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Child-Centred Assessment of Accessibility to Public Green Spaces

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Abstract: Equitable accessibility to public green spaces is vital for supporting urban children's health and well-being, requiring more nuanced assessment methods than traditional buffer or network analyses. This study applies the Gaussian Two-Step Floating Catchment Area (G2SFCA) model by integrating age-specific walking thresholds and context-specific parameters tailored to primary school children's physical accessibility to nearby public green spaces. A 400-metre pedestrian network distance threshold is applied, reflecting empirical evidence on the independent mobility of children aged 6 to 12. The model designates primary schools as demand points and nearby public green spaces as supply points, weighting demand by student populations. It also incorporates a Gaussian distance decay function to capture the decreasing likelihood of green space use with increasing travel distance, thereby improving assessment realism. Applied to 107 Flemish-speaking primary schools in the Brussels-Capital Region, results reveal substantial spatial inequalities: over 75% of schools exhibit very low accessibility, and more than 71% face limited green space availability. Higher accessibility clusters near large green spaces on the urban periphery, while dense central neighbourhoods show persistent underprovision. Although the accessibility scores exhibited a strong correlation with the availability of green space (Pearson's r ≈ 0.95), this relationship was not consistently observed across all cases, indicating that factors such as pedestrian network structure and competing demographic demand also influence accessibility patterns. This child-centred, context-aware model offers an improved framework for assessing spatial equity in urban green space accessibility, providing insights beyond simple availability metrics and supporting targeted planning interventions for underserved schools.

Keywords: Children; green space; accessibility; Brussels Capital Region (BCR).

1. Introduction

Public green spaces are defined as publicly accessible areas covered with vegetation, such as parks, gardens, playgrounds, tree-lined streets, and natural landscapes within built environments. They contribute to ecological health, urban resilience, and human well-being by providing ecosystem services such as climate regulation, air purification, flood control, and biodiversity support (*European Commission*, 2023). For children, contact with green spaces is especially critical, as it not only encourages physical activity and play but also enhances cognitive development, emotional regulation, and social interaction (Bikomeye et al., 2021; Shoari et al., 2021). Previous literature consistently shows that regular contact with green spaces in childhood is associated with improved attention, memory, and academic outcomes, as well as reduced risks of obesity, anxiety, and behavioral problems (Baró et al., 2021; van Velzen & Helbich, 2023).

However, green space is unevenly distributed in most urban settings (*European Environment Agency*, 2022). Studies show that low-income and minority neighbourhoods tend to have fewer, smaller, or lower-quality parks and playgrounds (Baró et al., 2021; *European Environment Agency*, 2022; Gallez, Canters, et al., 2024). Urban children growing up with limited nearby public green space receive fewer of its health benefits and exhibit higher

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stress, obesity rates, and attention difficulties compared to children with ample green surroundings (Bikomeye et al., 2021; *European Environment Agency*, 2022; Molina-García et al., 2022).

In densely built cities, these inequities are acute. Therefore, identifying underserved areas for green space interventions—particularly for vulnerable children—should be a central priority in urban planning (Colbert et al., 2024; Hou et al., 2024). Achieving this requires data-driven assessments of physical accessibility, meaning spatial analyses that evaluate children's ability to reach and enter urban green spaces (Lis et al., 2019; Teeuwen et al., 2023). Unlike simple availability measures, which only consider the presence or size of green space within a given area, physical accessibility assessments account for factors such as distance, competing demands, or local barriers, offering a more coherent understanding of environmental equity and urban planning priorities (Irajpour et al., 2025; Zare Sakhvidi et al., 2022).

Previous child-focused literature often used simplistic buffers or network analyses to assess children's physical accessibility to green spaces (Irajpour et al., 2025). However, such methods may not give a coherent assessment of children's complicated mobility patterns due to their oversimplifications (Semenzato et al., 2023). In contrast, gravity-based models—particularly the Gaussian two-step floating catchment area (G2SFCA) model—are recognized as more robust for measuring physical accessibility (Irajpour et al., 2025; Li et al., 2021; Zhou et al., 2023). The G2SFCA model accounts for both supply (green area) and demand (children population) as well as distance decay. These models thus better capture how accessibility diminishes with travel distance (Irajpour et al., 2025). Despite their methodological advantages, these approaches remain underutilized in child-centred research, particularly in studies that account for children's specific land uses, such as schools.

To ensure accurate child-specific assessments, this study emphasises the importance of integrating the following considerations:

- **Age-specific mobility**: Previous studies on children's accessibility to green spaces often overlook age-specific mobility constraints, leading to assessments that do not accurately reflect children's actual movement patterns (Teeuwen et al., 2023). Children face unique challenges in navigating urban environments, including limited independent mobility, heightened sensitivity to traffic hazards, and reliance on adult supervision. These factors, combined with institutional restrictions and safety concerns, further complicate their physical accessibility to green spaces, requiring integration into assessment frameworks (Gustafsson et al., 2021; Michail et al.).
- **Child-specific land uses**: children's land uses, such as school environments – areas within and nearby schools – are a crucial part of children’s daily routine. In Europe, children spend roughly 156–200 days per year in school environments (Gallez, Mujica, et al., 2024). School environments often provide the only guaranteed outdoor area for many children during the day. Notably, schools’ nearby public green spaces could improve physical activity, reduce stress, and enhance learning, especially in schools serving disadvantaged students during their outdoor activities and commuting times (Barenie et al., 2023).

This study incorporates these considerations into a G2SFCA model tailored for children and applies it to the school’s nearby public green spaces of Flemish-speaking primary schools in the Brussels-Capital Region (BCR). This study hypothesises that analyses of children’s physical accessibility to green spaces using the G2SFCA model will offer additional insights beyond traditional, simplified approaches considering (i) age-specific mobility patterns, and (ii) areas where children are mostly present, such as public green spaces near schools. The findings aim to provide actionable insights for greenery implementations in nearby parks that equitably meet the diverse needs of children.

2. Method

The G2SFCA model enhances spatial accuracy by integrating network-based travel distances with a continuous Gaussian distance-decay function. This approach models physical accessibility as a gradient rather than a binary threshold and considers demand-based competition by adjusting each green space’s influence relative to local population pressures (Dai & Wang, 2011). Its capacity to operate across multiple catchment scales allows alignment with urban policy targets and adaptability to diverse mobility patterns (Lin et al., 2024).

2.1. Incorporation of age-based analysis

According to the UNICEF (2018), the accessibility of urban green spaces for children needs to consider the spatial dimensions and scales of urban childhoods. This involves accounting for the urban scales, encompassing the spatial scales of the home, street, neighbourhood, and the city. Additionally, proximity and walkability are deemed crucial factors, given that children cannot drive, and their safety and rights can be significantly compromised in neighbourhoods dominated by cars, characterised by limited pedestrian spaces and physical barriers. As this study focused on primary school children aged 6 to 12, a walking distance threshold of 400 metres is adopted, based on UNICEF (2018) reports indicating that children in this age group typically walk between 200 and 400 metres, or approximately five minutes, to reach destinations.

2.2. Integration of nearby public green spaces in the G2SFCA model

This study assesses accessibility to public green spaces near schools (A_g). Accessibility scores are calculated using a combination of ArcGIS Pro 3.1.2 and Python 3.11.12. ArcGIS Pro's Network Analyst Origin–Destination (OD) cost matrix is employed to compute network-based distances between demand and supply locations, and the G2SFCA model is implemented in Python.
The demand (origin points) is defined as the number of children enrolled in each school, whereas the area of nearby public green spaces represents the supply (destination points). The accessibility scores are computed through the following two-step process:

2.2.1. Calculation of supply to demand ratio

To calculate the supply-to-demand ratio as the first step in the G2SFCA model, the distance decay for each route between origins and destinations is initially computed using the following formula
(Liao & Furuya, 2024):

$$G(d_{ij}) = \begin{cases} \dfrac{e^{-\frac{1}{2}\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}}, & d_{ij} \le d_0 \\ 0, & d_{ij} > d_0 \end{cases}$$

Where:

- $G(d_{ij})$ = distance decay weight between the school location i (demand point) and supply location j (i.e., nearby public green space)
- d_{ij} = network distance between i and j
- d_0 = predefined catchment threshold distance

According to UNICEF (2018), a distance threshold (d_0) of 400 metres is applied for calculating $A_G$reflecting the typical walking distance for primary school children.

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\le d_0\}} P_k\ G(d_{kj})}$$

Where:

- R_j = supply-to-demand ratio at the supply location j
- S_j = size of green space j
- P_k = population of students at the school location k
- $G(d_{kj})$ = distance decay weight between k and j
- d_{kj} = network distance between k and j
- d_0 = catchment threshold distanunce

2.2.2. Calculation of accessibility scores

As the second step of the G2SFCA model, each accessibility score is calculated as follows (Dai & Wang, 2011):

$$A_g = \sum_{j\in\{d_{ij}\le d_0\}} R_j\ G(d_{ij})$$

2.2.3. Further analyses

Additional statistical analyses (Pearson, Spearman, Wilcoxon) were conducted to examine the degree to which the sheer availability of green space within a 400-metre threshold correlates with or diverges from the calculated accessibility outcomes. This allows for a deeper understanding of whether variations in accessibility are primarily supply-driven or influenced by other spatial and demographic factors embedded in the G2SFCA method.

3. Results.

3.1. Case study

This study focuses on the BCR, a densely urbanized area comprising 19 municipalities and serving as the capital of both Belgium and the European Union. BCR is characterised by its socio-spatial diversity, compact urban form, and uneven distribution of green infrastructure, particularly in central and high-density neighbourhoods (Gallez, Canters, et al., 2024). The region faces persistent socio-economic and environmental inequalities that influence children's accessibility to nature and healthy environments(Gallez, Canters, et al., 2024). Given that over 20% of the region's population is under the age of 18 (Statbel, 2023)understanding the spatial equity of green space provision for children in BCR is both timely and policy-relevant.

Education in BCR is governed by a dual linguistic system. The city accommodates two main educational federations: one for French-speaking schools (Fédération Wallonie-Bruxelles) and one for Flemish-speaking schools (Onderwijs Vlaanderen). Each operates independently, with separate administrative structures, pedagogical systems, and school databases (Gallez, Canters, et al., 2024). Due to data protection restrictions and administrative limitations, student population data from French-speaking schools is not accessible to this study. Consequently, our analysis focuses exclusively on the Flemish-speaking schools, for which detailed and up-to-date population data are available through the Flemish Ministry of Education.

This study focuses on primary schools serving children aged 6 to 12, a group selected due to their heightened sensitivity to environmental influences, limited independent mobility, and the central role of schools as daily destinations and spatial anchors in their lives. These factors make primary schools particularly suitable units for evaluating spatial equity in child-centred urban planning (Bikomeye et al., 2021; Shoari et al., 2021; UNICEF, 2018). The final sample included 107 Flemish-speaking primary schools across the BCR.

As shown in Table 1, the processed datasets used to implement the G2SFCA model include school locations (serving as demand points or origins), the registered student population of each school (demand size), public green spaces (supply points or destinations) along with their respective areas (supply sizes), and a pedestrian network dataset (representing the routes between origins and destinations). These datasets are compiled from multiple sources to support the spatial accessibility analysis.

Table 1: Geographical datasets used in the study

Datasets	Sources	Process
School locations	URBIS (2025)	Specified as the origin in the Origin-Destination (OD) cost matrix; Snapped to the pedestrian network.
Registered student population	Dataloep Tableau (2025)	Matched to schools via unique identifiers; used as demand in the Gaussian Two-Step Floating Catchment Area (G2SFCA).
Public green spaces	URBIS (2025)	Specified as the destination in the OD cost matrix. Access points auto-generated (centroids); Additional entrances manually digitized for large parks using aerial imagery.
Pedestrian network	OpenStreetMap (2025)	Used to compute the OD cost matrix and catchment areas per school section

3.1. Accessibility scores

Accordingly, accessibility scores were calculated for each school to nearby public green spaces using the method described in Section 2. These scores were classified into five categories—from very low to very high—using the Jenks natural breaks method, which optimally minimises within-class variance and maximises between-class variance. By deriving class boundaries from the actual distribution of values, rather than imposing arbitrary thresholds as in equal interval or quantile classifications, this classification more accurately preserves spatial heterogeneity and ensures a statistically robust representation of urban accessibility patterns (ESRI, 2024). Figure 1 maps the accessibility scores, and the corresponding histogram is included to illustrate the distributional shifts in scores.

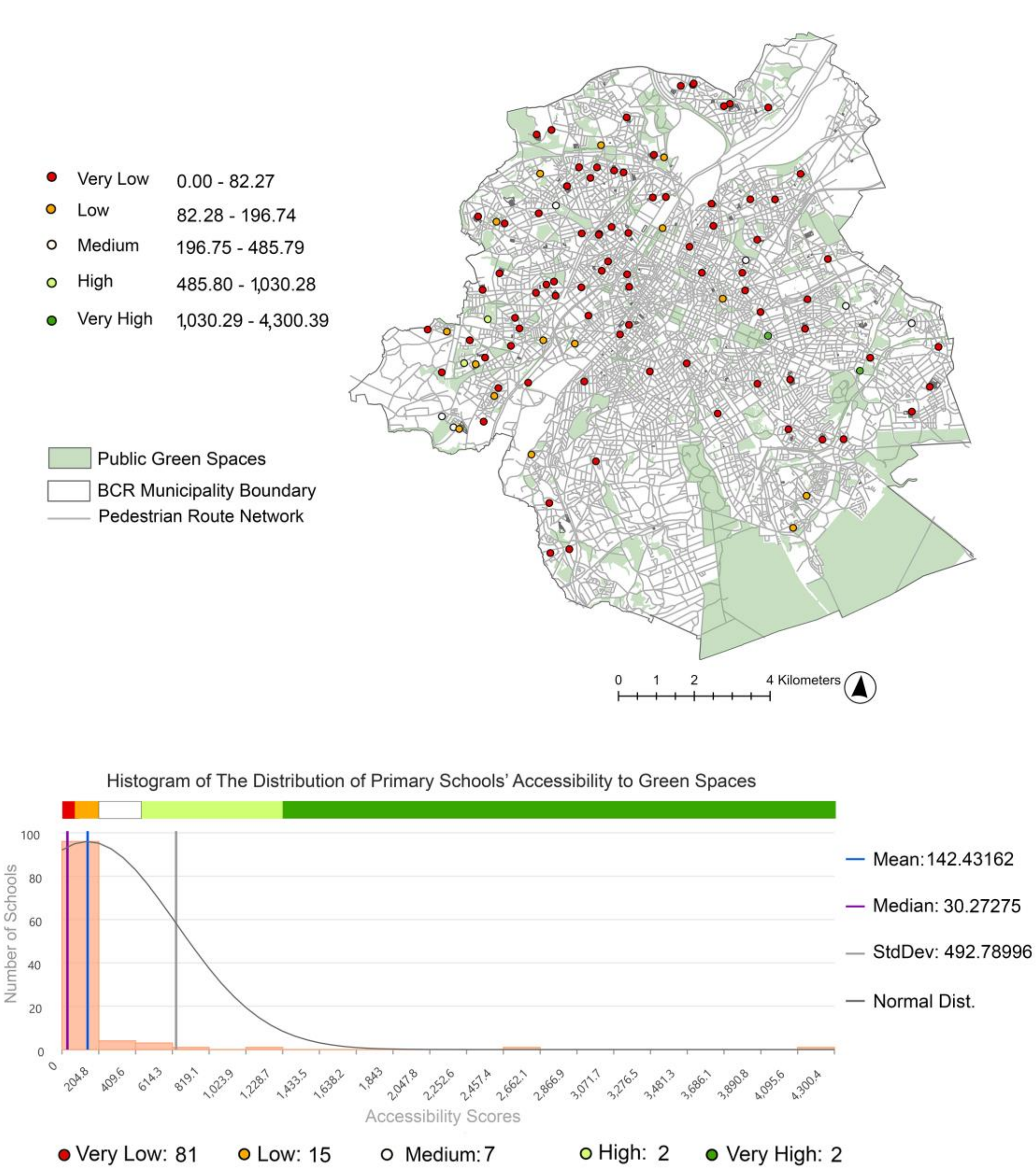

Figure 1: Accessibility scores of Flemish-speaking primary schools to nearby public green spaces

The spatial distribution and statistical analysis of primary Flemish-speaking schools' accessibility to nearby public green spaces in the BCR reveal marked inequalities. Most schools are concentrated in areas with very low accessibility scores, particularly in the central and north-central neighborhoods of the region. Out of 107 schools assessed, 81 (approximately 75.7%) fall within the "Very Low" accessibility category (0.00–82.27), and 15 schools (14%) are in the "Low" category (82.28–196.74). Medium, High, and Very High accessibility categories are significantly underrepresented, with only seven (6.5%), two (1.9%), and two (1.9%) schools, respectively. In terms of spatial patterns, higher accessibility scores are mainly observed in the southern and eastern peripheries of BCR, particularly near large contiguous green spaces such as the Sonian Forest and Parc du Cinquantenaire. In contrast, central urban neighborhoods, characterised by dense urban form and fewer green areas, show widespread lack of accessibility. The histogram further emphasises this skewed distribution. The mean accessibility score is 142.43, with a much lower median of 30.27, indicating a right-skewed distribution where a small number of schools benefit from disproportionately high accessibility values. The standard deviation is substantial (492.79), underscoring a high degree of variability in accessibility among schools. Most accessibility scores are clustered near the lower end of the distribution, with a steep decline in frequency as scores increase.

3.2. Availability of public green spaces near schools

Figure 2 presents the availability of public green spaces near schools within a 400-metre threshold distance. The map depicts their spatial pattern across the BCR, classifying the total nearby public green space areas into five categories using the Jenks natural breaks method, which is consistent with the classification approach applied in Figure 1. Additionally, the histogram below the map shows the distribution of public green space availability scores.

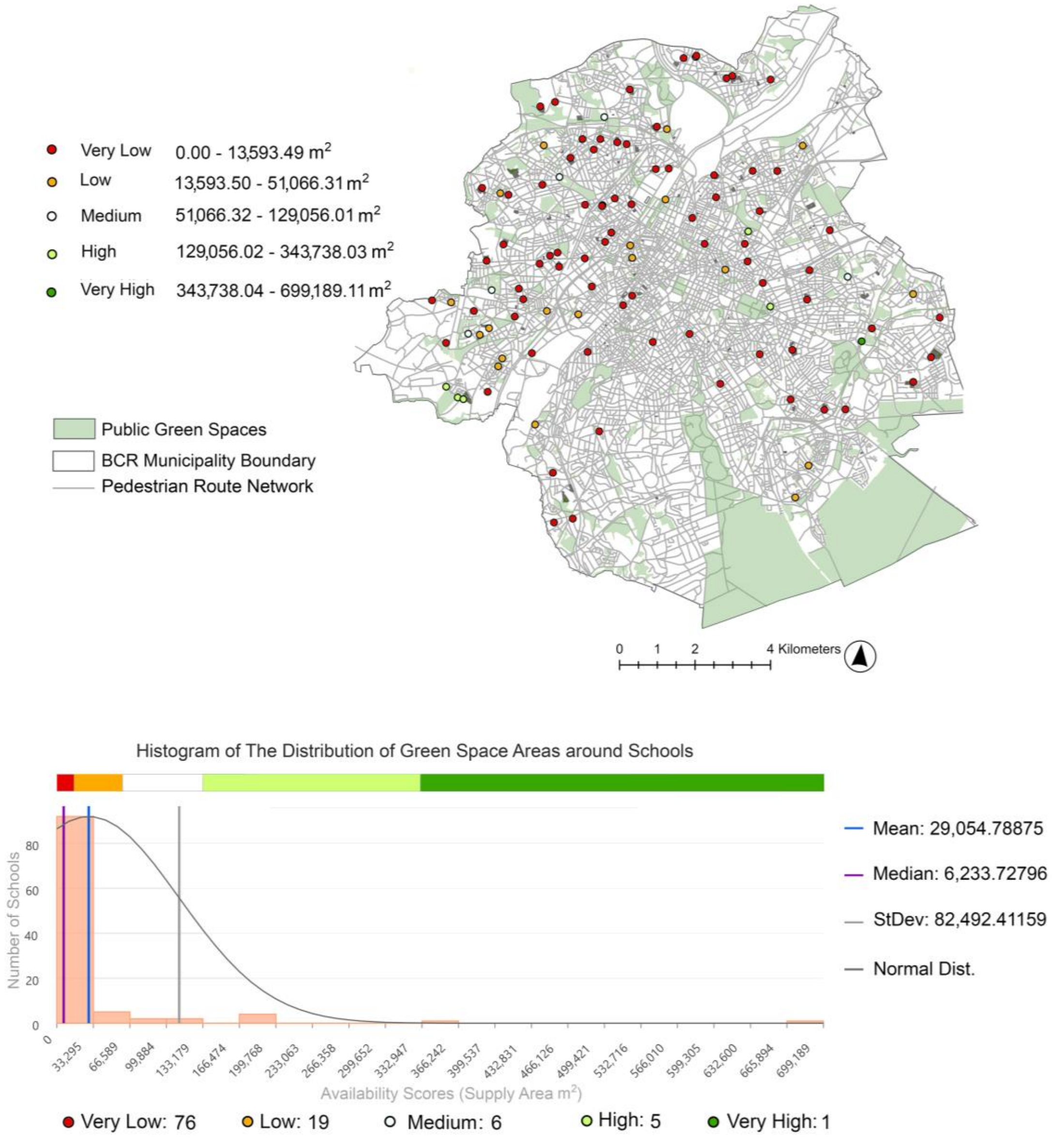

Figure 2: Availability of public green spaces near schools within a 400-metre threshold

Among the 107 schools analysed, the majority—76 schools (approximately 71%)—fall into the "Very Low" category (0.00–13,593.49 m²), while 19 schools (17.8%) are classified as "Low" (13,593.50–51,066.31 m²). six schools (5.6%) are in the "Medium" category (51,066.32–129,056.01 m²), five schools (4.7%) are in the "High" category (129,056.02–343,738.03 m²), and just one school (0.9%) reaches the "Very High" level (343,738.04–699,189.11 m²). The map shows that schools with the most nearby public green space are mainly in the southern and southeastern parts of BCR, near the Sonian Forest and large parks. In contrast, schools with very little green space are mostly found in the central, western, and northeastern neighborhoods, reflecting denser urban environments. The histogram confirms this imbalance, with a strongly right-skewed distribution—most schools have low green space availability (median: 6,233.73 m²), while a few have much more (mean: 29,054.79 m²; standard deviation: 82,492.41 m²).

When compared to Figure 1, several key insights emerge. Both figures reveal a significant proportion of schools falling into very low categories for both accessibility and availability, indicating a consistent pattern of underprovision. However, availability (Figure 2) appears slightly more dispersed across the BCR, with more schools falling into the "Low" and "Medium" classes compared to accessibility. Notably, Figure 1’s accessibility scores are even more concentrated at the lower end (median of 30.27) than Figure 2’s availability scores (median of 6,233.73), despite using consistent classification thresholds. These comparisons highlight spatial inequality in both the accessibility and availability of green spaces around primary schools in the BCR.

Table 2: Statistical correlation between accessibility scores and the availability of public green spaces near schools within a 400-metre threshold

Pearson	Spearman	Wilcoxon p-value
0.947	0.946	1.22E-17

As shown in Table 2, using Python 3.11.12, the Pearson and Spearman correlation coefficients are both very high (0.947 and 0.946, respectively), indicating a strong positive association between availability and accessibility. The Wilcoxon p-value of 1.22×10^{-17} confirms the statistical significance of this relationship. These findings suggest that while the G2SFCA-based accessibility scores are influenced by more complex spatial and demographic weighting mechanisms, they remain largely driven by the underlying distribution of nearby green space supply.

4. Discussion

- **Applying the G2SFCA model for child-specific urban planning:** This study contributes to equitable urban green space planning by applying the G2SFCA model to the spatial and developmental needs of children. Unlike traditional buffer or simple network-based approaches, which rely on adult-based uniform distance thresholds and treat all nearby green space equally, the model incorporates age-responsive thresholds reflecting children’s actual walking ability, as well as network connectivity, distance decay, and demand population within school environments. This provides a more precise and realistic representation of children’s accessibility, capturing spatial nuances that simpler methods overlook. The BCR case study illustrates the model’s advantages, revealing that, despite substantial nearby green space for many schools, several institutions in the northern and western areas remain functionally underserved due to limited network connectivity and high local demand.
- Importance of incorporating green space qualities into accessibility models: This study quantifies accessibility based on nearby green space area. Future studies could incorporate other supplies, such as courtyard green spaces, as well as qualitative attributes, such as the presence of tree canopies, playground equipment, shade, and biodiversity features known to attract children and support restorative play (Barenie et al., 2023; Shoari et al., 2021). Integrating these attributes into the supply-to-demand ratio would help move beyond outdoor surface metrics toward more child-relevant indicators of usability and safety.
- Broader applicability across educational levels: Although this study focuses on primary schools, the method is adaptable to preschools and secondary schools, with modified distance thresholds aligned to age-specific mobility patterns and independent travel rights. Preschool children, for instance, require even closer proximity to safe green spaces due to their higher dependence on adult supervision (UNICEF, 2018). In contrast, secondary school students may travel further and benefit from larger, more diverse green areas. Applying this method across age groups would create a holistic view of green space equity in educational systems (UNICEF, 2018).
- Insights from G2SFCA accessibility and public green space availability: Results from the BCR case study (Figures 1 and 2) reveal significant spatial disparities in both accessibility scores and the availability of public green spaces near schools. Comparative analysis reveals a strong statistical correlation between accessibility and availability (see Table 2), indicating that the quantity of nearby green space is a significant determinant of accessibility outcomes in this context. However, the high correlation between G2SFCA accessibility scores and simple availability measures ($r \approx 0.95$) does not diminish the model’s utility. The G2SFCA framework captures network-based differences in pedestrian accessibility, incorporating age-specific walking thresholds, demand population, and distance decay—factors not

reflected by green space area alone. For example, the Sint-Niklaasinstituut has substantial nearby green space (195,950 m²) but a low accessibility score (189.71) due to limited network connectivity and a high-demand population. In contrast, Regina Assumpta, with a smaller nearby green space area (129,056 m²) and a lower demand population, attains a high accessibility score (1,030.28) owing to more direct and accessible pedestrian routes. These examples demonstrate that while simple availability metrics provide a general overview, the G2SFCA model captures critical nuances in actual accessibility, identifying locations where substantial green space is functionally inaccessible. These findings support the study's hypothesis that applying the G2SFCA model provides additional insights beyond traditional availability metrics, highlighting spatial inequities and actionable patterns that simpler approaches cannot reveal.

- The model's sensitivity to both spatial structure and demographic load highlights the importance of not only increasing the quantity of green infrastructure but also ensuring its functional and equitable integration within the urban fabric. It is important to emphasise that the G2SFCA accessibility scores presented in this study are context-specific and relative to the spatial, infrastructural, and demographic conditions of the BCR. As such, they are intended to support intra-urban comparisons among schools within this setting and should not be interpreted as absolute measures or generalized across other urban contexts without appropriate adaptation.
- Implications for urban planning and intervention prioritization: The method presented here offers a diagnostic framework for identifying spatial inequities and targeting green space investments. It helps planners to prioritize interventions near schools with low physical accessibility and minimal green infrastructure, particularly in socio-economically disadvantaged zones (European Environment Agency, 2022). For future work, schools could be clustered by accessibility levels, greenery supply, and socioeconomic indicators to establish multi-dimensional prioritization schemes. Such clustering can inform place-based investments, including park refurbishments, street tree planting, or schoolyard greening initiatives. This echoes recent calls for distributive green justice in urban policy (Colbert et al., 2024).
- Toward a more holistic accessibility framework: Integrating physical accessibility with perceived accessibility—encompassing safety, perceived distance, barriers, and social norms—would provide a more holistic understanding of green space accessibility. Future surveys and interviews with children, parents, and school staff could capture these subjective dimensions, which vary widely across cultural and urban contexts (Irajpour et al., 2025; Park, 2017). Including qualitative feedback would increase the coherence and policy-relevance of accessibility data, offering a child-centered perspective to complement spatial modelling.
- **Limitations and data gaps**: A key limitation of this study lies in its exclusion of French-speaking schools due to data access constraints. The inability to incorporate French-speaking students may result in an underestimation of competition for nearby green spaces and limit the generalizability of our findings across the entire BCR. Another limitation concerns the assumption of equal usability of all public green spaces. Institutional, physical, or social barriers may prevent children from accessing green spaces even if they are technically within reach. Moreover, the supply-side estimation relies solely on green space area, as data on other critical factors—such as vegetation type, institutional accessibility restrictions, quality, and perceived safety—were not available for this study, despite their significant influence on the actual usability of green spaces for children.

5. Conclusion

This study employed a Gaussian two-step floating catchment area model to assess and compare the physical accessibility and availability of public green spaces around 107 Flemish-speaking primary schools in the Brussels-Capital Region. The results revealed substantial spatial inequities, with most schools concentrated in areas of very low accessibility and green space availability, particularly in the central, densely built neighborhoods. A strong statistical correlation between availability and accessibility highlights the need to enhance both the quantity and network-based reachability of green spaces. The child-centred G2SFCA model, which accounts for children's limited mobility, their land use, demand competition, supply availability, urban network structure, and the distance decay function, proved valuable in uncovering nuanced spatial disparities often overlooked by simple proximity metrics. These findings highlight the urgency for targeted green infrastructure interventions in underserved school environments and support the integration of child-responsive planning tools into urban policy frameworks to foster spatial equity and environmental justice in cities.

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