Modelling greenspace accessibility at multi-spatial contexts: a pilot study of comparing the E2SFCA and Gravity models

B.E. Breekveldt[*1], S.M. Labib[†2]

[1]Department of Information and Computer Science, Faculty of Science, Utrecht University
[2]Department of Human Geography and Spatial Planning, Faculty of Geosciences, Utrecht University

GISRUK 2023

Summary

Urban greenspace accessibility (UGA) has positive effects on people's health, well-being, and overall sustainability of urban areas. Existing studies inconsistently use various methods of modeling greenspace accessibility and often focus on specific city contexts. This caused an inadequate understanding of how to model UGA for any urban areas better. Here we tested and compared two widely used spatial accessibility modeling approaches, gravity and (enhanced) two-step floating catchment (E2SFCA) models and propose a reproducible and scalable methodology for modeling UGA using open data. Our results indicated that although both approaches have pros and cons, E2SFCA is better for modeling UGA.

KEYWORDS: urban greenspace access, spatial accessibility, urban park access, gravity model, floating catchment models

1. Introduction

Access to urban greenspace has diverse positive effects on people's physical and mental health, such as reducing cardiovascular disease, increased physical activity, reduced stress, depression, and improved general well-being (Markevych et al., 2017; Labib et al., 2020). In addition to health effects, urban greenspaces provide other ecosystem functions in mitigating heat islands, lowering air pollution concentration, and increasing biodiversity (Markevych et al., 2017). Considering the multidimensional benefits of urban greenspace, accessibility to urban greenspaces is considered one of the targets of the Sustainable Development Goals (11.7), "*provide universal access to safe, inclusive and accessible, green and public spaces.*"

The methods used to model and measure access to greenspaces in previous studies have been highly varied and often focus on a specific city or region (Labib et al., 2020; Wang et al., 2021). The approaches used by most of these studies often are neither reproducible nor scalable due to a lack of clear documentation and inaccessible data (e.g., used local or country-wide data sources). Such issues hinder the ability to compare access to greenspaces between cities, particularly between different regions.

Additionally, it is currently not well understood which modeling approach is best suited for realistically representing access to greenspaces. Much epidemiological research regularly uses a container approach, a statistical analysis of the amount of greenspace within specific administrative units or certain buffer zones around a specific address. One key issue with this method is that it is vulnerable to the modifiable areal unit problem (MAUP) (Labib et al., 2020). Additionally, many studies used spatial proximity methods such as measuring the Euclidean or road network distance between UGS access points and specific addresses (Wang et al., 2021). While a few of these methods might overcome the MAUP, they do not account for other major issues, including (i) the attractiveness of the greenspaces

[*] b.e.breekveldt@students.uu.nl
[†] s.m.labib@uu.nl

(e.g., size, quality), (ii) distance decay effects, and (iii) the competing demand and supply based on the number of available greenspaces in close proximity and amount of people who might use these greenspaces.

In this study, we aim to address the limitations previously mentioned by evaluating two commonly used accessibility modeling methods, the gravity model and the E2SFCA, which consider factors such as the attractiveness of greenspaces, distance decay, and supply and demand when modeling accessibility. Furthermore, we have developed a reproducible and scalable methodology that utilizes open data and an easily implementable programming workflow. The methodology can be accessed at: https://github.com/Bart-Breekveldt/Urban_Greenspace_Accessibility

2. Methods and materials

2.1 Case study areas and data

For this study, we selected five world cities: Dhaka, Ghent, Philadelphia, Tel Aviv, and Washington D.C., considering their geographic and socio-economic diversity.

City boundary and road network

We used OpenStreetMap (OSM) to extract city boundaries and road network data (Boeing, 2017). Although we assumed greenspaces would be mostly accessed through walking, due to the incompleteness of pedestrian network data on OSM, especially in developing countries, we considered all road types when creating road networks. However, highways and high-speed trunk roads (>40mph/65 kmh) are determined unsuitable for pedestrians and thus removed.

Greenspace

Greenspace data is taken by the tag “leisure: park” from OSM. We only considered greenspaces above 0.04 ha. Based on World Health Organization (WHO) guidelines for the size of urban greenspaces. We also validated OSM greenspace data with local greenspace datasets obtained from open city portals or other regional or national data sources (Browning et al., 2022).

Population grids

Population data is taken from WorldPoP (Tatem, 2017) and consists of grids with 100m resolution; their centroids are believed to be the population centers. Grids that have a rounded population over zero and completely fall within city boundaries are retained.

2.2 Methodological Process

In this study, we developed a five-step process to model and evaluate UGA (Figure 1). First, we extracted the data. We used the city boundary as the primary spatial unit of analysis; however, to account for the edge effect, we extracted additional data outside the city boundary up to the extent of potential walking distance thresholds to travel to greenspaces. We also processed the OSM and local greenspace data to create possible access points to the greenspaces, using methods described in Labib et al. (2021). The access points are considered destination points. Second, we fitted the classic gravity model and E2SCFA at each population grid centroid (origin point) to estimate the accessibility score, considering three distance thresholds: 300, 600, and 1000 m. The details of gravity and E2SCFA can be found here respectively, Hansen (1959) and Luo & Qi (2009). The service area distances were selected based on the WHO guideline (i.e., access to greenspace within 300 m from home) and about 5 to 10 min walking distances that people might be willing to access greenspace. We used OSMnx and NetworkX packages to route between the origin and destination points Dijkstra-based route algorithm (Boeing, 2017). Third, we evaluated whether the two data sources produced considerably different results; we performed this evaluation by calibrating models twice using local and OSM greenspace data in the previous step. Fourth, we compared the results between the gravity and E2SCFA models for all the cities for different distance thresholds and evaluated the model representativeness of UGA.

Figure 1: Methodological for UGA

Finally, for both models, we created an easy to interpreter classification scheme of six classes: no-, low, mediocre-, sufficient-, good-, and excellent access. For the gravity model, this depends on the amount of 'perfect scores,' consisting of a route to a UGS with no route cost (population center within UGS is a perfect score). Every category states a multiplication of perfect scores for classification, with excellent being more than four perfect scores. The E2SCFA-model classes are according to WHO standards for required $9m^2$ and preferred $30m^2$ per person of greenspace. Low < $9m^2$, mediocre: 9 to $18m^2$ (twice $9m^2$). Sufficient: 18 to $30m^2$ (preferred), good: 30 to $100m^2$, and excellent > $100m^2$. We estimated the city-wide population-weighted percentage of accessibility for each accessibility class.

3. Results

We identified no considerable between OSM and local greenspace data for both models for our case cities. The differences are relatively small, and it does not alter the relative differences between cities when classification schemes are applied to the accessibility scores. Thus, we argued that in large or global cities with extensive OSM coverage, the OSM greenspace data could be an acceptable source of greenspace data. Considering such an argument, we only reported the results of OSM greenspace models in the following section.

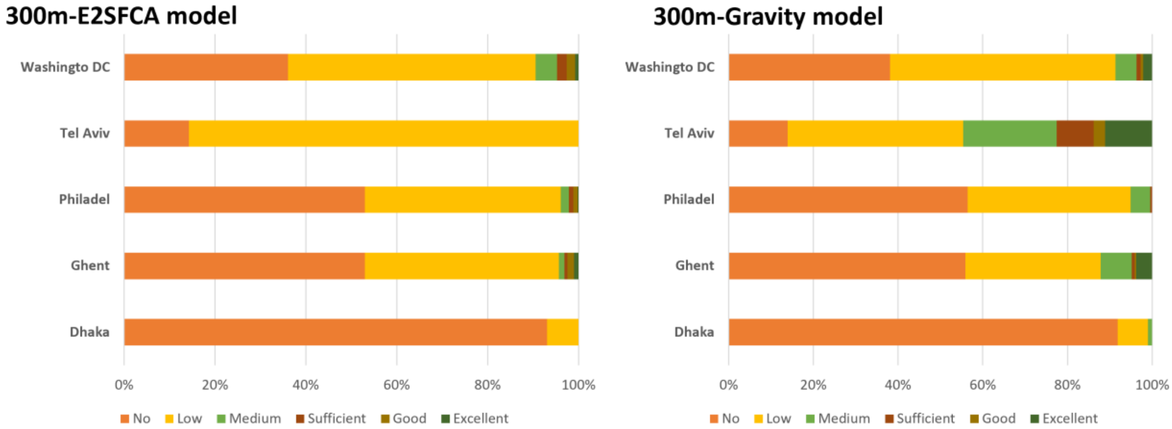

Figure 2: Difference in overall population weighted greenspace accessibility level between two models at 300 m threshold

Figure 2 indicates among the five case cities; Dhaka has the least greenspace accessibility in both models. In E2SFCA, Washington DC, has a better UGS distribution than other cities, but in the gravity model, Tel Aviv has relatively greater UGS than other cities. Figure 2 also highlights that for both models, the accessibility classes indicate similar results in most cities, except for Tel Aviv. This is most likely because the gravity model favors good distribution of greenspaces in a city; the distances and amount of reachable UGS matter more in accessibility estimation, in contrast to the E2SFCA model, which is more influenced by the supply-demand ratio. In the case of Tel Aviv, this means that greenspaces are relatively well spread over the city but with an insufficient capacity for the number of people in Tel Aviv (Figure 3).

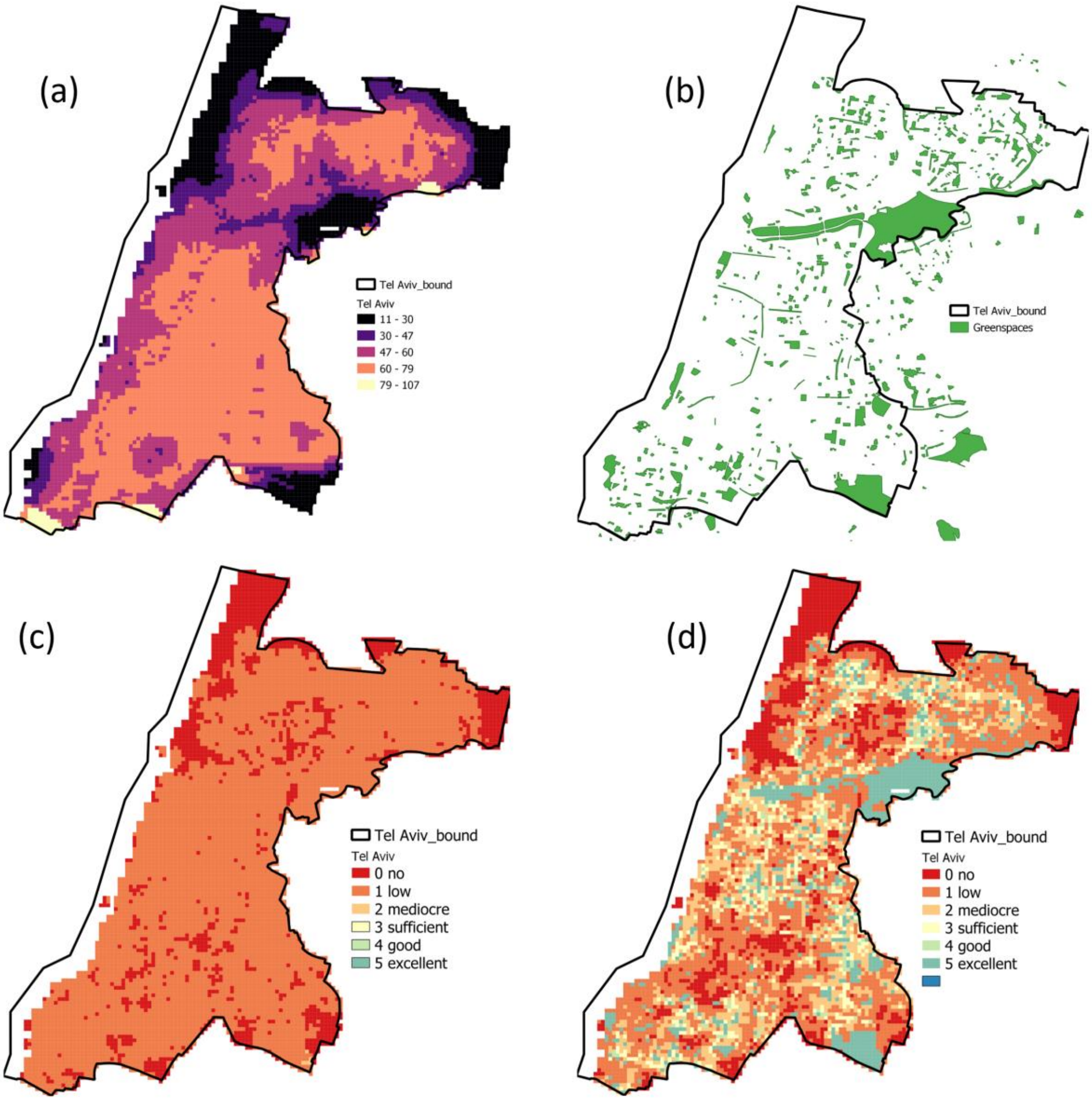

Figure 3: Tel Aviv maps (a) population distribution, (b) greenspace locations, (c) E2SFCA-model classification scores and (d) Gravity model classification scores for the 300m threshold

4. Discussion and conclusion

We found both Gravity and E2SFCA models usually presented similar results, yet the Gravity model lacked accounting for population demand and overcrowding issues. While the E2SFCA model accounted for these, they lacked in considering 'options' for specific greenspace access for people. However, comparing both models, we argue that E2SFCA might provide a better representation of UGA; additionally, E2SFCA can be easily compared with WHO standards for UGA.

Although we developed comparable, replicable, and scalable UGA models tested and evaluated on multiple cities using two different models, our study has several critical limitations. First, the access point we modeled using spatial methods following other studies (Labib et al., 2021) might not reflect the actual access points. Second, we only consider one tag, "leisure: park," from OSM, which might not cover other publicly accessible greenspaces such as gardens, nature reserves. These issues might over or underestimated UGA. However, our methodological process and code are adaptable to further modifications to resolve these issues. Nonetheless, our approach would be useful for better modeling of UGA in a comparable, replicable, and scalable manner for different cities around the world.

References

Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, Environment and Urban Systems*, *65*, 126-139.

Browning, M. H., Rigolon, A., Ogletree, S., Wang, R., Klompmaker, J. O., Bailey, C., ... & James, P. (2022). The PAD-US-AR dataset: Measuring accessible and recreational parks in the contiguous United States. *Scientific Data*, *9*(1), 1-15.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of planners*, *25*(2), 73-76.

Labib, S. M., Lindley, S., & Huck, J. J. (2021). Estimating multiple greenspace exposure types and their associations with neighbourhood premature mortality: A socioecological study. *Science of The Total Environment*, *789*, 147919.

Labib, S. M., Lindley, S., & Huck, J. J. (2020). Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. *Environmental research*, *180*, 108869.

Luo, W., & Qi, Y. (2009). An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health & place*, *15*(4), 1100-1107.

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A.M., De Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M.J. and Lupp, G., (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental research*, *158*, pp.301-317.

Wang, S., Wang, M. and Liu, Y., (2021). Access to urban parks: Comparing spatial accessibility measures using three GIS-based approaches. *Computers, environment and urban systems*, *90*, p.101713.

Tatem, A. J. (2017). WorldPop, open data for spatial demography. *Scientific data*, *4*(1), 1-4.

Biographies

B.E. Breekveldt. Masters student Applied Data Science (Utrecht University). Bachelor in Business Economics. Research interests: geospatial modelling, data science, natural language processing, human geography, economic geography, economics, network theory, and programming.

S.M. Labib is an Assistant Professor of Data Science & Health at Utrecht University and a visiting research associate at the Public Health Modelling Group in the MRC Epidemiology Unit, University of Cambridge. His research interests are in spatial data science, GIS, and their applications in environmental epidemiology and urban health.