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Age-group-based evaluation of residents' urban green space provision: Szeged, Hungary. A case study

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Abstract

Analysis of urban green space (UGS) provision is becoming increasingly important from an urban-planning perspective, as processes related to climate change tend to worsen the urban heat-island effect. In the present study, we aimed to map the UGS provision of Szeged, Hungary, using a GIS-based complex approach. Different age groups, especially the elderly, have different demands on the ecosystem services and infrastructure of UGSs. To provide an in-depth assessment of UGS provision for planners, we analysed the UGS availability and accessibility, using sub-block-level population data, which includes not only the total number of residents but also provides information about the age-group distribution for each building of the city. We delineated areas having different UGS provision levels (called provision zones) and assessed the age distribution of the residents living in each zone. We found that the residents within 2-min walking distance to public green spaces are older than expected by comparison to the age distribution of Szeged. In provision zones with abundant locally available UGSs (measured as UGS per capita within 50-m buffers), we found that the youngest (0–18 years) and oldest (≥ 61 years) inhabitants are overrepresented age groups, while the age group 19–40 has the lowest overall UGS provision within the city of Szeged. Our research, which has the potential to be adapted to other settlements, contributes to the identification of UGS-deficit areas in a city, thereby providing essential information for urban planners about where increases in UGS are most needed and helping to assess infrastructural enhancements that would be adequate for the locally most-dominant age groups.

Keywords: availability, accessibility, provision, urban park, green infrastructure

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Introduction

The term urban green space (UGS) is defined by World Health Organization as an urban area covered by any kind of vegetation (WHO 2017; WHO Regional Office for Europe 2017). UGSs are among the main contributors to human well-being within a city (Neuvonen, M. *et al*. 2007; James, P. *et al*. 2009; Schipperijn, J. *et al*. 2010; Rossi, S.D. *et al*. 2015; Kothencz, G. *et al*. 2017; Kovács-Győri, A. *et al*. 2018; Csete, Á.K. *et al*. 2021). UGSs also contribute to the liveability of a settlement through a high variety of positive effects, which are collectively known as ecosystem services (MEA 2005; Makovníková, J. *et al*. 2019; CICES 2022). Via evapotranspiration and shading, vegetation impacts microclimates (MEA 2005; Takács, Á. *et al*. 2016; CICES 2022; TEEB 2022). The urban heat island effect, which is an increasingly significant problem in modern cities can also be mitigated by UGSs (Gál, T. *et al*. 2016; Henits, L. *et al*. 2016; Herbel, I. *et al*. 2016; Pongrácz, R. *et al*. 2016; Mucsi, L. *et al*. 2017). Other important regulating functions of UGSs include surface-runoff mitigation, the enhancement of air quality, as well as wind speed and noise reduction (MEA 2005; Csete, Á.K. and Gulyás, Á.

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2021; CICES 2022; TEEB 2022). Additionally, vegetation in private and community gardens may also contribute to food provision (MEA 2005; CICES 2022; TEEB 2022). In the form of cultural ecosystem services, UGSs help to create an aesthetic and calm environment ideal for both physical recreation and spiritual rejuvenation (MEA 2005; Razak, M.A.W.A. *et al*. 2016; Ayala-Azcárraga, C. *et al*. 2019; Szilassi, P. *et al*. 2020; Cheng, Y. *et al*. 2021; CICES 2022; TEEB 2022).

Considering all the advantages that UGSs provide, it is not unexpected that recently the issue of proper UGS provision has been receiving ever-growing attention within the field of urban planning (Zepp, H. *et al*. 2020). However, the definition and measurement of UGS provision and access are not uniform among researchers (Wolch, J.R. *et al*. 2014; Ekkel, E.D. and de Vries, S. 2017; Wüstemann, H. *et al*. 2017; Blaschke, T. and Kovács-Győri, A. 2020; Wu, L. and Kim, S.K. 2021). For example, Le Texier, M. *et al*. (2018) specified four levels of UGS provision and access: availability, fragmentation, public-private ownership, and accessibility. Other researchers identified five components of green space access, a concept similar to UGS provision: virtual access, viewing, utilizing and being in green space, active hands-on engagement, and ownership and/or management (Weldon, S. *et al*. 2007; Edwards, D. *et al*. 2009).

One of the most well-systematized definitions in connection with UGS provision comes from Biernacka, M. and Kronenberg, J. (2019). Their approach involves three levels of UGS provision: availability, accessibility, and attractiveness. Among these three, UGS availability is the most fundamental, as it indicates whether green space exists within a given proximity. The most common method for the evaluation of UGS availability is the calculation of the total area of UGSs within a buffer zone; it is most commonly measured in hectares or square metres per capita (Fuller, R.A. and Gaston, K.J. 2009; Kabisch, N. and Haase, D. 2014; Kabisch, N. *et al*. 2016; Biernacka, M. and Kronenberg, J. 2019; Biernacka, M. *et al*. 2020; Kolcsár, R.A. *et al*. 2021). Csomós, G. *et al*. (2021), however, used different, more-complex methodologies to quantify UGS availability. Owing to various physical or psychological barriers, the second level of UGS provision, UGS accessibility, is not guaranteed to all or to part of the population for any particular existing (and, thus, available) UGS (Wright, W.H.E. *et al*. 2012; Park, K. 2017; Biernacka, M. and Kronenberg, J. 2019; Biernacka, M. *et al*. 2020; Kolcsár, R.A. *et al*. 2021). Physical accessibility means the lack of physical barriers (e.g., busy streets, fences or buildings) along the road that can potentially hinder or preclude access to a given green space (Biernacka, M. and Kronenberg, J. 2019). Buildings and road networks also can highly modify pedestrian travel times by making the route between the starting point and destination far longer than the straight-line distance between the two points (Kolcsár, R.A. *et al*. 2021). Psychological accessibility is defined by more-abstract barriers, such as the real or perceived relative safety of areas that some might choose to avoid, thereby lengthening their travel time to the UGS (Park, K. 2017). UGS accessibility is usually mapped either within buffer zones (Oh, K. and Jeong, S. 2007; Wright, W.H.E. *et al*. 2012; Braquinho, C. *et al*. 2015; Bahrini, F. *et al*. 2017; Koprowska, K. *et al*. 2018; Csomós, G. *et al*. 2020) or with more-accurate methods (such as service areas) based on road networks (Shahid, R. *et al*. 2009; Le Texier, M. *et al*. 2018; Mora-Garcia, R.T. *et al*. 2018; Kolcsár, R.A. *et al*. 2021), and even more elaborate methods based on least cost path algorithms (e.g., using AccessMod and CostDistance) have been devised, such as applied by Chênes, C. *et al*. (2021). Among the three levels of UGS provision, attractiveness is arguably the most difficult to objectively measure. Any available and freely accessible green space needs to have certain qualities in order to attract residents to visit the area. UGS attractiveness is determined by various factors, which may involve cultural ecosystem services, aesthetic values, and infrastructure among others (Kronenberg,

J. 2015; Biernacka, M. and Kronenberg, J. 2019). The attractiveness of an UGS is shown to degrade by the increase of walking distance (Morar, T. *et al*. 2014), while some UGSs are simply unattractive to visitors (Wright, W.H.E. *et al*. 2012; Biernacka, M. and Kronenberg, J. 2019). In some studies, the terms UGS quantity and UGS quality are considered to correspond to the concepts of availability and attractiveness, respectively (You, H. 2016; Kraemer, R. and Kabisch, N. 2021). Evaluation of availability and accessibility of sectors other than UGSs (e.g., health care) is also possible with numerous occurrences in the scientific literature (Hare, T.S. and Barcus, H.R. 2007; Kwan, M.P. and Weber, J. 2008; McGrail, M.R. and Humphreys, J.S. 2009; Kraft, S. 2016; Uzzoli, A. *et al*. 2020). Van den Bosch, C.K. (2021) proposed the 3-30-300 rule, as a very similar concept of UGS provision. According to this rule, ideally, there should be at least three trees visible from one's window, while at the same time one's neighbourhood should have at least 30 percent UGS coverage (preferably trees), and one's home should be no farther, than 300 m from the nearest urban park.

Most authors agree that, depending on its size and function, a walking distance of 2–15 min to get to a public park is optimal for defining a catchment or area within which local residents can easily access public green spaces (Stanners, D. and Bourdeau, P. 1995; Barbosa, O. *et al*. 2007; Pafi, M. *et al*. 2016; Stessens, P. *et al*. 2017; Poleman, H. 2018; Kolcsár, R.A. *et al*. 2021). Although the growing number of spatial data sources and GIS analysis techniques make it easier to determine the number, and demographic characteristics (age, gender distribution, etc.) of the local inhabitants living within the different catchment areas of the public parks (Bok, J. and Kwon, Y. 2016; Wüstemann, H. *et al*. 2017; Poleman, H. 2018; Zepp, H. *et al*. 2020), to date little information is available on the age structures of different UGS provision zones.

The aim of the present study has been to investigate the age structure of areas with different UGS provisions in a Hungarian study area, specifically as a case study of Szeged. We sought to evaluate the UGS provision at the building-plot scale with a method that incorporates two of three UGS provision levels (availability and accessibility) identified by researchers (Biernacka, M. and Kronenberg, J. 2019; Kolcsár, R.A. *et al*. 2021). Given that the equality of UGS provision is an important component of environmental justice (Wen, C. *et al*. 2020), this method could potentially help urban planners to localize deficiency in the green infrastructure with the consideration of the age-related needs of local residents (Kemperman, A.D.A.M. and Timmermans, H.J.P. 2007; Artmann, M. *et al*. 2017; Levy-Storms, L. *et al*. 2018; Bozkurt, M. 2021; Yang, L. *et al*. 2021). Based on our overall aims, we set out to answer the following research questions in this research:

– How can we specify and delineate the low-, medium-, and high-level UGS provision zones?
– What is the age structure of local inhabitants living in low-, medium-, and high-level UGS provision zones?

Answering these questions is important from the perspective of urban planning, as it will help in the delineation of UGS-deficit areas within cities and, thus, where the improvement of UGS provision is necessary. Analysing UGS provision by age group is also essential for both environmental justice and urban park design.

Materials and methods

Study area

The study area of the present research, Szeged *(Figure 1),* is in the centre of the Southern Great Hungarian Plain (EU NUTS2 level statistical region of Hungary). By population, Szeged is the third largest city in Hungary and the second largest in the Great Hungarian Plains (KSH 2021).

The radio-concentric city has multiple urban parks of various sizes and structures, the largest of which (~ 20 ha), Erzsébet Liget

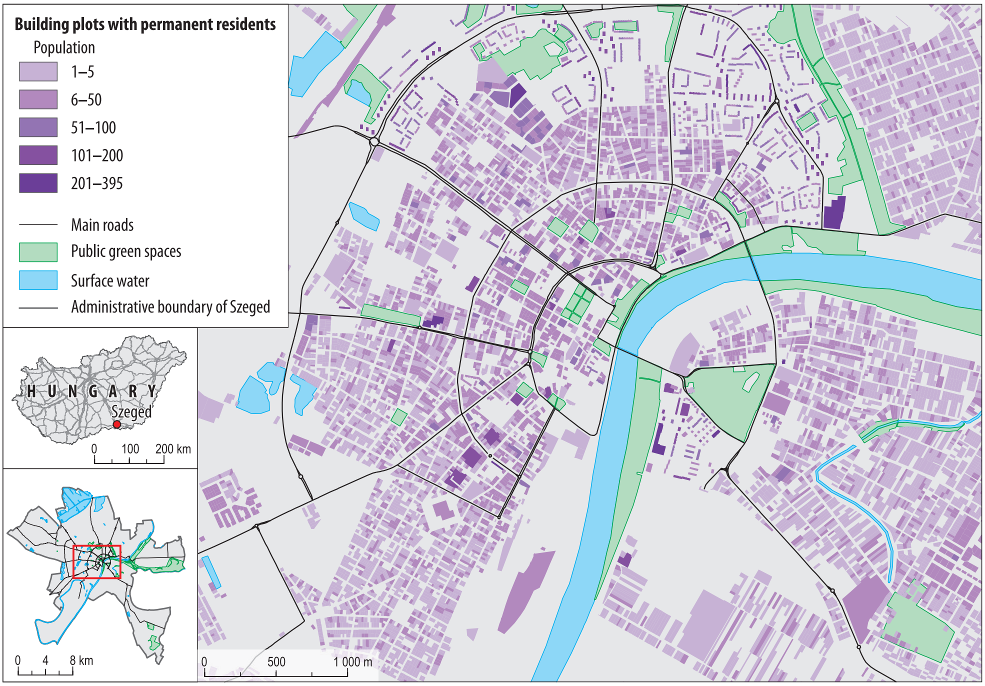

Fig. 1. Study area within Szeged, Hungary, showing building-plot-scale population distribution and public green spaces selected for accessibility estimation.

(Elisabeth Park) is located on the western side of Újszeged district. Besides its urban parks, Szeged has a notable amount of forest areas as well. These are decisively floodplain forests along the bank of its two rivers, Tisza and Maros. Informal green spaces (especially in the housing estate areas) and private gardens also constitute a significant part of the green infrastructure of Szeged.

Data used

A detailed address-level population database was used both for local UGS availability (as per-capita estimations) and for demographic analyses of the UGS provision zones (Belügyminisztérium 2019). To enable spatial evaluations and visualization, a polygon layer containing Szeged's building plots with permanent residents was also created (see *Figure 1*). Layer contained information solely about the population with permanent residency in Szeged, thus, other forms of residency (e.g., renters, students living in dormitories etc.) were not included in this study.

For local green space availability mapping, we used a high-resolution Normalized Difference Vegetation Index (NDVI) layer (0.5 x 0.5 m raster size) derived from an orthophoto (Lechner Tudásközpont, 2015). Public green space accessibility mapping required the usage of layers (e.g., road network and points of interest) from the open-source GIS database OpenStreetMap (Geofabrik, 2021). For both the local green space availability and public green space accessibility analyses, we incorporated the land-use and land-cover polygons of the 2018 version of the European Environmental Agencies Urban Atlas (Coopernicus, 2018).

Figures of the present paper were produced using data provided by Copernicus (Urban

Atlas), Geofabrik (OpenStreetMap), Lechner Tudásközpont (orthophoto of Szeged), the Hungarian Ministry of the Interior (address-level population data), and the 2018 building-code modification document of Szeged (building plots) (Lechner Tudásközpont 2015; Copernicus 2018; Fehér, É. 2018; Belügyminisztérium 2019; Geofabrik 2021).

Population data pre-processing

Building plots were chosen as the administrative unit for our study as they provide a realistic picture of the spatial extent of living space of the urban population (particularly for detached houses). The polygon layer containing building plots was digitized from maps in the 2018 building-code modification document for Szeged (Fehér, É. 2018). At our disposal was a building-polygon database that contained highly accurate, address-level population data (capita per building) based on the postal mailing addresses of all inhabitants of Szeged as of 1 January 2019 (Belügyminisztérium 2019). The building-polygon layer with population data was spatially joined to the polygon layer of the building plots. Generally, one building plot contains only one building, in the case of building-plot polygons containing two or more buildings, however, we used the sum of population values of all buildings within its area for the building-plot population. By joining the two layers, building plots with no permanent residents were deleted from the layer. Age-group categories in the source data were merged into larger categories to reduce fragmentation for the current analyses, thereby creating four new age groups: minors (0–18 years), young adults (19–40 years), middle-aged adults (41–60 years), and the elderly (≥ 61 years) *(Figure 2)*, with differently attributed UGS usage habits and design requirements (Kemperman, A.D.A.M. and Timmermans, H.J.P. 2007; Artmann, M. *et al.* 2017; Levy-Storms, L. *et al*. 2018; Bozkurt, M. 2021; Yang, L. *et al*. 2021). The division of these four merged categories was restricted by the original, narrower age groups, which had very inconsistent ranges regarding the span of years

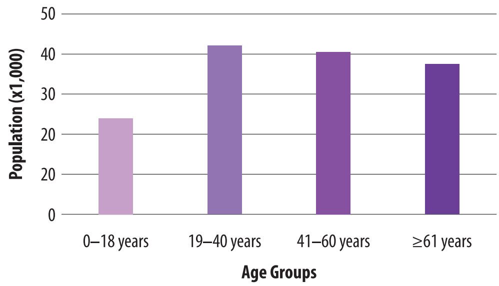

Fig. 2. The total number of residents within investigated age groups of Szeged, Hungary.

(e.g., 0–2 years, 3 years, 7–10 years, 41–45 years, 63–70 years, etc.). According to our population database, there were ~144,000 permanent residents within the study area (Szeged) on January 1, 2019.

Local green space availability analysis

We defined local green space availability (the local availability of any type of green space) as the total area of UGSs within 50-m-radius buffer zones of each building plot divided by the building plot's number of residents (square metres per capita). The size of the buffer zone was chosen according to J. Gehl's thresholds (2010), which were based on consideration of human-scale distance.

To delineate areas covered with vegetation within the city, we created a raster-based NDVI map from a high-resolution orthophoto (0.5 x 0.5-m raster size) provided by the University of Szeged Department of Climatology and Landscape Ecology. The image was acquired during May–July 2015 by Lechner Tudásközpont (2015). The footage was a four-band (RGB–NIR) UltraCam X orthophoto that had an appropriate resolution for highly accurate NDVI maps *(Figure 3)*. 0 was chosen as the pixel value that represents minimal vegetation. Although the 0.2 value defined by the United States Geological Survey (USGS) is the most commonly accepted lower threshold of vegetation coverage (USGS 2018), Aquino, D. *et al.*

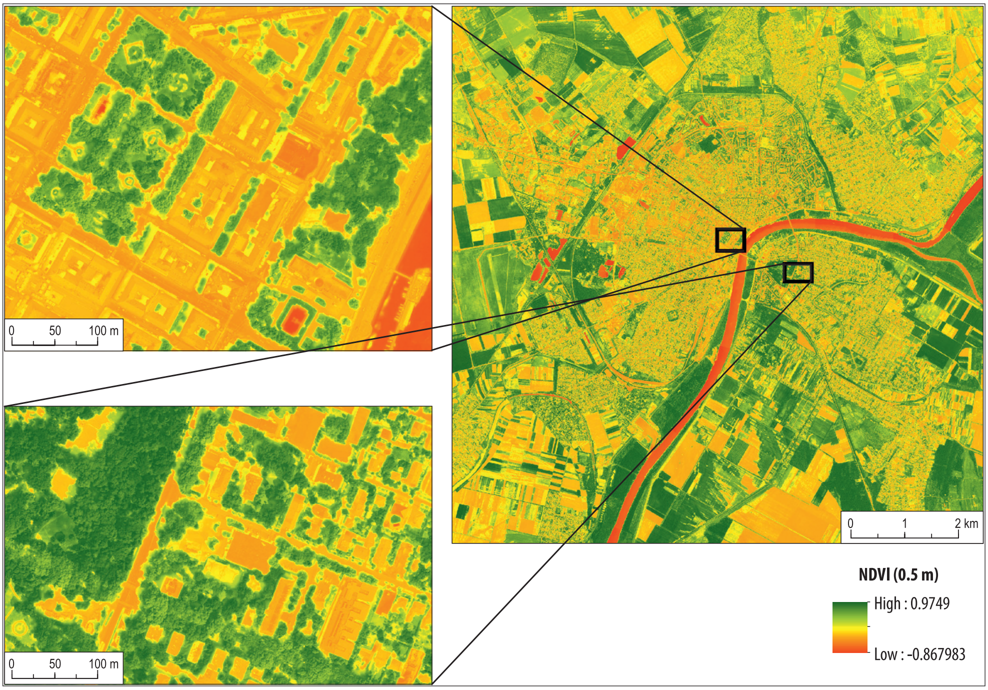

Fig. 3. Normalized Difference Vegetation Index (NDVI) layer generated from 2015 orthophoto of Szeged, Hungary.

(2018) argued that it is possible that areas with very low vegetation coverage to fall between NDVI values of 0 and 0.2. In the case of our orthophoto, the most realistic delineation of vegetation coverage was achieved by applying 0 as the minimum value. The suspected reason for a significant amount of UGSs was being found between values 0 and 0.2, was the heat stress that the vegetation suffered at the time of the data collection. Because of their seasonality and meager recreational value, plow fields were excluded from the NDVI map. To mask out these undesirable areas, we used the European Environmental Agencies Urban Atlas 2018 land-use and land-cover database's annual-crops polygons (code 21000) (Copernicus 2018).

After the selection procedure, 50-m buffer zones were generated around polygons enclosing building plots with permanent residents, and the sum of green pixels (NDVI ≥ 0) was calculated for each 50-m buffer zone *(Figure 4)*. We calculated total vegetation coverages (as square meters) from the raster resolution and the sums of pixels within the buffer zones. Dividing the resulting values by the number of residents for each corresponding building plot, we determined how much local green space is available for an inhabitant of a given building plot within its 50-m buffer zone.

We then delineated zones with low, medium, and high local green space availability (local green space availability zones) based on the previously calculated square metres per capita values. We chose 50 m^2 per capita as the boundary value between low and medium categories based on the the recommendations of World Health Organization (2017) which is widely used in various publications (Morar, T. *et al.* 2014; Maryanti, M.R. *et al.* 2016). As the boundary value between medium and high categories, we used 500 m^2

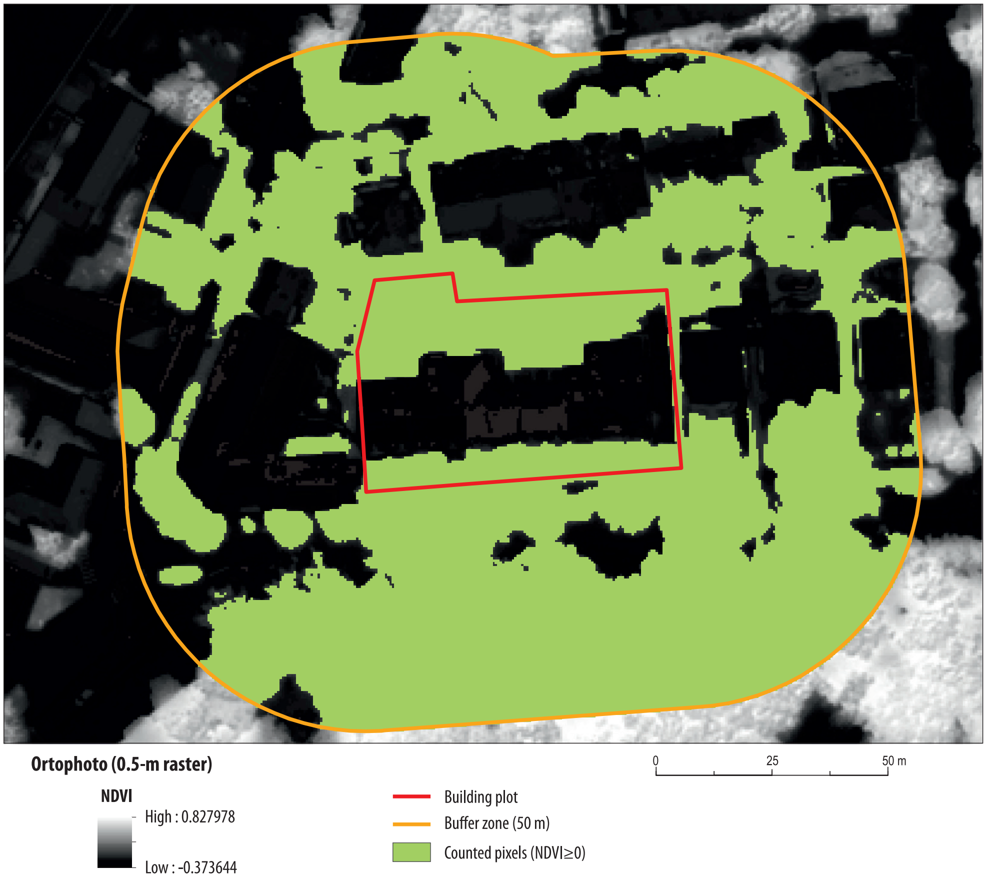

Fig. 4. Principle of calculation of local green space availability, demonstrated via example building plot. NDVI = Normalized Difference Vegetation Index.

per capita derived from the optimal minimum green space availability defined for use in Berlin (5,000 m^2 per capita within 500-m buffer zones) by converting it to the 50 m buffer zones of the present study (Kabisch, N. *et al*. 2016). A score between values 1–3 was also assigned to the local green space availability categories *(Table 1).*

Accessibility mapping of public green spaces

For the accessibility analysis, we created a subgroup of UGSs called public green spaces, which aims to include every urban park, public urban forest or any other functionally similar area. Additionally, we aimed to include in this category informal green spaces

Table 1. Category limits of local green space availability and public green space accessibility

Indicator	Low (score 1)	Medium (score 2)	High (score 3)
Local green space availability, m^2 per capita	< 50	50–500	> 500
Public green space accessibility, min.	> 10	2–10	< 2

as well, which are known contributors to the urban quality of life (Rupprecht, D.C. *et al*. 2015). Thus, on the basis of Kolcsár, R.A. *et al*. (2021) we defined public green spaces as areas which meet all of the following conditions:

1. The area must be defined by Urban Atlas (Copernicus 2018) land use and land cover database as either "Green urban areas" (14100), "Forests" (31000) or "Land without current use" (13400).

2. The area must be a public space.

3. The area has functions or services important enough to the public that it's reflected in OpenStreetMap's Point of Interest (POI) layer (Geofabrik 2021).

Because, by definition, public green spaces are open to everyone, accessibility analysis can be used to incorporate them in a city-scale UGS provision assessment. Private gardens on the other hand, by their nature are inaccessible to the public and, thus, were not included in the accessibility analysis.

The first step of our selection process was to select polygons defined in Urban Atlas as Green urban areas, Forests or Land without current use. The latter category was included because of its potential to contain informal green spaces. As the next step, we overlapped the point of interest (POI) layer, which consists of volunteered geographic information (Jiang, S. *et al*. 2015; Zhang, X. *et al*. 2017) with the selected UGSs to find the areas with at least one function or service significant enough to appear in the publicly accessible and editable database. In most cases, POI-s within these USG polygons represented objects connected to amenities (e.g., street furniture, drinking water, and toilets), recreation (e.g., playgrounds) or aesthetic values (e.g., statues, fountains, and landmarks) all of which can be connected to the multi-functionality of the USG. Because of this, the POI layer proved to be an invaluable tool to identify and delete UGS polygons with little to no functions. One UGS polygon was retained although it is not notably represented in the POI layer in the database. While none of the POI layer's points intersected its geometry, a point was found within its direct proximity which was identified as a POI of this particular public green space. The remaining polygons were individually evaluated as to whether or not they are publicly accessible, and all private areas were excluded from further analysis.

On the basis of the work of Stessens, P. *et al*. (2017) and Kolcsár, R.A. *et al*. (2021), we divided a selection of public green spaces into two separate groups by size: local public green spaces (0.3–10 ha) and district public green spaces (10–1,000 ha). We then assigned to each group a maximum walking distance to represent its catchment size: 200 m for local public green spaces and 800 m for district public green spaces.

Following Kolcsár, R.A. *et al*.'s methodology (2021), the OpenStreetMap road network was overlapped with the public green space polygons (Geofabrik 2021), and entry points were generated at the intersections of the road lines and the polygons. With the help of ArcGIS Pro's Network Analyst tool (ESRI 2018), service areas (catchments) were generated around these entry points to indicate the maximum pedestrian travel time required to reach any given point within the city. Assuming a 5-km/h pedestrian velocity, catchments were converted into travel times: ~2 min in the case of local public green spaces and ~10 min in the case of district public green spaces. Accordingly, catchments representing 2 min walking distance were generated around each of the entry points, while catchments representing 10 min walking distance were generated only around the entry points of district public green spaces. By merging these catchments together (2-minute catchments and 10-minute catchments separately), the public green space accessibility zones were created.

With the help of the Select Layer by Location tool of ArcGIS (using the centroids of each building-plot polygon with permanent residents), public green space accessibility zones were projected to the building plot layer. Each building plot was then categorized based on their public green space accessibility. Building plots with a centroid within < 2-min public green space accessibility zones were evaluated as exhibiting high public green space accessibility, and those within 2- to 10-min public green space accessibility zones were evaluated as exhibiting medium public green space accessibility. Any building plots outside the public green space accessibility zones (> 10-min) were defined as having low public green space accessibility. A score between the values of 1–3 was also assigned to the public green space accessibility categories (see *Table 1*).

Overall UGS provision assessment

Using the local green space availability and the public green space accessibility scores (1–3), we implemented a combined scoring system to evaluate the overall UGS provision of each building plot *(Table 2).* From these scores (2–6), we created the overall UGS provision categories. A three-level classification was created so the overall UGS provision results would be comparable with the local green space availability and public green space accessibility estimates. A five-level classification was also created to illustrate finer differences between provision zones.

Based on *Table 2*, overall UGS provision zones (and the corresponding scores) can be interpreted as follows:

Low UGS provision zones (score 2-3):

1. Areas with no or very little locally available UGS (below 50 m^2/capita) and no accessible public green space within 10 minutes of walking.

2. Areas with no or very little locally available UGS (below 50 m^2/capita), but the nearest public green space can be accessed between 10 and 2 minutes by walk.

3. Areas with an acceptable amount of locally available UGS (between 50 and 500 m^2/capita) but no accessible public green space within 10 minutes of walking.

Medium UGS provision zones (score 4):

1. Areas with no or very little locally available UGS (below 50 m^2/capita) but the nearest public green space can be accessed within 2 minutes by walk.

2. Areas with an acceptable amount of locally available UGS (between 50 and 500 m^2/capita) and an accessible public green space between 10 and 2 minutes by walk.

3. Areas with an abundance of locally available UGS (500 m^2/capita or higher), but no accessible public green space within 10 minutes of walking.

High UGS provision zones (score 5 and 6):

1. Areas with an acceptable amount of locally available UGS (between 50 and 500 m^2/capita) and the nearest public green space can be accessed within 2 minutes by walk.

2. Areas with an abundance of locally available UGS (500 m^2/capita or higher), and an accessible public green space between 10 and 2 minutes by walk.

3. Areas with an abundance of locally available UGS (500 m^2/capita or higher), and the nearest public green space can be accessed within 2 minutes by walk.

Age-group distributions of UGS provision zones

We performed age-group-based demographic analyses of the data within the building-plot polygons. As a result of the overall UGS provision evaluations, the age-group distribution could be estimated for the three UGS provision zones (low, medium, and high) as

Table 2. Numeric evaluation of overall urban green space provision

Indicator	Public green space accessibility scores		
Local green space availability scores	Low (score 1)	Medium (score 2)	High (score 3)
Low (score 1)	very low (score 2)	low (score 3)	medium (score 4)
Medium (score 2)	low (score 3)	medium (score 4)	high (score 5)
High (score 3)	medium (score 4)	high (score 5)	very high (score 6)

well as separately for the local green space availability and the public green space accessibility zones. In addition to the actual population numbers (p_a), we also calculated an estimated population number (p_e) (Eq. 1), showing what would be the number of residents within each age group if the age distribution of the given provision zone's population were the same as that of the entire city.

Comparing these two values (p_a vs. p_e) gives an insight into which age groups are underrepresented or overrepresented within the high, medium, or low zones regarding local green space availability, public green space accessibility, or overall UGS provision:

$$p_e = 0.01\, p_t \cdot r, \tag{1}$$

where p_e is the estimated population of a given age group within given overall UGS provision zone, local green space availability zone, or public green space accessibility zone (low, medium, or high); p_t is the total population (sum of four age groups) within a given overall UGS provision zone, local green space availability zone, or public green space accessibility zone (low, medium, or high); and r is the proportion of a given age group within the total city population.

We then calculated the percentage difference (Eq. 2) between p_a and p_e by

$$d = (p_a - p_e)/p_a \cdot 100, \tag{2}$$

where d is the percentage difference between the actual and expected number of residents within a given age group of the given overall UGS provision zone, local green space availability zone, or public green space accessibility zone (low, medium, or high); p_e is the estimated population of a given age group within the given overall UGS provision zone, local green space availability zone, or public green space accessibility zone (low, medium, or high); and p_a is the actual population of a given age group within the given overall UGS provision zone, local green space availability zone, or public green space accessibility zone (low, medium, or high).

Results

Overall urban green space provision mapping

On the basis of the local green space availability map *(Figure 5)*, we concluded that the overall state of local green space availability in Szeged is good. About 88 percent of the building plots have high local green space availability, while the average score is ~2.8. As expected, the largest concentration of building plots (classified as high, or scored as 3) are in the suburban areas, where detached houses are dominant. Building plots classified as medium (scored as 2) or low (scored as 1) are primarily in the city centre, where the dense building coverage and high proportion of paved areas result in low NDVI values, and in housing areas where an otherwise acceptable amount of vegetation coverage has to satisfy the needs of a large residential population.

Based on the results, the state of public green space accessibility appears to be lower throughout Szeged. Only ~16 percent of the building plots were identified as being part of the high public green space accessibility zones. In this case, the average score of the city was 1.6. Public green space accessibility maps *(Figures 6* and *7)* indicate that the best public green space accessibility is within the more densely populated downtown of Szeged, where large public green spaces are more prominent, complementing the results of the local green space availability map. Low public green space accessibility building plots are primarily identified in the suburban areas, where public green spaces are less frequent compared to the city centre.

Regarding the spatial characteristics of the overall UGS provision zones *(Figure 8)*, it can be stated that in general, the overall UGS provision of Szeged is good. Approximately 38 percent of the building plots received high scores (5 or 6) as a result of the aggregation of their local green space availability and public green space accessibility scores. Additionally, another ~58 percent of the building plots were categorized as having medium overall

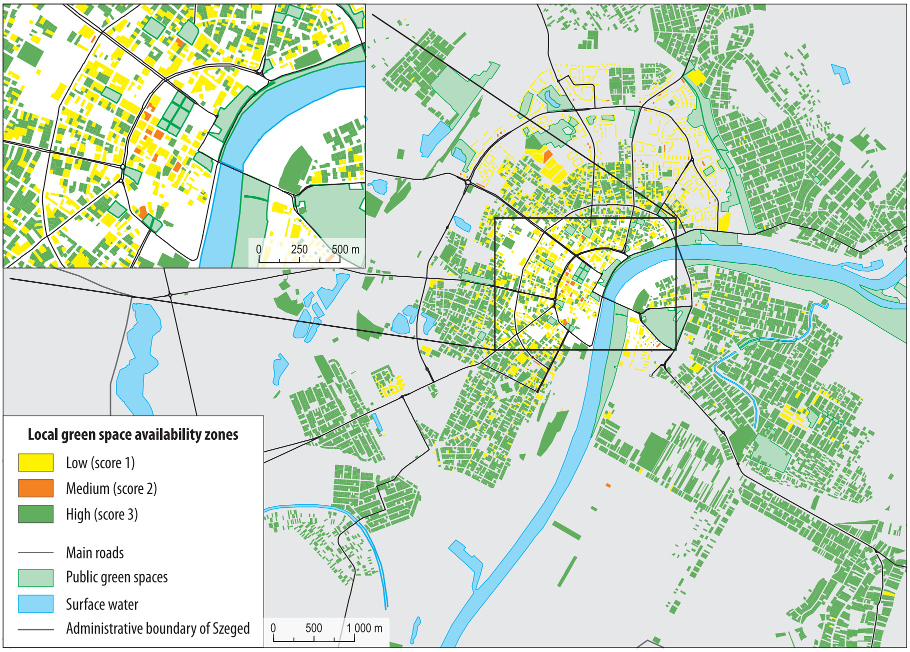

Fig. 5. Building-plot-scale local green space availability (square meters per capita), Szeged, Hungary.

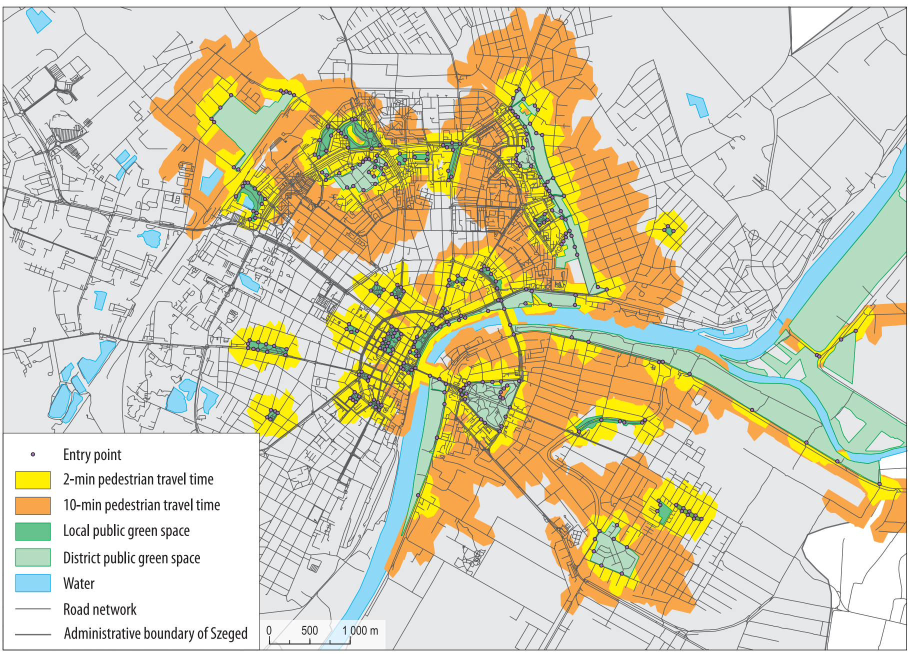

Fig. 6. Accessibility map, showing selected public green spaces with their designated size-based catchments in Szeged, Hungary.

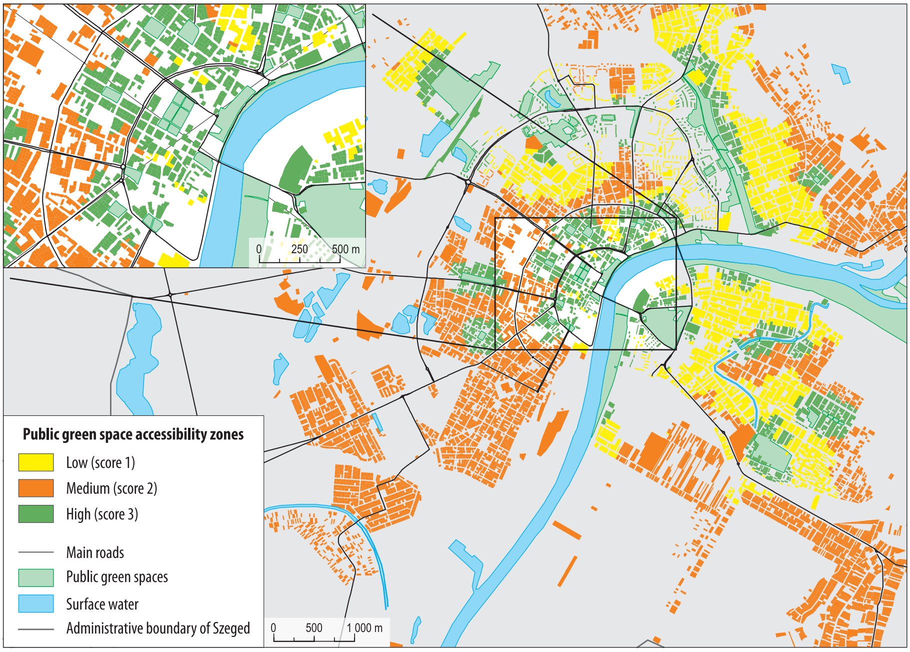

Fig. 7. Building-plot-scale public green space accessibility, Szeged, Hungary.

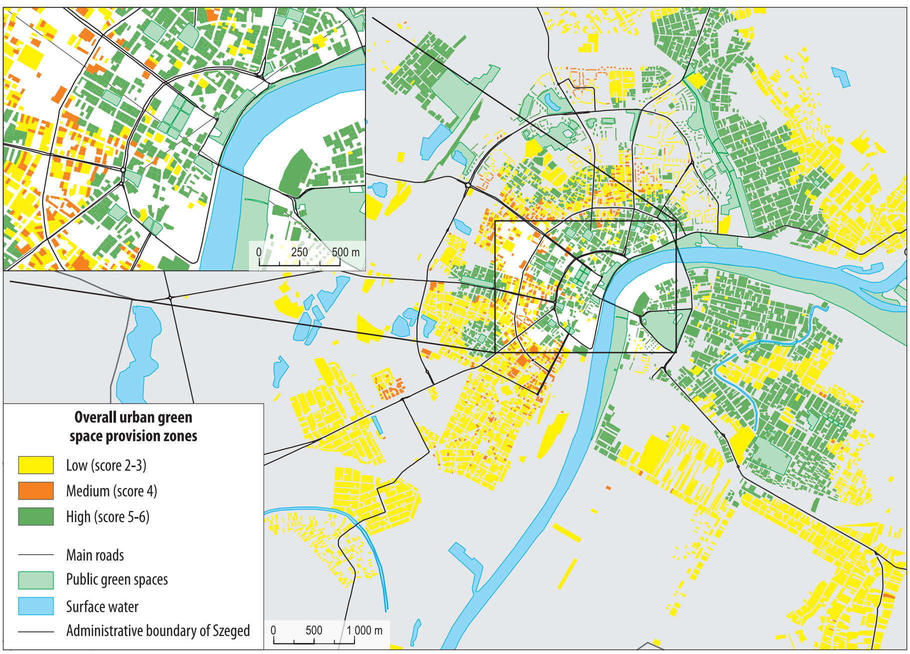

Fig. 8. Building-plot-scale overall urban green space provision map of Szeged, Hungary.

UGS provision (with a score of 4). The average overall UGS provision score in Szeged was 4.5. *Figure 8* also shows areas within the city that lack both local green space availability and public green space accessibility.

Building plots with a very low or low public green space accessibility score *(Figure 9)* need the most attention regarding green space development. Building plots in the very high overall UGS provision zones are generally found in the direct proximity of the public green spaces where part of the locally available green space is the closest accessible public space itself.

Population distribution assessment

Results of the age-group analyses of different overall UGS provision zones (three-level classification) show that the vast majority of residents live in either medium or high overall UGS provision zones. However, a notable number of people (~ 19,000) of the total population (~144,000) live in areas categorized as low overall UGS provision zones *(Figure 10).*

The population diagram *(Figure 11)* indicates that only a very small proportion of the population (~ 800 people) live in the green-deficit areas, for which the lowest possible overall UGS provision score (2) was applied. In contrast, the population of very high overall UGS provision zones (score 6) is nominally < 9,000.

Both underrepresentation and overrepresentation are apparent when looking at the age groups *(Figure 12).* Compared to the age distribution of Szeged, the 0–18 age group is overrepresented in the areas with high local green space availability, implying that relatively speaking this age group has the best local green space availability in the city,

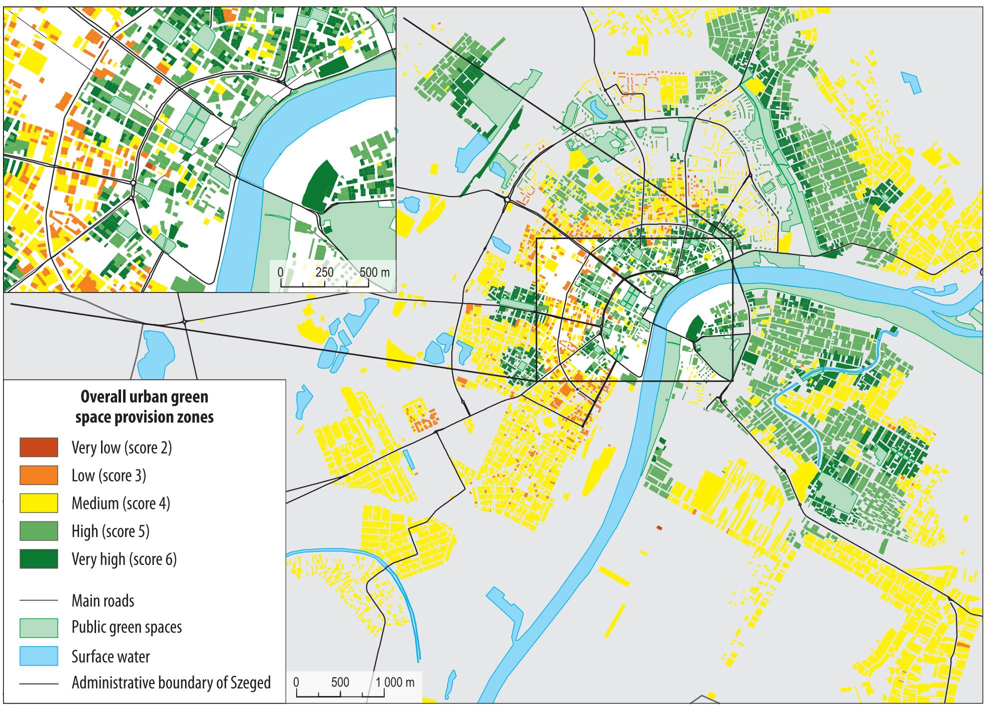

Fig. 9. Building-plot-scale map of Szeged, Hungary, showing five urban green space provision zones.

while in an absolute sense, members of age group 41–60 are present within these zones in the largest number. In contrast, the 19–40 age group is highly underrepresented in the high local green space availability zones compared to the proportion of the other age groups. Similarly to the age group of 0–18, age groups of 41–60, and ≥ 61 are also overrepresented in areas with high local green space availability.

In many cases, we found that the population distribution from the public green space accessibility analyses show patterns opposite to the results of the local green space availability mapping *(Figure 13)*.

The age group of 0–18 is strongly overrepresented in areas of low public green space accessibility. In contrast, age groups of 19–40 and ≥ 61 are overrepresented in areas of high public green space accessibility. It is also noteworthy that more than a third of the total population lives within low public green space accessibility zones. Overall UGS provision analysis shows that while only a small proportion of the residents can be found in

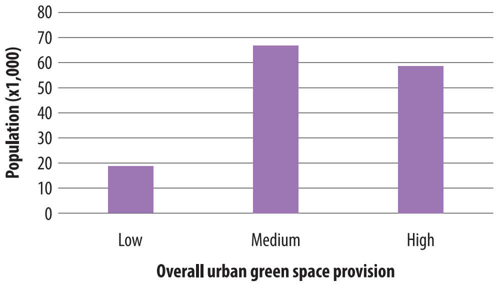

Fig. 10. Total population distribution of three overall urban green space provision categories for Szeged, Hungary.

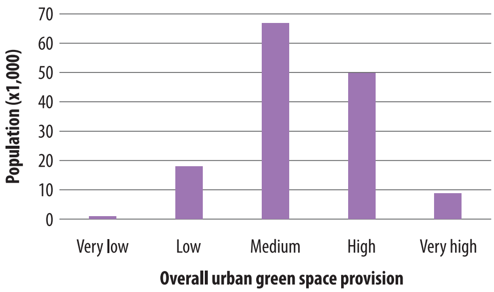

Fig. 11. Population distributions of five overall urban green space provision zones in Szeged, Hungary.

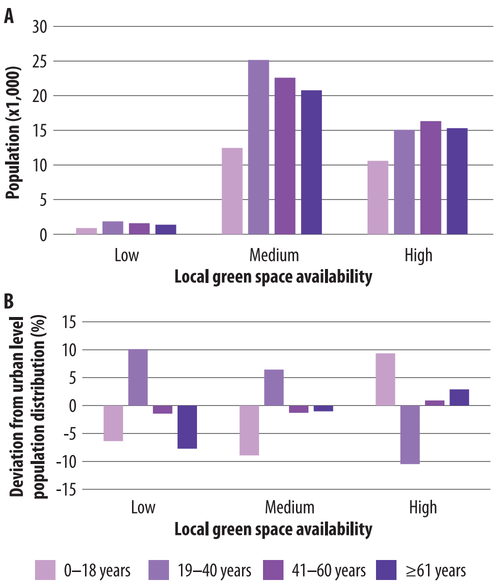

Fig. 12. Age-group distributions, Szeged, Hungary. A = Local green space availability zones; B = Percentage differences between actual and expected population.

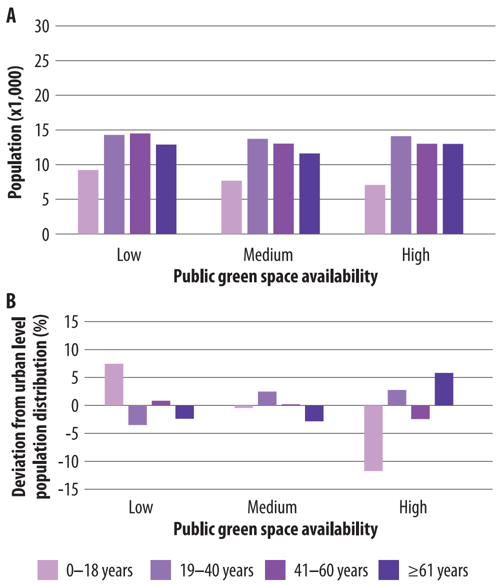

Fig. 13. Age-group distributions, Szeged, Hungary. A = Public green space accessibility; B = Percentage differences between actual and expected population.

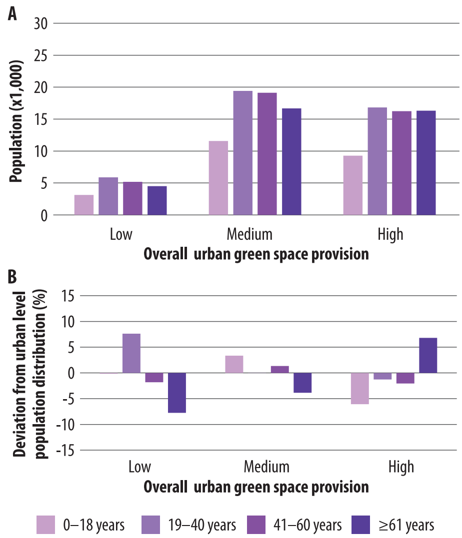

Fig. 14. Age-group distributions, Szeged, Hungary: (A) Overall urban green space provision zones; (B) Percentage difference between actual and expected population.

areas with low classification, their relative distribution within the zones favours the ≥ 61 age group *(Figure 14)*. Within the low overall UGS provision zone, the 19–40 age group is the most overrepresented. In contrast, in the high overall UGS provision zone, every age group but the elderly (≥ 61) appears to be underrepresented compared to the actual age distribution of the entire population of Szeged (see *Figure 14*).

Discussion

As regards our findings, it can be stated, that based on our results the average level of overall UGS provision in the city is slightly above medium. Our methodology identified areas within Szeged with a low score regarding both aspects (accessibility and availability) of UGS provision. Given that Kemperman, A.D.A.M. and Timmermans, H.J.P. (2007) argued that families with children are more likely to visit urban parks, the underrepresentation of age group 0–18 in public green space accessibility can be considered suboptimal. The elderly being favoured regarding UGS provision is not unique to Szeged, Wen, C. *et al*. (2020) drew similar conclusions in the case of Hannover, Germany. Good UGS provision is unquestionably beneficial for the elderly (especially for those ≥ 65), because UGSs provide them numerous physical and psychological benefits (Loukaitou-Sideris, A. *et al*. 2016), however, the UGS usage habits of this age group have their own peculiarities which need to be addressed in urban planning. According to Kemperman, A.D.A.M. and Timmermans, H.J.P. (2007) for instance, UGS usage habits of seniors tend to be extreme, as they either visit urban parks or other public green spaces very frequently or almost never. Their willingness to visit UGSs is largely defined by the ecosystem services provided by these UGSs (e.g., where trees provide enough shading and sufficiently cool microclimate) as well as the infrastructure of both the UGSs and its neighbourhood (e.g., street furniture, well-maintained safe roads, etc.) (Kabisch, N. and Haase, D. 2014; Kántor, N. 2016; Loukaitou-Sideris, A. *et al*. 2016; Arnberger, A. *et al*. 2017; Artmann, M. *et al*. 2017; Wen, C. *et al*. 2020). Because public green space accessibility favours seniors in Szeged, urban development should primarily focus on infrastructure development of these existing public green spaces as well as their neighbourhood to enhance the effective UGS usage by this age group (Levy-Storms, L. *et al*. 2018).

The value of the overall UGS provision metric used in present the study could realistically be increased in two possible ways. The first way is to increase the vegetation coverage (represented by NDVI values) within the 50-m proximity of the building plots where local green space availability is low. This can be done primarily via grassing or by bush or tree plantation, as well as by the creation of green roofs and green walls. The second possibility is to establish new public green spaces at the centre or otherwise in close proximity to building-plot clusters that have low UGS provision values. This method enhances both public green space accessibility and local green space availability. This type of green space provision development might be most efficient in areas with large, but functionless green space patches, where urban parks or public gardens can be created via landscaping and expanding the area's functions. Although the establishment of urban parks or other similar public green spaces is often limited by resources and available space, a growing body of literature demonstrates that pocket parks can be an effective solution to this problem, such as the work of Kerishnan, P.B. and Maruthaveeran, S. (2021), Naghibi, M. *et al*. (2021) or Rosso, F. *et al*. (2022).

Our methodology also enables identifying age groups that are underrepresented in high UGS provision areas (e.g., age group of 0–18 years in the case of Szeged) to prioritize UGS development in low UGS provision areas where the concentration of the age group is higher.

Conclusions

In this study, we calculated the building-plot-scale UGS provision for Szeged, Hungary with a methodology incorporating two of the prior-established UGS provision levels: availability and accessibility (Biernacka, M. and Kronenberg, J. 2019). In Szeged, local green space availability is higher in the peripheral, single-family housing areas, while public green space accessibility is higher in the densely populated city centre. These two metrics complement each other, providing good overall UGS provision conditions throughout the residential areas of the entire city. The majority of the residents live in areas with medium or high UGS provision. All the age groups except the elderly (≥ 61) are underrepresented in areas with high overall UGS provision. This is especially true of the 0–18 age group.

Our methodology proved to be an adequate tool to delineate zones within Szeged with insufficient UGS provision, as well as identify disadvantageous age groups within these areas. We hope that the present methodology and our results will be applicable in other cities for high-resolution preliminary UGS provision assessments as well.

There are, however, certain limitations that need to be addressed in the future. Our methodology used numerous parameters based on (or derived from) internationally accepted thresholds (e.g., category-limit values and applied buffer-zone radius for local green space availability, catchment sizes for public green space accessibility, etc.). In the future, more robust inferences could be made of the UGS provision by sensitivity analyses to different parameters.

Future studies should also aim to investigate the UGS provision of different age groups separately, applying parameters that better reflect the examined focus group. For example, the public green space accessibility assessment of the elderly, who are generally less mobile than the younger age groups, should be carried out with a lower average walking velocity (compared to the 5 km per hour walking speed used in the present study). In future studies, vehicle-based accessibility mapping besides the walking-based method should also be considered.

A clear limitation of the broad applicability of our framework is that data at a similar resolution might not be available for other study areas. Knowing such limitations, certain input data can be replaced by more broadly available but less-detailed data, such as population attributes from the 2012 and 2018 European Environmental Agencies Urban Atlas land use and land cover databases (Copernicus 2018; Kolcsár, R.A. *et al*. 2021). A different, raster-based method for the identification of public green spaces, e.g., methodologies proposed by Huang, B. *et al*. (2018), and Bui, D.H. and Mucsi, L. (2021), should also be tested in the future.

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