moran's I to assess whether the CIPQAY values are not randomly distributed on the map. Then, the Local Moran's I is used to identify local clusters and is especially useful to identify areas concentrating low CIPQAY scores. For the generation of neighbors, the queen contiguity is used considering the small sizes of residential lots in Montreal. Finally, by overlaying the Low-Low clusters with the maps of the "Structured play diversity", "Nature", "Park size", "Maintenance", "Safety", and "Number of parks", we can assess the contribution of each category to the low CIPQAY scores across the territory.

4. Results

4.1. Distribution and scores of the CIPQAY index for the city of Montreal

The accessibility results of all the variables, or features required to build the variables, for the 374,599 residential lots are summarized in Table 2 with the five weighting categories. Alongside the statistical results, the proportion of residential lots that have access to the variable is given. This proportion along with the number of the features (N) for each variable are useful indicators for the binary scoring.

Since very little theoretical guidance or standards exist in the literature, several scoring approaches were selected based on the distribution of the results across the region. These scoring approaches were then associated to the variables as described in Table 3.

First, *natural areas*, *community gardens*, *distant views*, *water for recreation*, *water as visual amenity*, and *public swimming pool* are valuated as binary scores based on statistical results. This choice is due to their low accessibility across the city (more than 70 % of the population with no access) (Table 2). Binary scoring was also selected for *trails*. Since the latter is represented by multiple points (and not a line), the assumption is based on the following two statistics: (i) access to an average of 3.21 points (median) and (ii) only 51.03 % of residential lots have access to at least 1 point. In this case, we consider that having access to multiple trails is rare as a unique trail is represented on average by 12 points (multiple points along the trail). Finally, binary scoring was also attributed to *splash parks* based on the variable's definition. Although the number of splash parks (N = 248) is bigger than the number of swimming pools (N = 70) in Montreal, the same scoring type is chosen for consistency reasons. Splash parks and swimming pools both involve

Table 2
Summary statistics of the accessibility results for the different variables and separated features.

Variables	Number of features accessible					
Name	N	Min	Max	Mean	SD	With access to (%)
Structured play diversity (44 %)						
Playground	979	0	23	5.78	3.54	96.85
Sports-field types	5	0	3	0.69	0.57	63.39
Sports-court types	10	0	8	1.84	1.59	79.47
Walking/bike paths and hiking trail	1399*	0	146	3.21	7.09	51.03
Public swimming pool	70	0	3	0.33	0.55	29.35
Supporting facilities: picnic area	74	0	4	0.32	0.64	24.94
Supporting facilities: water fountain	812	0	24	5.05	3.95	91.26
Splash parks	248	0	8	1.57	1.34	76.67
Nature (28 %)						
Water as visual amenity	183	0	16	0.39	1.05	21.06
Water for recreation	7	0	2	0.02	0.12	1.48
Tree canopy ratio (tree canopy surface / park surface area)	NA	0	1	0.31	0.16	NA
Vegetation/ shading around behavior settings: ≥ 50 % of playgrounds enclosed	533**	0	13	3.49	3.42	86.06
Vegetation/ shading around behavior settings: ≥ 50 % of sport activities enclosed	280**	0	12	1.56	1.58	70.06
Natural areas	123	0	11	0.278	0.87	17.54
Community gardens	41	0	3	0.24	0.5	20.92
Distant views (waterfront)	241	0	16	0.68	1.54	25.03
Distant views (hills)	31	0	3	0.09	0.33	7.61
Park size (9 %)						
Park surface area (km^2)	NA	0	5.65	0.41	0.53	99.6
Maintenance (10 %)						
Park maintenance standards proxy	NA	0	3	1.81	0.72	NA
Safety (9 %)						
Violent crime	19703***	0	1100	119.41	130.31	NA

(*) Number of trail "points" accessible
(**) Number of accessible enclosed behavior settings
(***) Number of violent crimes in accessible parks and in 100 m buffer around accessible parks

Table 3
Final model of the CIPQAY for the city of Montreal vs. initial QUINPY index.

	Combined Index of Parks Quality and Accessibility for Youth (CIPQAY)		QUINPY (Rigolon and Németh, 2018)*	
Categories	Variables	Score	Variables*	Score*
Structured play diversity (weight: 44 %)	Playground number	0: no accessible playground 1: number of accessible playgrounds in the first tercile in the city 2: number of accessible playgrounds in the second tercile in the city 3: number of accessible playgrounds in the third tercile in the city	Playground number	0: no playground 1: 1 playground 2: 2 or more playgrounds
	NA		Playground surface	0: below median playground surface for parks in city 1: above median playground surface for parks in city
	Sports field (by type)	Continuous value between 0 (no accessible sport field) and 2 (all the sports-field types are accessible). (e.g, 1 is an equivalent value to 50 % of sports-field types are accessible)	Sports field (soccer, baseball, football, rugby and lacrosse)	0: no sports-field 1: sports-field of one type 2: sports-fields of two or more types
	Sports courts (by type)	Continuous value between 0 (no accessible sport courts) and 2 (all the sports-court types are accessible). (e.g., 1 is an equivalent value to 50 % of sports-court types are accessible)	Sports courts (basketball, tennis, skateboard and handball)	0: no sports-court 1: sports-court of one type 2: sports-courts of two or more types
	Walking/ bike paths and hiking trail	0: no accessible paths or hiking trails 1: accessible paths or hiking trails	Walking/ bike paths and hiking/ horseback trail	0: no paths or hiking trails 1: paths or hiking trails are included
	Public swimming pool	0: no accessible swimming pool 1: a swimming pool is accessible	Public swimming pool	0: no swimming pool 1: a swimming pool is included
	Supporting facilities (picnic areas, water fountain)	0: no accessible picnic area or water fountain 1: accessible picnic area or accessible water fountain 2: accessible picnic area and accessible water fountain	Supporting facilities (picnic areas, benches, bbq, bathrooms/ water fountain)	0: no picnic area/BBQ/ benches or bathroom/ water fountain 1: picnic area/ BBQ/benches or bathroom/ water fountain 2: picnic area/ BBQ/benches and bathroom/ water fountain
	NA		Organized sport activities (after school programs or rec centers)	0: no organized sport activities 1: organized sport activities
	Splash parks	0: no accessible splash park or paddling/ play pool 1: accessible splash park or paddling/ play pool	NA	
Nature (weight: 28 %)	Water as visual amenity (lakes, fountains)	0: no water as visual amenity is accessible 1: water as a visual amenity is accessible	Water as visual amenity (lakes, streams, fountains, or beach)	0: no water as visual amenity 1: water as a visual amenity is included
	Access to water for recreation (water-to-swim, canoe or kayak)	0: no access to water for recreation 1: water for recreation is accessible	Access to water for recreation (water-to-swim, canoe or kayak)	0: no access to water for recreation 1: access to water for recreation is included
	Tree canopy: (accessible tree coverage-park size ratio)	0: tree coverage-accessible park size ratio in the lower tercile for residential lots in the city 1: tree coverage-accessible park size ratio in the	Tree canopy: Tree coverage in relation to park acreage	0: tree coverage-park acreage ratio in the lower tercile for parks in city 1: tree coverage-park acreage ratio in the middle tercile for parks in city 2: tree coverage-park acreage ratio

(continued on next page)

Table 3 (*continued*)

	Combined Index of Parks Quality and Accessibility for Youth (CIPQAY)		QUINPY (Rigolon and Németh, 2018)*	
		middle tercile for residential lots in the city 2: tree coverage-accessible park size ratio in the higher tercile for residential lots in the city		in the upper tercile for parks in city
	Vegetation/ shading around behavior settings (by type): tree cover enclosed settings for more than 50 % of perimeter	0: no accessible behavior settings are enclosed 1: number of accessible enclosed behavior settings of one type is higher than median in the city (playground or sport facility) 2: number of accessible enclosed behavior settings of two types is higher than median in the city (playground and sport facility)	Vegetation/ shading around behavior settings: tree cover enclosed settings for more than 50 % of perimeter	0: no behavior settings are enclosed 1: one type of behavior setting is enclosed (playground or sport facility) 2: two types of behavior settings are enclosed (playground and sport facility)
	Natural areas or nature preserves	0: no accessible natural areas/ preserves 1: natural areas/ preserves are accessible	Natural areas, nature preserves, or nature centers	0: no natural areas/ preserves/ centers 1: natural areas/ preserves centers are included
	Community gardens	0: no accessible gardens 1: accessible gardens	Community gardens	0: no gardens 1: gardens
	Distant views (from waterfront or hills)	0: no accessible distant views 1: accessible distant views	Distant views (from waterfront or hills)	0: no distant views 1: distant views
Park size (weight: 9 %)	Park surface area (km^2)	0: accessible park surface area in the lower quartile in the city 1: accessible park surface area in the middle-lower quartile in the city 2: accessible park surface area in the middle-upper quartile in the city 3: accessible park surface area in the upper quartile in the city	Park acreage	0: park acreage in the lower quartile in the city 1: park acreage in the middle-lower quartile in the city 2: park acreage in the middle-upper quartile in the city 3: park acreage in the upper quartile in the city
Maintenance (weight: 10 %)	Park maintenance standards	Continuous value between 0 (lowest maintenance level) and 3 (highest maintenance level). (e.g, 1 is equivalent to a mid-low maintenance level; 2 is equivalent to a mid-high maintenance level)	Park maintenance standards	0: Lowest maintenance level (e.g natural areas) 1: Mid-low maintenance level 2: Mid-high maintenance level 3: Highest maintenance level (metropolitan park…)
Safety (weight: 9 %)	Violent crime density (total number of violent crimes in accessible parks and in 100 m buffer around accessible parks divided by the combined surface of the accessible parks and of its 100 m buffer)	0: violent crime density in the higher quartile for accessible parks in the city 1: violent crime density in the mid-higher quartile for accessible parks in the city 2: violent crime density in the mid-lower quartile for accessible parks in the city 3: violent crime density in the lower quartile for accessible parks in the city	Violent crime density (total number of violent crimes in park and in 100-yard buffer around a park divided by the combined surface of the park and of its 100-yard buffer	0: violent crime density in the higher quartile for parks in the city 1: violent crime density in the mid-higher quartile for parks in the city 2: violent crime density in the mid-lower quartile for parks in the city 3: violent crime density in the lower quartile for parks in the city

water activities, and the former are typically only enjoyed by children.

Second, categorical scoring is chosen for the *supporting facilities* simply due to the definition of the variable. This variable is based on having access to a picnic area and/or a water fountain.

Third, rank scoring was attributed for the *playgrounds*, *tree canopy*, *violent crime density,* and *park surface area*. The four variables have varying accessibility results across the region: they have a wide distribution and high variation as shown in Table 2. The scoring fits the context well and is relative to the city's results by dividing values into

terciles and quartiles. For the *maintenance standards* proxy, the number also represents a rank, although a decimal is present since it is a surface-weighted average. A particularity shows for the *vegetation/shaded around behavior settings* variable. Following QUINPY, it is a categorical scoring variable, of two rank scoring features (shaded playgrounds and shaded sports activities) based on their accessibility results (Table 2). Median values (3 for playgrounds, 1 for sport activities) are used as thresholds. Residential lots below the median access get a score of 1; those above median access get a score of 2.

Finally, 8 different *sports-courts* and 5 different *sports-fields* are present in this study. For each variable, having access to several types (by variable) highlights the diversity aspect that can be evaluated by scoring these variables. Standardized scoring is chosen then, with a value that ranges between 0, equivalent to not having access for any sports type of the variable and 2 representing a full diversity in access.

It is important to mention that the scoring approach is determined here based on the Montreal accessibility results, and direct application to another city using the same thresholds is not advised. The same logic can nonetheless be applied. Further work with citizens could also identify desirable thresholds.

As a final result, Table 3 presents the CIPQAY – the quality index of the surrounding parks for youth – for the case study of Montreal, with 17 variables and a total score of 30 in comparison to the initial QUINPY index.

4.2. Results of the CIPQAY index for the city of Montreal

The distribution of the index scores by number of residential lots is displayed in Fig. 3. With a mean of 12.77, the results vary between 0 (residential lots with no access to parks) and 23.21 as maximum value, with approximately 55 % of the residential lots having a score between 10 and 15. This distribution confirms the presence of discriminated groups of residential lots based on the quality of parks accessible to youth throughout the city. The distribution was split into five quintiles, which will be used in further analysis.

Fig. 4 presents the results for the CIPQAY for all 374,599 residential lots across the region. The four administrative areas of Montreal are also presented, with the "Center" and "CBD" areas outlined with a dotted line and a solid line respectively. As illustrated, high and low scores for the CIPQAY are spatially dispersed across the city, with several local clusters. High score (above 15.55) clusters can be found primarily near large parks and near water bodies. As for low scores (below 10.09), spatially distributed gaps in access are present across the city with a concentration in the West region of the city as well as downtown. The gray areas are part of the City of Montreal but are non-residential lots, whereas white areas represent other municipalities. These maps highlight areas

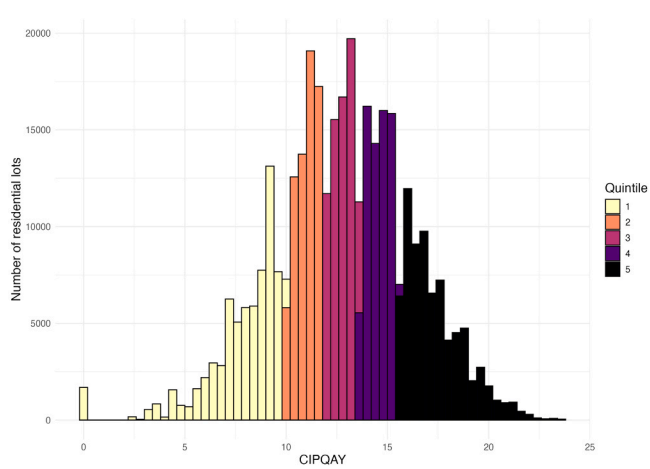

Fig. 3. Distribution of the CIPQAY scores with five quintiles.

that could be prioritized for further investigations and interventions. While other considerations such as deprivation levels, the number of people impacted, or other societal concerns would need to be considered, the CIPQAY index provides a diagnostic tool to identify areas with low levels of quality of the surrounding parks for youth.

To assess the spatial distribution of the CIPQAY values, the Global and Local Moran's I are calculated. These indicators measure spatial autocorrelation to identify if CIPQAY scores are randomly distributed over the Montreal territory. First, the Global Moran's I statistic is statistically significant and positive (I=0.955, $p < .001$), indicating that some neighbouring residential lots tend to have similar CIPQAY scores. Second, the Local Moran's I identified 19.2 % residential lots belonging to High-High clusters, 22.6 % to Low-Low clusters, with only 0.2 % High-Low, and 0.1 % Low-High clusters. These findings suggest that there are few spatial outliers.

As shown in Fig. 5, the Local Moran'I analysis confirms the previous observations: most neighborhoods in the lowest CIPQAY quintile, outlined on the map, are characterized by Low-Low clusters.

The number of parks accessible and the area of parks accessible are commonly used measures for measuring park accessibility (Reyes et al., 2014; Comber et al., 2008; Wozniak et al., 2025). The relationship between CIPQAY's quintiles and those measures are presented in Fig. 6. The CIPQAY is positively associated with both the number and the area of parks. One-way ANOVA tests on the CIPQAY quintiles are significant for both the area ($F(4,374594) = 9206$, $p < .001$) and the number of parks ($F(4,374594) = 1997$, $p < .001$). This result is less pronounced for the number of parks as the interquartile range is between 4 and 14 parks for all five quintiles, indicating low statistical dispersion. In contrast, the accessible area shows a more significant variation, with the fifth quintile having a median value (0.47) almost six times higher than the first quintile (0.08). These observations are confirmed by Tukey HSD tests, with differences in the park area accessible being statistically significant for every pair of quintiles ($p < .001$). For the number of parks, every pair is statistically significant except for quintiles #2 and #3 ($p = .935$).

The Z-scores of each category are computed for every individual and then averaged for the five CIPQAY quintiles. The results shown in Fig. 7 demonstrate how each category is associated with the CIPQAY score. ANOVA tests were performed between quintiles for each category and revealed significant differences for the five categories: structured play diversity ($F(1, 3) = 53.08$, $p = .005$), nature ($F(1, 3) = 221.2$, $p < .001$), park size ($F(1, 3) = 63.18$, $p = .004$), maintenance ($F(1, 3) = 549.8$, $p < .001$), and safety ($F(1, 3) = 18.21$, $p = .024$). Overall, the lower quintiles exhibit lower scores for all categories. For the highest quintile (5), the "Nature" category is first, followed closely by "Park size" and "Structured play diversity" in terms of relative importance with average Z-scores above 0.75. The "Structure play diversity" category also has the highest variation between quintiles, with average Z-scores ranging from −1.13–0.81. The third quintile shows average values (near 0 z-scores) for all indicators except the "Structured play diversity" (positive) and the "Park size" (negative). Parks in this quintile are most likely small parks with a high number of features. Examining carefully the map presented in Fig. 4, this quintile is indeed predominantly found in areas with several small parks.

In addition to analyzing the average Z-scores, maps are produced to identify spatial discrepancies for the five categories of the CIPQAY, as well as the number of parks (Fig. 8). The "Structured play diversity" category, which includes playgrounds and sports fields has higher scores in central areas. "Safety" exhibits an opposite pattern, with low scores in central areas, gradually increasing with distance from the center of the city. "Park size" is only high near big parks, similar to the "Nature" category. The "Nature" category also shows high values near the north and south riverbanks. The number of parks is highest downtown (CBD) and in the Center area. The downtown area illustrates the shortcomings of the number of parks as a measure of accessibility to parks, having a high density of parks, but lacking infrastructure for activities, nature sights, and maintenance. However, we must restate that a direct

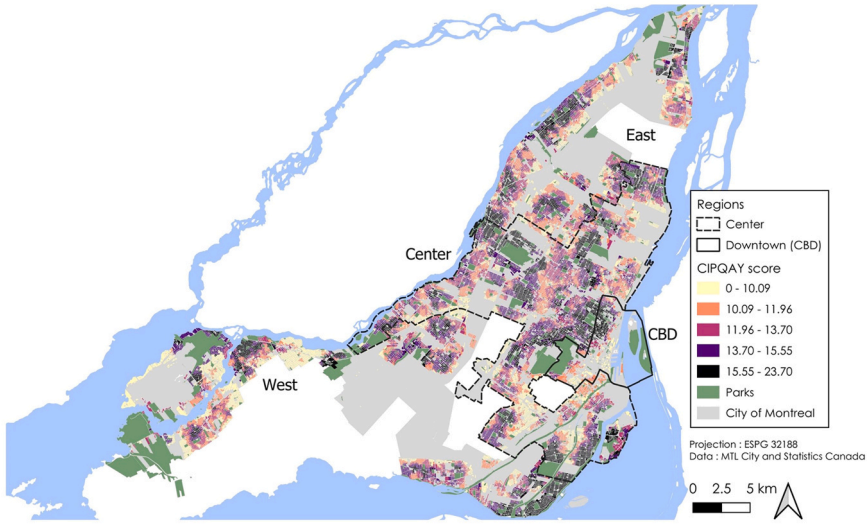

Fig. 4. CIPQAY scores of residential lots in Montreal, Canada, grouped by quintile.

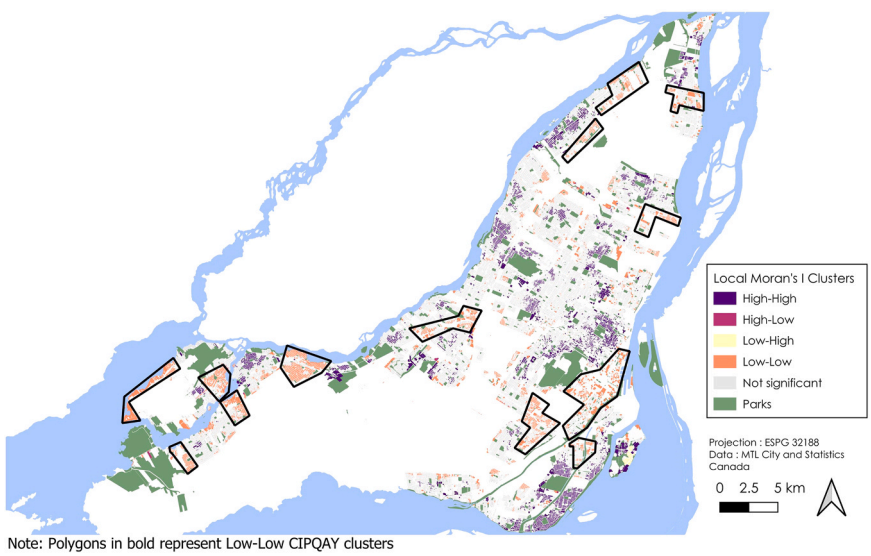

Fig. 5. Local Moran's I clusters.

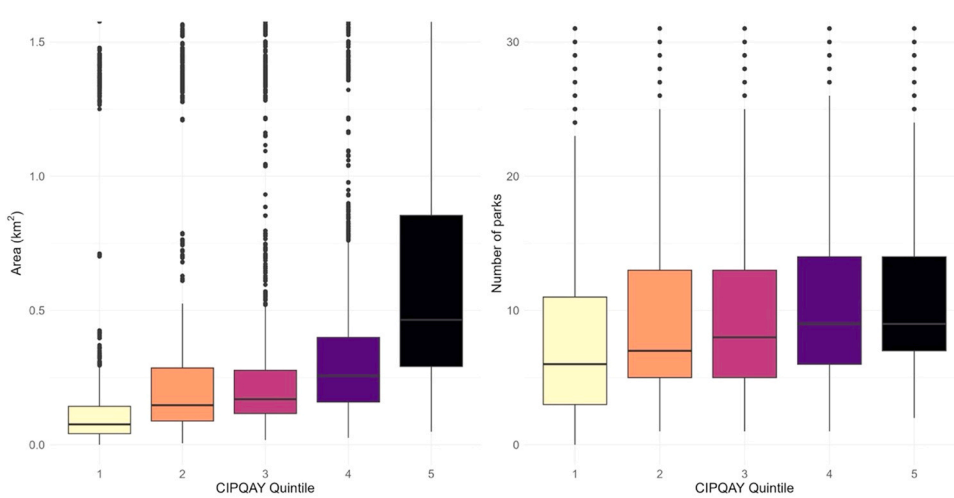

Fig. 6. Boxplots for the number of parks and the area with the CIPQAY quintiles.

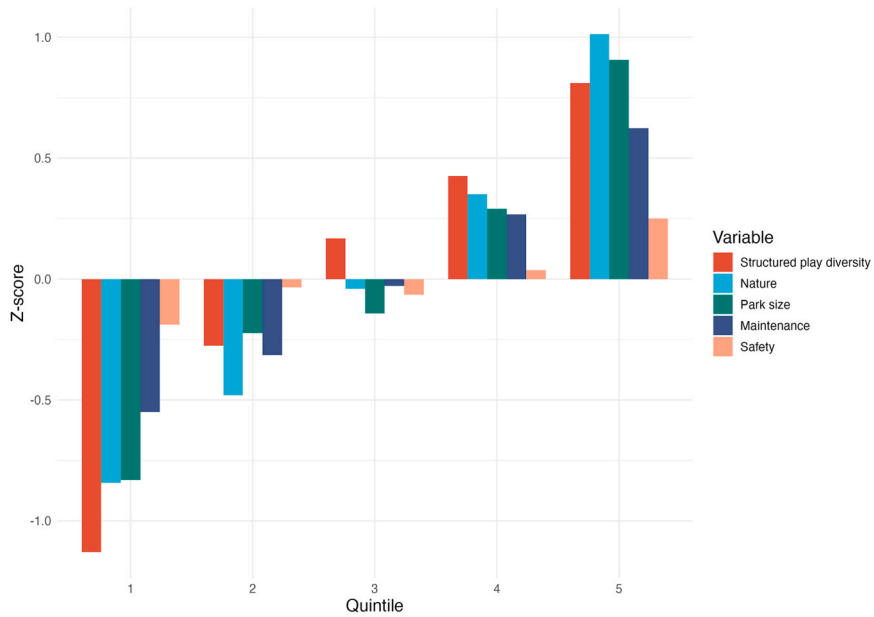

Fig. 7. Average Z-scores for the five categories of the CIPQAY.

measure of maintenance at each park was not used.

Looking now at the low CIPQAY areas, we can identify, for each of these areas, which categories contribute to the low results. For example, the downtown areas exhibit low values for all categories except for the number of parks. Conversely, the areas to the western tip of the island predominantly exhibit values in the lowest quintiles only for the "Structured play diversity" and "Park size" categories, while all scores are in the highest quintile for the "Safety" category.

Overall, these discrepancies highlight the relevance of a composite index, to capture the diverse features of parks. The index's applicability was also demonstrated in another study by the authors, which confirmed its positive association with perceived accessibility (El Murr et al., 2023).

5. Discussion

This paper proposed a new methodology to develop an index combining the quality and accessibility of parks. Building on an existing park-based index, the QUINPY (Rigolon and Németh, 2018), variables and scores were first adapted to reflect the combined quality of surrounding parks. Second, using open-source data, CIPQAY variables and scores were defined and operationalized based on the study context of Montreal and data availability. The final index for Montreal contains 17 variables for a total (maximum) score of 30 and was computed for the 374,599 residential lots. Results of the statistical analysis first revealed that the commonly used accessibility indicators (number of parks and park surface area) were on average significantly higher for residential lots with higher CIPQAY scores. Findings thereby suggest that CIPQAY scores are positively associated with the number of parks and surface area accessible.

However, discrepancies still exist between the CIPQAY and these two indicators when the results are examined spatially. While some areas concentrating low CIPQAY scores are also characterized by a low number of parks, others are characterized by a number of parks in the three highest quintiles. Most evidently, as discussed previously, the downtown area of Montreal exhibits a high number of parks (5th quintile), but low CIPQAY scores (with most residential lots in the lowest quintiles for the "Structured play diversity", "Nature", "Maintenance" and "Safety" categories). While not as pronounced, we also observe some areas with low CIPQAY scores in the highest park size quintile, as is the case in the downtown area.

The differences observed between the CIPQAY score and commonly used indicators of park access are worth considering as previous research has shown a positive and significant association between the CIPQAY and perceived park accessibility in Montreal (El Murr et al., 2023). That previous work compared calculated measures of accessibility (number of parks accessible, park area accessible, and the CIPQAY) with a measure of perceived accessibility to parks collected through an online survey. Controlling for socio-demographic variables, the study demonstrated that a higher CIPQAY score was associated with a higher perceived park accessibility among respondents. In contrast, no significant relationship was observed for the park size, and a negative relationship was observed for the number of parks (El Murr et al., 2023). While the study was based on adults' perceived accessibility, the CIPQAY score was developed specifically for youth. Future research could investigate the relationship between the CIPQAY and adolescents' perceived park accessibility. Nonetheless, this indicates that efforts to increase the CIPQAY score, and not solely the number of parks, should be considered to increase parks' quality and accessibility. Whereas an increased number of parks presents an opportunity to increase accessibility, the quality of these parks should not be neglected.

In line with this, the proposed combined index can be used by practitioners and policymakers to first identify areas with low CIPQAY scores (namely through a local clustering approach) and then, for each of these areas, examine which of the five dimensions should be improved. In the context of limited resources for improving accessibility to parks, the composite CIPQAY score enables practitioners and policymakers to target areas that should be prioritized in terms of interventions. Then, for each of these areas, they can analyze the five CIPQAY categories to identify which features related to structured play diversity, nature, maintenance, or safety are lacking for instance. Specific interventions can then be prioritized for each area. In the case of a neighborhood with a high number of parks accessible but a low CIPQAY score (e.g., Montreal's CBD), the CIPQAY categories could be assessed to plan interventions regarding specific park features missing (e.g., playgrounds, sports courts, community gardens). Conversely, neighborhoods lacking green spaces where construction of new parks is planned could benefit from the CIPQAY analysis to identify locations to maximize the population's accessibility. The five CIPQAY categories can also be analyzed for the whole region to plan for city-wide interventions.

Another strength of the CIPQAY is that it is measured at a fine spatial unit (here residential lots), and it can be adapted to any spatial unit of

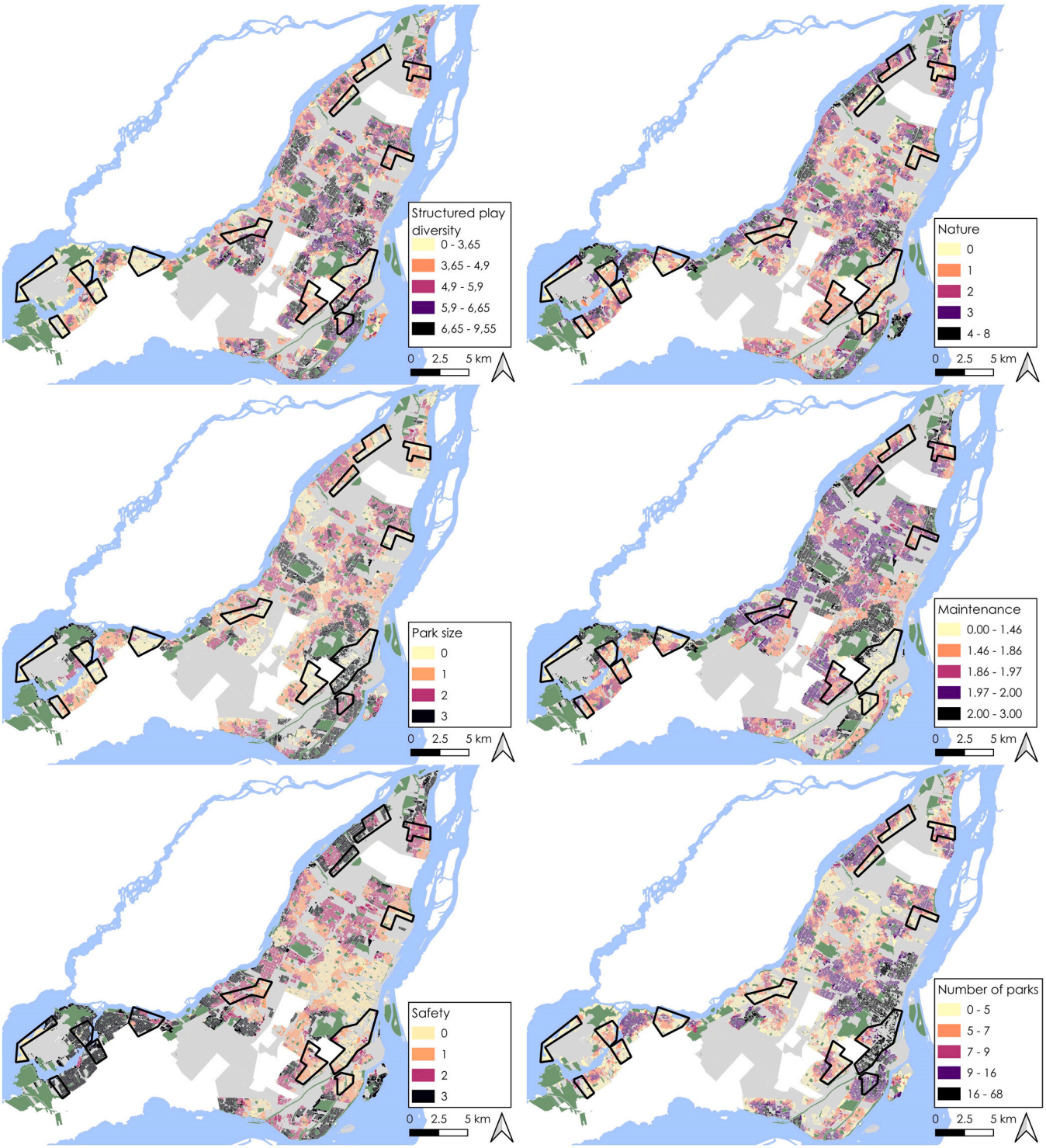

Fig. 8. Residential lot scores for the five categories of CIPQAY and the number of parks.

interest (e.g., census block, dissemination area). By combining these measures with sociodemographic characteristics, it is possible to understand who benefits from these high-quality parks and whether those benefits are equitably distributed, as done in other studies (Reyes et al., 2014; De Alvarenga et al., 2018; Xing et al., 2020). These measures could be used by planners and decision-makers to guide and inform the future development of parks from an equity perspective.

However, as a composite index integrating 17 variables and an accessibility component, the CIPQAY can be of limited use for explaining specific gaps in park quality in its composite form. In fact, to analyze and understand what explains low or high CIPQAY scores, the index must be decomposed into its different categories. Further, the CIPQAY is unitless which limits its interpretability, an important criterion to consider when developing an accessibility measure (Geurs and Van Wee, 2004). As discussed previously, the CIPQAY results were presented and analyzed using ranked accessibility categories with quintiles. With these categories, it is impossible to directly interpret the accessibility score. Decision-makers or planners could prefer indicators measuring the

number of parks or surface area accessible, which could be used to set accessibility targets, as done by the City of Montreal (Ville de Montreal, 2024). However, as shown in El Murr, et al (El Murr et al., 2023)., such measures, especially the number of parks, should be used with caution given their negative or weak relationship with perceived park accessibility. Park-based indicators, as compared to accessibility measures such as the CIPQAY, also present some strengths and could be useful for planning interventions or improvements in each park, by comparing their features and amenities (Rigolon and Németh, 2018; Bird et al., 2015). Park-level scores are also intuitive, easy to communicate and easier to compute than accessibility measures.

Overall, both types (park-based and accessibility measure) of indicators have their strength and weaknesses and can be used in a complementary manner: park-level indicators (i.e. the QUINPY) can support decision-making at the park level, whereas accessibility indicators (i.e. the CIPQAY) can be used for broader planning strategies (as done by the City of Montreal in their land use and mobility plan (Ville de Montreal, 2024)). Future studies could investigate how both types of indicators can be used simultaneously and explore how they are adopted in practice.

The proposed framework can be replicated to adapt the index to other cities and contexts. It demonstrates how to select and define the variables and thresholds based on their relevance to the study context. For instance, splash parks were added to the Montreal analysis considering their importance for youth, which may not apply to other cities in different climate contexts. Nevertheless, future studies replicating this approach and comparing the different indicators would further contribute to the understanding of the different measures.

6. Conclusion

In this paper, we proposed a methodology to generate an index that combines the quality and accessibility of parks. The methodology contributes to the literature on park accessibility by assessing groups of parks as a combined environment. Specifically, the Combined Index of Parks Quality and Accessibility for Youth (CIPQAY) integrates a recently developed quality index of parks for youth, QUINPY (Rigolon and Németh, 2018), within cumulative-opportunity measures (as measures of accessibility).

To test the applicability of the methodology, the index was applied to the city of Montreal. Results show clear discrepancies between commonly used accessibility indicators (number of parks and park area accessible) and the CIPQAY index. The CIPQAY score and its five categories (structured play diversity, nature, park size, maintenance, and safety) can offer planners and decision-makers insights into strategies to improve park accessibility.

There are nonetheless limitations and further potential developments that are worth mentioning. First, methods that rely on open-source data, like this 17-variable index, are susceptible to flawed data or missing data. The wide range of variables required to compute the index can also limit replication to other cities depending on the data availability. For the open-source data of Montreal, some data (supporting facilities for example) are present only for large parks, that are under the supervision of the City, but not for the 1000 + other urban parks, that are managed by other administrative entities, namely boroughs. Other cities or jurisdictions may have access to high quality databases, suggesting this is more a limitation to the Montreal case study rather than a limitation of the method itself.

Second, the type of geospatial data has effects on results: the majority of the data here are represented by points, thus the operationalization of the different variables is less precise or not achievable. This is the case for playgrounds and sport activities: the playground surface variable was, therefore, removed from the index, while assumptions were taken to calculate the proportion of vegetation around behavior settings. As for the level of maintenance, it was assigned based on the type of parks since no maintenance data was available. This might not reflect actual park conditions. Future research is required to examine how park maintenance can be better assessed with other forms of data such as capital investments or online ratings, and how it affects individuals' perceived accessibility. Moreover, violent crime density was used as a proxy for safety, though it provides a limited representation of perceived safety since it neglects other factors such as functional lighting, presence of law enforcement and visibility in the area. Safety could be measured with alternative data sources, including police reports and online comments, or by surveys capturing the perceived safety of parks (Lapham et al., 2016). In addition, several important factors that could influence park accessibility such as physical barriers, traffic volumes, and quality of walking infrastructure were not considered.

Third, several assumptions were made to set the scoring approaches and thresholds. As such, the absence of normative guidelines requires that some arbitrary choices are made, largely based on the case study. Considering that binary scoring is chosen due to the current reality of the study city, it does not mean that having access to at least one specific feature is reasonable, yet it is a planning tool based on the context results. The presence of guidelines would allow for improved index results which would help to identify problematic areas. It would also allow for comparison across cities. Similarly, a threshold of 1000 m was selected based on the existing literature, which more closely reflects walking behavior. Future studies could investigate to what extent different thresholds yield different results, namely in terms of spatial distribution of the index. Other thresholds could be applied, namely to reflect cycling access to parks.

In this study, the distribution of the accessibility results is based on the residential lot. Further studies could calculate the distribution based on the general population or on specific population groups. Although the CIPQAY considers the availability of park features intended for youth (e.g., splash parks, playgrounds, and swimming pools), it can still be relevant to adults as it considers park features relevant to all such as sports courts, sports fields, tree coverage, etc. Further efforts could also include the population's characteristics (e.g., at the census block level) in the development of the accessibility measures. Indices specifically designed for different population groups could be developed, as needs, preferences, and perceptions in terms of park features certainly vary (Smiley et al., 2016). Lastly, this developed index should be validated by experts similarly to the validation of the QUINPY index.

Despite the limitations of this study, this research proposes a new methodology to measure the quality and accessibility of parks within a single index. This replicable and adaptable methodology can be valuable for practitioners to prioritize areas in need of improvements and identify targeted interventions to improve park accessibility. Future research can build on the present methodology to further improve and validate the index.

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CRediT authorship contribution statement

Genevieve Boisjoly: Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Frédéric Cournoyer:** Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **El-Murr Karl:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Waygood Owen:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Genevieve Boisjoly reports financial support was provided by Mitacs Inc. Genevieve Boisjoly reports financial support was provided by City of Montreal. If there are other authors, they 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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