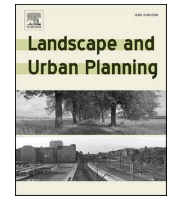
Landscape and Urban Planning 257 (2025) 105301

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan



Assessing accessibility and crowding in urban green spaces: A comparative study of approaches

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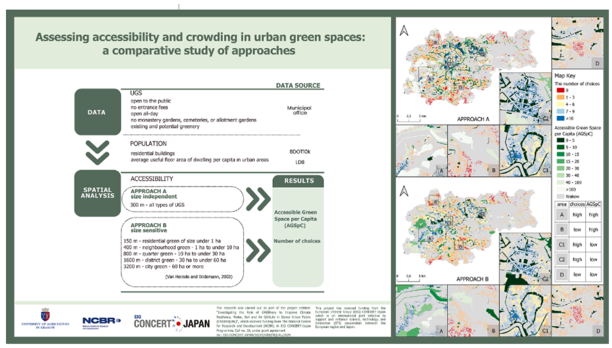
HIGHLIGHTS

- Potential crowding of a green space may be shown with Accessible Green Space per Capita and expressed in square meters.
- Accessible Green Space per Capita varies and depends on the size of the green space, population, and accessible distance.
- Both presented approaches give similar results for the lowest accessibility.
- The approaches show the UGS accessibility for individual residential buildings and identify patterns throughout the city.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Accessibility
Urban green areas
Environmental justice
Population

ABSTRACT

Urban green spaces (UGS) are pivotal elements of the structure of urbanised areas, important for the well-being of the city inhabitants. Therefore, it is necessary to provide tools for determining the accessibility and crowdedness of the UGS. To this end, we assess how much space there is for potential UGS users in individual green spaces. It is pilot quantitative study limited to an area of one city, showing the crowdedness of UGS in two approaches. In both approaches, we assume an extreme event observed in the time of pandemic that all people in the accessible distance visit a UGS at the same time. In the approaches, we have combined parameters from literature and the idea that analysing UGS accessibility could be size sensitive to come up with methods for assessing residents' accessibility to green spaces with spatial analysis. Our study shows the variability of UGS accessibility throughout the city. The results indicate that to identify areas in cities with insufficient UGS, analyses using the commonly referenced 300-meter accessibility measure may be sufficient. However, for a more comprehensive assessment of UGS accessibility, it is necessary to conduct studies that are sensitive to UGS size and factor in the estimated population within it. The study tackles the UGS accessibility problems in a novel way of comparing two popular approaches and providing practical insights. The approaches may be useful for spatial planning practices to show the differences in local UGS accessibility and delimit areas with lower UGS

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https://doi.org/10.1016/j.landurbplan.2025.105301
Received 2 August 2024; Received in revised form 5 December 2024; Accepted 14 January 2025
Available online 24 January 2025

accessibility. The findings may support the municipality in the practical task of monitoring the crowding of UGS in the city and facilitate decision making in the new UGS site selection process.

1. Introduction

Balancing various interests while designating urban areas for UGS or building them up is a challenging task that is constantly tackled by urban planners. On the one hand, the cities are under growing urbanisation pressure which results in developing and sealing open space (Wellmann et al. 2020). On the other hand, the access and proximity of green spaces are crucial to our well-being which was recently once again demonstrated by COVID19 pandemic (Noszczyk et al. 2022; Wang and Wang 2021). During pandemic, the world shrank to the nearest neighbourhoods, as people's travels were very limited, and the closest green spaces became the most important (Mehta 2020; Wilson, Neale, and Roe 2024). Despite social distancing, both the news and researchers (Mustafa et al. 2023; Venter et al. 2020) reported crowded UGS that everybody started exploring instead of the more distant green destinations. It became clear that many urban areas were lacking sufficient accessible UGS that could mitigate some urban ills and improve life for the residents of the cities (Wolch, Byrne, and Newell 2014) not only in the extreme reality of pandemic. Striving to provide sufficient UGS for all (Luz et al. 2019) and monitoring UGS accessibility can improve many aspects of the city life. It is difficult to identify single most important UGS function as their role in urban planning is complex, therefore, we will briefly present some that are emphasised in the literature. Accessible UGS improve the quality of citizens' life by providing the venue for physical activities, recreation and cultural events (Zachariasz 2016), which positively impacts physical and mental health (van den Berg et al. 2015; Lin et al. 2019a; de Vries et al. 2003), strengthens community bonds (Addas 2023), reduces social isolation and enhances the engagement of local societies (Su, Zhang, and Xuan 2024), while also building social equity and enriching community life in line with sustainable urban development. Unsealed green areas have an environmental impact leading to climate resilience as they improve air quality and mitigate urban heat islands (Chen, Bach, and Nice 2024; Fu, Liu, and Fang 2021; Wu et al. 2024; Xiao et al. 2018) as well as facilitate hazard management by reducing flooding, absorbing storm water (Staccione et al. 2024), and providing shelter (Fei, Lu, and Li 2023). UGS improve urban aesthetics (Wang et al. 2019) and also boost economic development by increasing neighbouring to UGS property values (Chen et al. 2024; Fu et al. 2021; McCord et al. 2024; Wu et al. 2024; Xiao et al. 2018). For all that reasons, UGS accessibility is more and more seen as a leverage point to address urban challenges, particularly in the context of environmental justice and public health (La Rosa 2014).

1.1. UGS accessibility, crowdedness, measurements and standards

Despite, the fact that one precise definition of UGS accessibility would benefit the strategic management of the cities, it is still missing, and multiple definitions are adopted in the literature. Wang et. al. (2021) define spatial accessibility as a 'relative ease' of reaching a green space contrary to Huang et al. (2018) who phrase it as 'overcoming the difficulty' related to distance, time and cost that are necessary to reach a green space. Other authors (Van Herzele and Wiedemann 2003; Shen et al. 2012) also suggest that accessibility is a degree of difficulty that may impede the desire and ability of the residents to access green spaces for recreation. In other words, accessibility describes a measure that quantifies the effort required to visit UGS, depending on a person's location (Oehrlein, Niedermann, and Haunert 2019) and various mobility options. UGS are accessible if their spatial distribution is corelated with the diverse needs of various population groups using green infrastructure services (Lindsey, Maraj, and Kuan 2001). Each of the definitions mentions spatial aspects of accessibility. However, there is no one coherent approach for measuring spatial UGS accessibility (Wolch et al. 2014). Most of the main approaches are based on distance, the shortness of which has been found to be the most important precondition for the use of UGS (e.g.(Grahn 1994)). These approaches include Euclidean distance, network analysis, and distance decay analysis based 2 step floating catchment area (Wolff 2021). A basic step in all these methods is the need to determine or decide which distance is considered accessible. That means answering the question, which proximity means that the UGS is spatially accessible. Many standards define this proximity. A widely used standard is the one that adopts 300 m as an accessible distance assuming that a green space has at least 0.5–1 ha. This distance according to WHO corresponds to approximately 5 min walk along a walkable pathway (WHO Regional Office for Europe 2016). Another widely recognised standard is Accessible Natural Greenspace Standard (ANGSt). It states that (English Nature 1996): '(1) no person should live more than 300 m (in a straight line) from their nearest area of natural greenspace; (2) there should be at least one accessible 20 ha site within 2 km from home; (3) there should be one accessible 100 ha site within 5 km; (4) there should be one accessible 500 ha site within 10 km; (5) there should be at least 2 ha of accessible natural greenspace per 1000 population'. Use of this indicator for spatial planning derives from Sustainable Development Indicator recommendation (SDI Goal 11 (UN 2015)) that recommends: 'By 2023, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for woman and children, older persons and persons with disabilities'. The 300 m proximity can be found also in the 3–30-300 rule, in which 3 stands for 3 trees which every citizen should be able to see from their home, 30 stands for tree canopy cover percentage in their neighbourhood and 300 is a distance from the nearest park or green space from each citizen's house (Konijnendijk 2023). Another example is Dutch Green City Guidelines (de Roo 2011) which states that every household should be within 500 m of an 'arm of the green network'. Similarly, the Berlins' Department of Urban Development and the Environment recommends a 500 m distance for every resident to a UGS of minimum 0.5 ha (Kabisch and Haase 2014).

Another important feature of a green space is its size. On the one hand, small urban green spaces are more frequently visited (Lin et al. 2019b), but on the other hand people need larger areas to benefit their physical and mental health (Wallner et al. 2018). Therefore, many studies focus only on the spaces with the minimum area of 1 ha or 2 ha (Fan et al. 2017). According to Van Herzele and Wiedemann (2003) the size of UGS can influence the number of potential visitors. The combination of distance to and size of a green space has produced the idea that bigger UGS may draw residents living further away, therefore, it is a common approach to check the accessibility to UGS on various functional levels. The common division of functional levels based on the size of the green space is the one introduced by Van Herzele and Wiedemann (2003). According to this division, the bigger the green space is, the more influence it has and the bigger the accessible distance becomes.

The overall surface area of green areas in the city also matters as it is commonly used as a UGS availability indicator in the form of UGS surface area per capita. WHO experts recommend the number of square meters of green space per capita as an indicator for monitoring progress and success in achieving the principles of sustainable urban development, but they do not propose a specific value that cities should provide (WHO 2012). The researchers often cite 9 square meters per capita as the standard proposed by the WHO. However, with regard to this widely cited recommendation, there is a concern that it is merely a myth. We have carefully checked references to WHO reports that supposedly propose the aforementioned standard, which did not yield a positive result, and this recommendation was not found in any WHO official documents. This problem has been already noted by researchers (cf. (Inostroza 2022; Teo 2017) however, the mentioned 9 square meters per capita is still circulating in academic papers, blogs and webpages. There is no consensus among scientists regarding the optimal size of green spaces per capita (Lin et al. 2019b). It is also worth noting that the requirements for green space per capita can evolve over time, as highlighted e.g. by Hladíková and Jebavý (2020), who conducted research for Prague. Researchers noticed changes in the recommendations for green space per capita, with the values increasing from 30 m^2 to 50–75 m^2 over the course of the 20th century. But even without set optimal number of UGS square meters per person, this measure is widely used. Ferri et al.(2016) analyse the differences in green space per capita across 300 European cities, using data from the European Settlement Map (ESM) and Urban Atlas (UA) from 2016. The average green space per capita in Europe is 72.53 m^2. However, the authors highlight significant variation across cities, with some areas having far more green space (e.g. Aveiro, Portugal, 266,11 m^2), while others have much less (e.g. Athens, Grece, 25,57 m^2), reflecting disparities in urban planning and environmental priorities. However, taking into account only the core cities of 917 European Functional Urban Areas, the average surface area of publicly accessible green space per inhabitant is 18.2 m^2 (Maes et al. 2019).

All these studies obtain a result of number of square meters of UGS per capita per city, therefore, choosing not to prioritize the patterns inside the city. There are not many studies showing various patterns of numbers of square meters per capita on the level of neighbourhoods that could show what is the number of square meters of UGS per capita in a certain city location or that could indicate the possibility of a UGS being crowded. Laan and Piersma (2021) (present population to UGS surface area ratio as an accessibility measure in Amsterdam showing various scenarios for crowding but without using the term crowding or defining it. A crowded UGS is defined by Geneletti, Cortinovis, and Zardo (2022) as one having less that 9 m^2 per person, a value adopted after Italian planning regulations. Indirect ways of defining crowdedness may be traced to E.T. Hall's (1966) concept of proxemics that explores the distances maintained by individuals in various social situations. The ideas introduced by Hall were later adopted in architectural theory by Lawson (2001) and Hammad (2002). Based on Hall's theory, we may assume that space is definitely crowded if it is not possible to maintain personal space of 0.5 m to 1.25 m from other individuals. However, the perception of crowdedness is subjective. It depends on the cultural background, characteristics of a space, the aim of somebody's presence in a certain space, and the level of familiarity with people already present in the space (Alrabadi 2020). The perception of personal space changes. During social distancing in the pandemic, personal space was expanding or shrinking according to the changing context (Mehta 2020). This may be also translated into the perception of the crowdedness and accessibility of a green space that also changes depending on the context. Knowledge on the nuances in spatial accessibility and crowding may provide a robust basis for qualitative studies on perception.

Considering all these insights, in this study accessibility is described as the compilation of following parameters: accessible distance, the number of UGS choices each person has and the crowdedness that is understand as a number of UGS meters per capita in each UGS that is additionally modified by the UGS size in one of the approaches.

1.2. Novelty of the study

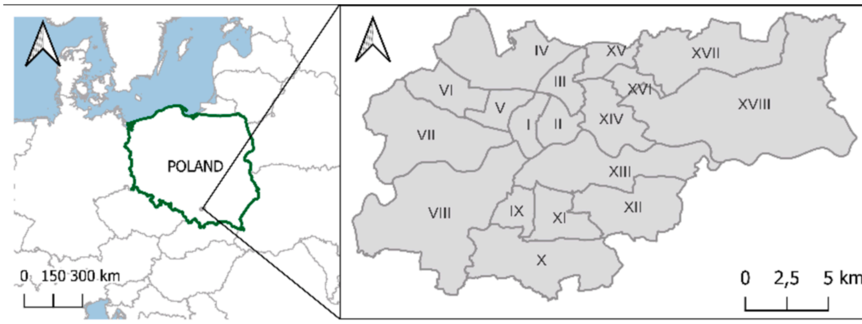
While the due importance of UGS and research on it are becoming more prevalent, as little as knowing that the UGS exist in the area may not be sufficient to fully grasp its relevance to the neighbourhood. In literature, there are currently not enough comprehensive methods using easily accessible data, which would help to determine how crowded the green spaces are and what is the surface area that is offered per resident. This is particularly important as WHO deems the area of UGS per person as one of the health indicators of sustainable cities (WHO 2012). As noted by Hua (2022) the inequality of access to green space means that, in addition to supply, demand must also be considered. This paper is our response to a research gap that addresses this issue with spatial analysis. To this end we would like to answer the following questions: (1) How many square meters are there per person in each UGS if all people living in an accessible distance would decide to visit this particular UGS? (2) How many UGS choices do the residents have in their accessible distances? (3) Does using various accessible distances and various approaches influence the results of UGS accessibility analysis? To answer these questions, we test two approaches, the first one with no regard to the UGS size and the second one including UGS size as a modifying factor. The aim of the study is to compare the results coming from these two approaches and to examine if the access to UGS is equal throughout the city. The novelty of the approach is expressed by not only presenting which parts of the city are equipped in UGS but also, if individual UGS are overcrowded with potential UGS users. We express this crowdedness in the form of Accessible Green Space per Capita (AGSpC) that is presented in the number of square meters per person in an accessible distance from each UGS. Research on UGS accessibility, crowding and distribution is usually either conducted on the area of a whole districts or zip-codes (Beyer et al. 2014; Iraegui, Augusto, and Cabral 2020; Mustafa et al. 2023). Alternatively, studies might generalise results for the area of the whole city or even a country (Bille, Jensen, and Buitenwerf 2023; Grunewald et al. 2017; Zepp, Groß, and Inostroza 2020), which, while useful for some aspects, ignores the urgent need to better inform urban development. To our best knowledge there are currently no studies on UGS accessibility using more than one approach. Therefore, there are also no studies showing what could be the differences between the approaches' results and how these could influence decision makers' choices.

2. Study area

The study area is Kraków, a large city under urban and population pressure. It is a city that is considered green, picturesque, without a dominant industrial function. that has a clear urban greenery management policy but at the same time struggles with poor air quality. Kraków is located in the central, north-western part of the Malopolska region in southern Poland (Fig. 1.). It is one of the largest and most populous cities in Poland, with an intensively developing suburban zone (Kudas and Wnęk 2021; Różycka-Czas, Czesak, and Staszel 2021). In 2022, the population density of the city was 2457.6 ppl/km^2 with the average for Poland equal to 120.8 ppl/km^2 and for Malopolska region 225.8 ppl/km^2. The number of residents in Kraków is growing. In 2022, the population change per 1,000 residents in the city was 0.9, in contrast to the declining trends observed in the country (based on Local Data Bank (Statistics Poland, 2024)).

Kraków can be considered a green city. The city came fifth in the European Green Capital 2022 contest finals and has been shortlisted as one of four finalists for the UE's European Green Capital 2023 award (European Commission 2021). According to Husqvarna Urban Green Space Index (2021), Kraków was the second greenest city in Europe and fourth in the world in 2021. In order to meet the challenges of enhancing the quality of life for the city's residents in 2015 Kraków established a new administrative unit called ZZM (in Polish: Zarząd Zieleni Miejskiej) – Management of the Kraków Municipal Greenspace Authority whose role is to manage and maintain public green spaces, including the creation of new forms of urban greenery. Undoubtedly, Kraków has been undertaking many initiatives aiming at increasing the availability of public green spaces to the residents, but to our knowledge, there is no monitoring if city is meeting the residents' demand for green spaces.

Cities in Poland are among Europe's worst for air quality (EEA 2023a). According to WHO, exposure to PM2.5 pollution in Poland had consistently exceeded the WHO standards by at least a factor of two for many years. Kraków is a city in which air pollution is particularly severe. Apart from the common problems of emission sources, that characterise



District name	number	District name	number
Stare Miasto	I	Swoszowice	X
Grzegórzki	II	Podgórze Duchackie	XI
Prądnik Czerwony	III	Bieżanów-Prokocim	XII
Prądnik Biały	IV	Podgórze	XIII
Krowodrza	V	Czyżyny	XIV
Bronowice	VI	Mistrzejowice	XV
Zwierzyniec	VII	Bieńczyce	XVI
Dębniki	VIII	Wzgórza Krzesławickie	XVII
Łagiewniki-Borek Fałęcki	IX	Nowa Huta	XVIII

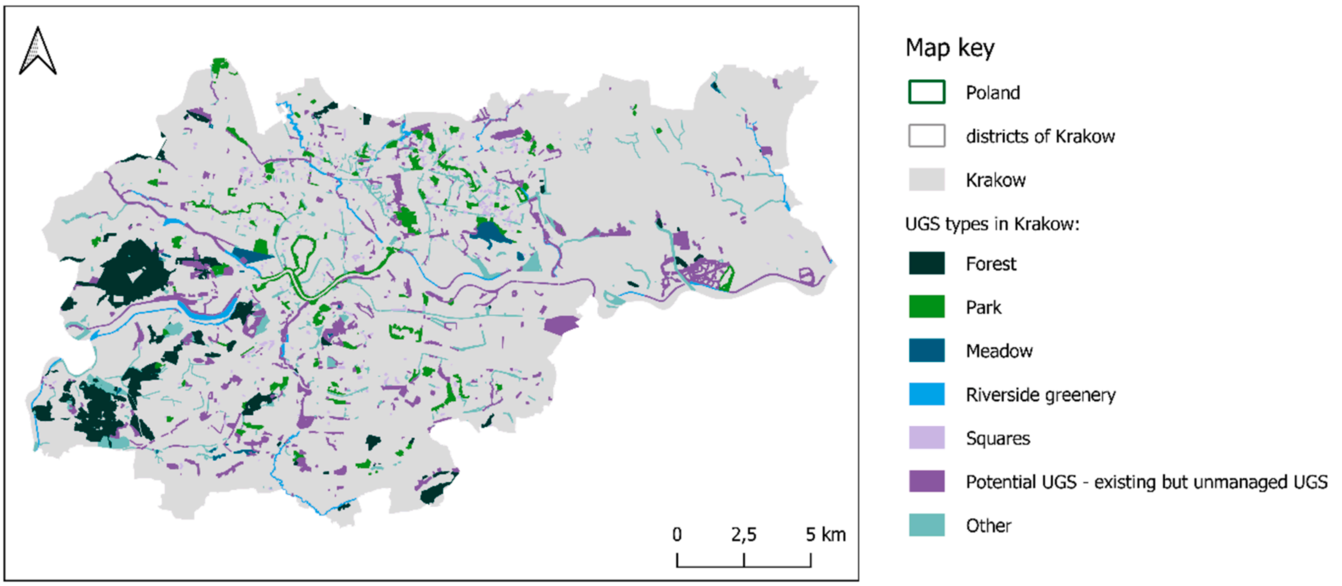


Fig.1. Research area.

most urbanised areas, Kraków also faces consequences related to its location. The city is located in a concave landform which, among other reasons, causes poor natural ventilation and frequent air temperature inversions. Although the pro-clean-air legislation implemented by the city authorities has resulted in the average concentration of PM in Kraków falling steadily since 2011. European Environmental Agency has placed Kraków at position no. 7 on the list of the 375 most polluted cities of the European Union (based on the levels of fine particulate matter measured in the air in cities in 2021 and 2022) (EEA 2023b).

3. Materials and methods

3.1. Selecting the UGS and spatial data preprocessing

Although Kraków is rich in green areas, not all of them are accessible to the general public. Therefore, the aim was to assess the accessibility of only these areas that are open to the public, both existing and potential, do not have any entrance fees, and are not closed during any time of day or night. We have obtained spatial vector data on UGS from ZZM. Firstly, we have analysed and classified the vector layer. We have excluded such areas as monastery gardens that are closed to the public, cemeteries, and allotment gardens which in Poland have restricted accessibility. All green spaces that were marked by ZZM as accessible with no limit as to their size have been used for the analyses. We have also used green areas marked as potential as this greenery is freely accessible but lacks park infrastructure yet. We have assumed that such uncontrolled greenery may also play a role in ecosystem services and be used for recreation. Secondly, we have classified UGS into four types (Fig. 2.) according to Van Herzele and Wiedemann (2003) who distinguish residential green that has a size up to 1 ha and that should be located in the maximal distance of 150 m which is the accessible distance for residential green. Next category are the neighbourhood green areas in size up to 10 ha that should be in the maximum distance of 400 m. The quarter green should be no smaller than 10 ha and it has an impact of 800 m. The district green minimal surface area is 30 ha, and it impacts residents living in the distance of 1600 m. The biggest city green size is 60 ha or more and its accessible distance is 3200 m. Van Herzele and Wiedemann (2003) also add one more category that are urban or metropolitan forest of minimal size of over 200 ha for smaller cities and over 300 ha for big cities and accessible distance of 5000 m. It is not clear what does a big city mean here. In Polish context Kraków is a big city but in the global context it could be not perceived as such. The surface area of the biggest disjoint polygon delimiting UGS in the spatial data set that we have obtained was 213 ha. Therefore, the last category from Van Herzele and Wiedemann (2003) division was not used for this study.

3.2. Estimating population

To count the number of residents we have used a Topographic Objects Database (BDOT10k) data set containing buildings. BDOT10k is an official, freely available data set. We have selected only residential buildings for the analyses. The data set contains number of floors for each building that was used to count the residential area intensity. The number of floors attribute was verified and corrected based on orto-photomap and StreetView as in some cases a building had the same height and structure as the neighbouring buildings, but the number of floors varied in the database. To count the number of people living in each building we have used average useful floor area of dwelling per capita in urban areas, an indicator that was obtained from Local Data Bank (LDB). The value of this indicator for Kraków is 30.5 square meters

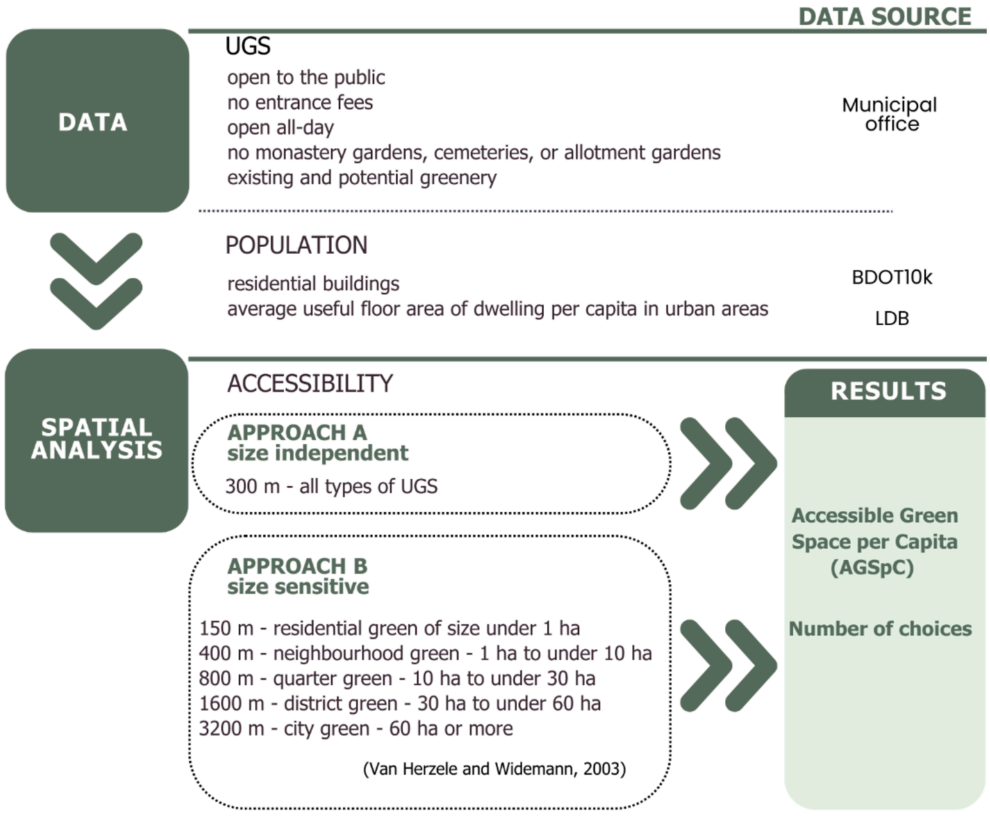


Fig.2. Method.

per capita. Useful floor area of dwelling per capita is calculated based on census, which is obligatory for everybody independently of their nationality, official registration place etc. We have chosen this method of estimating the population, as residence registration in the city council is not compulsory and in fact many of the inhabitants are not registered where they actually live, such as students, young professionals or workers registered elsewhere for tax purposes.

3.3. *Approaches*

Based on the literature review we have used a mix of approaches for this research. We adopted 300 m accessible distance, and the functional division created by Van Herzele and Wiedemann (2003). Buffer zones were chosen as the approximation method for this analysis. This removes the need of making subjective decisions that could influence algorithms (such as types of paths picked, starting point of routing or the necessity to map the road network). This should not only make the analysis easier to understand but also facilitate the decision making for city planners.

We have determined accessible green space per capita (AGSpC) in two approaches. For the first approach (Approach A) we have adopted a 300 m accessible distance and with this distance we have created buffers for each green area. The intensity of residential built-up area has been counted in each buffer. Then, using average useful floor area of dwelling per capita in urban areas, obtained from the statistical register, the number of people living in each buffer has been counted. Finally, we have counted how many square meters of green area is there for each person living in the buffer zone.

For the second approach (Approach B) of the research, we have divided green areas according to the distinction made by Van Herzele and Wiedemann (2003) who assumed that the impact of green areas differs according to its size. Again, the buffers were made for each UGS but in this approach the buffers' size differed according to the size of green areas. Residential green area had a buffer of 150 m, neighbourhood areas of 400 m and then all the other categories had their respective buffers according to Van Herzele and Wiedemann (2003) categories. Then, exactly like in the first approach the built-up area intensity and number of inhabitants were counted. Finally, the surface area of each green space was divided by the number of people in each buffer which again gave the number of meters per person in each green area.

In both approaches some buffers overlap. It means that the same person may be in the accessible distance of more than one green area. To account for the overlap of the green areas' buffers, we have created a map that counts the number of buffers overlapping with each building. This represents the number of accessible green areas' choices that people in each building have. We have made such analysis both for A and B approaches.

4. Results

4.1. *Surface area of UGS*

Analysis of the data on green areas showed that total surface area of UGS in Kraków is of 3720 ha. Out of this number 73% of UGS already exists in the forms of various sizes parks, meadows or urban forests. The remaining 27% is green areas that, although accessible to the public, are unmanaged and lack recreational arrangements. There are 1442 urban green spaces that are smaller than 1 ha which is 77% of all UGS. The next biggest group are UGSs that are between 1 ha and 10 ha, and they are only 19,5% of the total UGS number but they cover the biggest surface area of 1180.2 ha which is 31,7% of the total UGS surface area. The count of the biggest UGSs is much lower than the count of the smallest UGSs. The 8 biggest UGSs have the second biggest share in the total surface area (Table 1).

The results of a spatial analysis show that UGSs in Kraków are

Table 1
Sizes and surface areas of urban green areas.

UGS area	under 1 ha	from 1 ha to under 10 ha	from 10 ha to under 30 ha	from 30 ha to under 60 ha	of 60 ha and over
Count	1442 (77.0 %)	365 (19.5 %)	48 (2.6 %)	10 (0.5 %)	8 (0.4 %)
Surface area [ha]	334.3 (9.0 %)	1180.2 (31.7 %)	840.4 (22.6 %)	413 (11.1 %)	952.1 (25.6 %)
Existing green areas [ha]		Potential green areas [ha]		Total green area [ha]	
2704 (73.0 %)		1016 (27.0 %)		3720 (100.0 %)	

unevenly distributed across the city (Fig. 1). This is especially relevant for the largest urban green spaces, predominantly located in the western part of the city.

4.2. Accessible green space per capita

According to official LDB data there was 801 242 people in Kraków in 2021 (Statistics Poland, 2024). This official data may be underestimated as Kraków is inhabited by many people that are not registered in the official data base as they study or work in the city and even though they live in Kraków they are registered in their hometowns. For that reason, we calculated the number of inhabitants in this research based on the LDB index and floor area of all residential buildings which gave total number of 1 352 848 inhabitants.

The total number of UGS square meters per person in Kraków calculated based on the official population data is 46 square meters. The same calculation made with the number of inhabitants based on the total floor area gives 27 square meters per capita. Our more detailed approaches (A and B) show various results for various parts of the city (Fig. 3).

Fig. 3 shows the values of AGSpC in each of the UGS. Part A of the figure shows the values assuming that everyone living within a 300-meter buffer zone around a green area visits this particular space simultaneously. Part B of the figure shows the same results using buffers differentiated based on the functional levels (sizes) of UGS proposed by Van Herzele and Wiedemann (2003). In both cases many of the green areas marked dark green on the map are of 5 square meters or under 5 square meters of UGS per person. These areas are mainly in the centre of the city and in the northern parts of the city.

Comparing the patterns of accessibility within these two approaches we have noticed that there are some similarities despite different accessible distances. In both approaches the UGSs in the centre of the city have low AGSpC.

There are however also differences. For the buffers generated according to the functional levels of green areas (Fig. 3.B), the number of green areas with the lowest AGSpC is bigger than for the accessible distance of 300 m (Fig. 3.A). The size sensitive approach suggests that larger parks tend to be more crowded. Conversely, the size independent approach, does not indicate significant crowding of the largest parks.

4.3. The number of UGS's choices

Another factor that we have considered is the fact that a person living in the city may have more than one choice of green area in an accessible distance.

The map (Fig. 4) presents the number of UGS choices that the inhabitants of residential buildings have. The results vary depending on the chosen analysis approach. In approach A, the number of choices varies from zero to 38 choices. The 4.3 % of residential buildings has access to more than 10 UGS. The highest number of choices may be observed in the historic centre of the city. Moreover, residents of the southern part of Prądnik Biały district, Prądnik Czerwony, the southern part of the Mistrzejowice district, Bieńczyce districts, as well as the adjacent to Bieńczyce part of the Nowa Huta district, also have relatively many choices available. These areas, when combined, create a contiguous region spanning the central and northern sections of the city. Apart from the Old Town, a common feature of mentioned areas is the predominant high-density, multi-family residential development. Furthermore, a distinct clustering of areas with no available UGS options can be observed, with these areas being notably concentrated in the southern sections of the Swoszowice and Debniki districts. Significantly larger areas without access to UGS can also be found near the border of Bronowice and Prądnik Biały districts, within the Wzgórza Krzesławickie district, as well as in Podgórze Duchackie districts. In approach A, 4.7 % of the city inhabitants does not have any access to an UGS.

Number of choices differs when we change the size of the buffers and generate the buffers according to the functional scale of green areas (approach B). The highest number of choices in this case is 28 and the lowest number of choices is again 0. The 2.8 % of residential buildings have access to more than 10 UGS. There are still areas that do not have any green areas nearby. The highest number of choices is naturally lower as the buffers around the smallest UGS in this case are only 150 m. Therefore, such areas encompass less residential buildings. The highest number of choices is visible in the west part of the city that has few

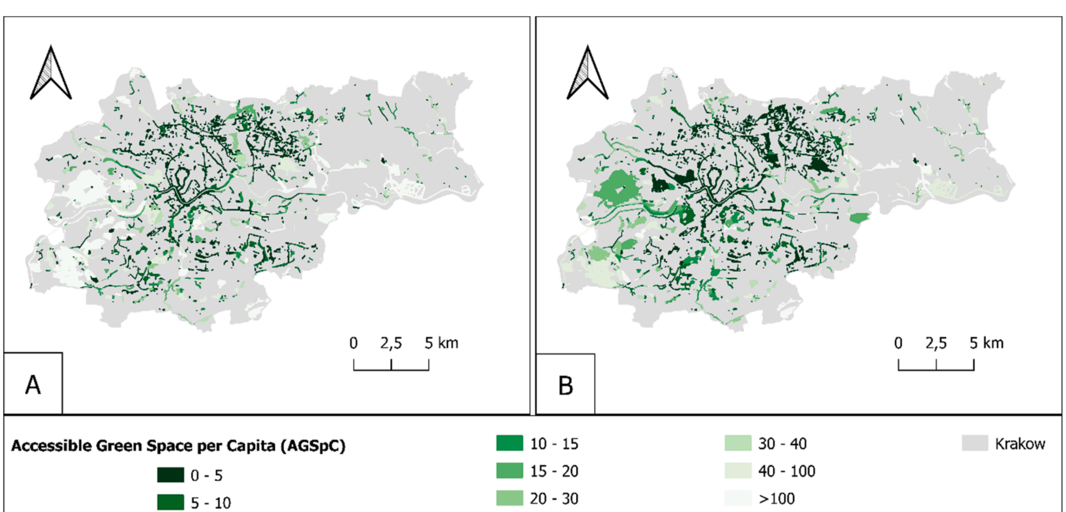


Fig.3. Numbers of square meters per person in approaches A and B.

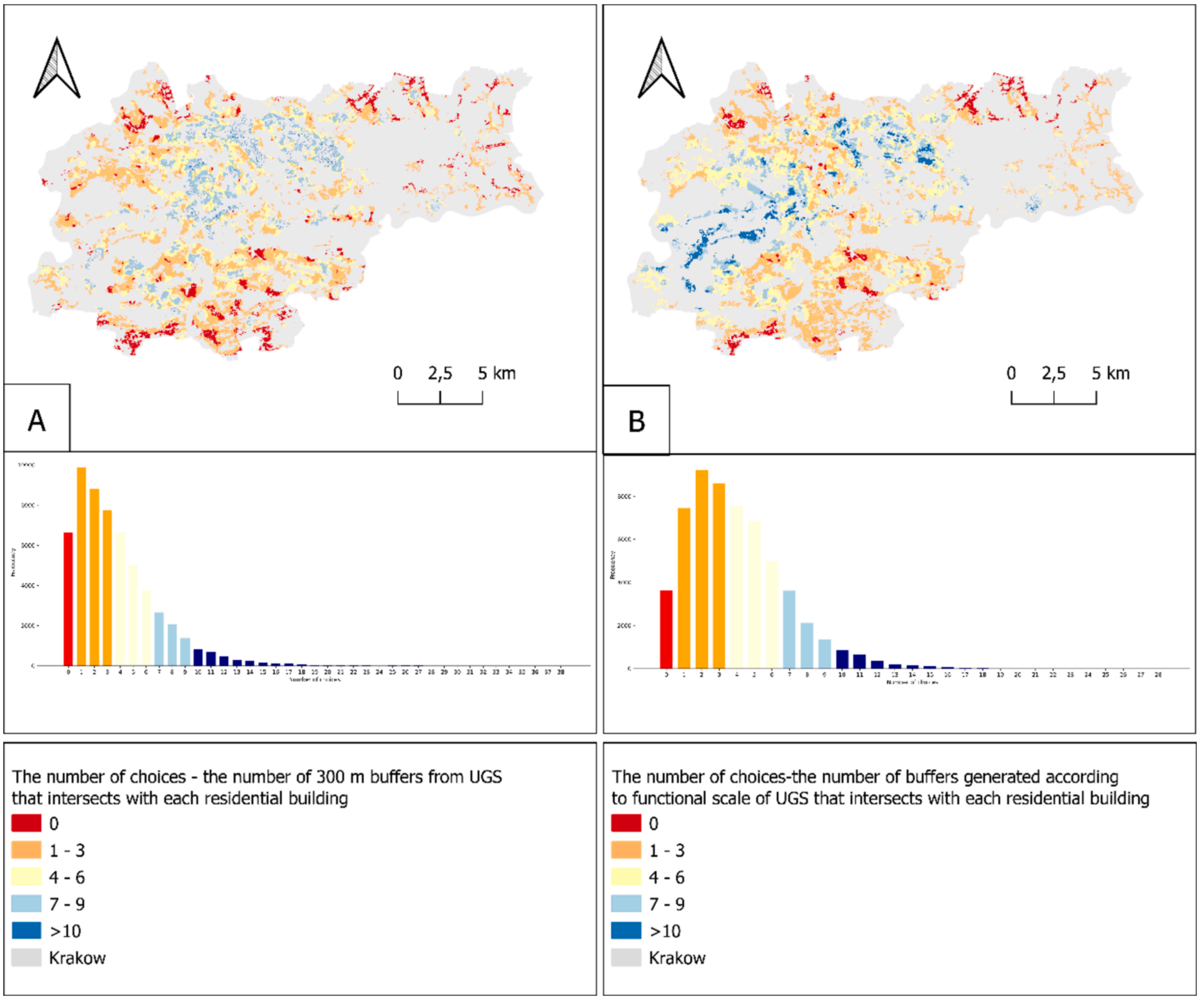


Fig.4. Number of UGS's choices.

bigger parks and also many smaller green areas.

The most significant differences become evident in the Dębniki and Zwierzyniec districts, where the count of residential buildings with access to 10 or more UGS options significantly surpasses that of Approach A. In relation to areas lacking UGS access, the most substantial disparities in outcomes between the two approaches are discerned within the Swoszowice district, characterised by a notably diminished count of areas with fewer UGS options. The total percentage of city inhabitants that do not have an access to green area in approach B is 2.9 %.

4.4. UGS accessibility

The combined results show that in some cases the higher number of choices may counteract against lower green area supply expressed by AGSpC. However, there are areas with no access to UGS and at the same time low AGSpC which shows that the size and distribution of UGS may be not sufficient.

Figure (Fig. 5) shows the results from both approaches A and B. It combines the results of the two previous analyses showing various patterns related to the number of choices and AGSpC values. The first pattern (area A: high-high) corresponds to a high number of choices and high AGSpC and it is present in the west part of the city, mainly around bigger urban forests or urban meadows that are environmentally significant and legally protected. The second pattern (area B: low–high) is none or low number of choices but high AGSpC. It is found mostly in the peripheral parts of the city. The third pattern (area C1 and area C2: high-low) is a higher number of choices in the areas that have low AGSpC. This pattern is represented by areas with a dense urban fabric, for example the historical heart of the city: area C1 – Kraków Old Town, and area C2 – Nowa Huta, which was originally built as a separate town but is now part of Kraków. The fourth pattern (area D: low-low) with none or only few choices and a low AGSpC is present in the southern fringe urban areas.

Size sensitive approach B resulted in some similar patterns and some that are different to approach A. Area A in approach B shows more choices than in the approach A but slightly lower AGSpC. Area B shows bigger crowding of UGS than area B in approach A but the number of choices for some residential buildings in area B increased insignificantly in approach B in comparison to approach A. Interestingly, both dense central urban fabrics of old city centre and Nowa Huta did not change much independently of the approach. The difference is visible only in bigger UGS in the lower part of area C2 that is much more crowded in the approach B. The pattern in area D that presents dense and mixed fabric of housing estates also did not changed between approaches A and B. Area D presents spaces in which rural areas were first developed into urban tissue after the systemic transformation in the 90′ and are under constant urban pressure until now. The two patterns high-low and low-low changed the least between two approaches.

5. Discussion

5.1. UGS distribution, accessibility and crowding

In an era of progressing urbanisation, urban green spaces are gaining

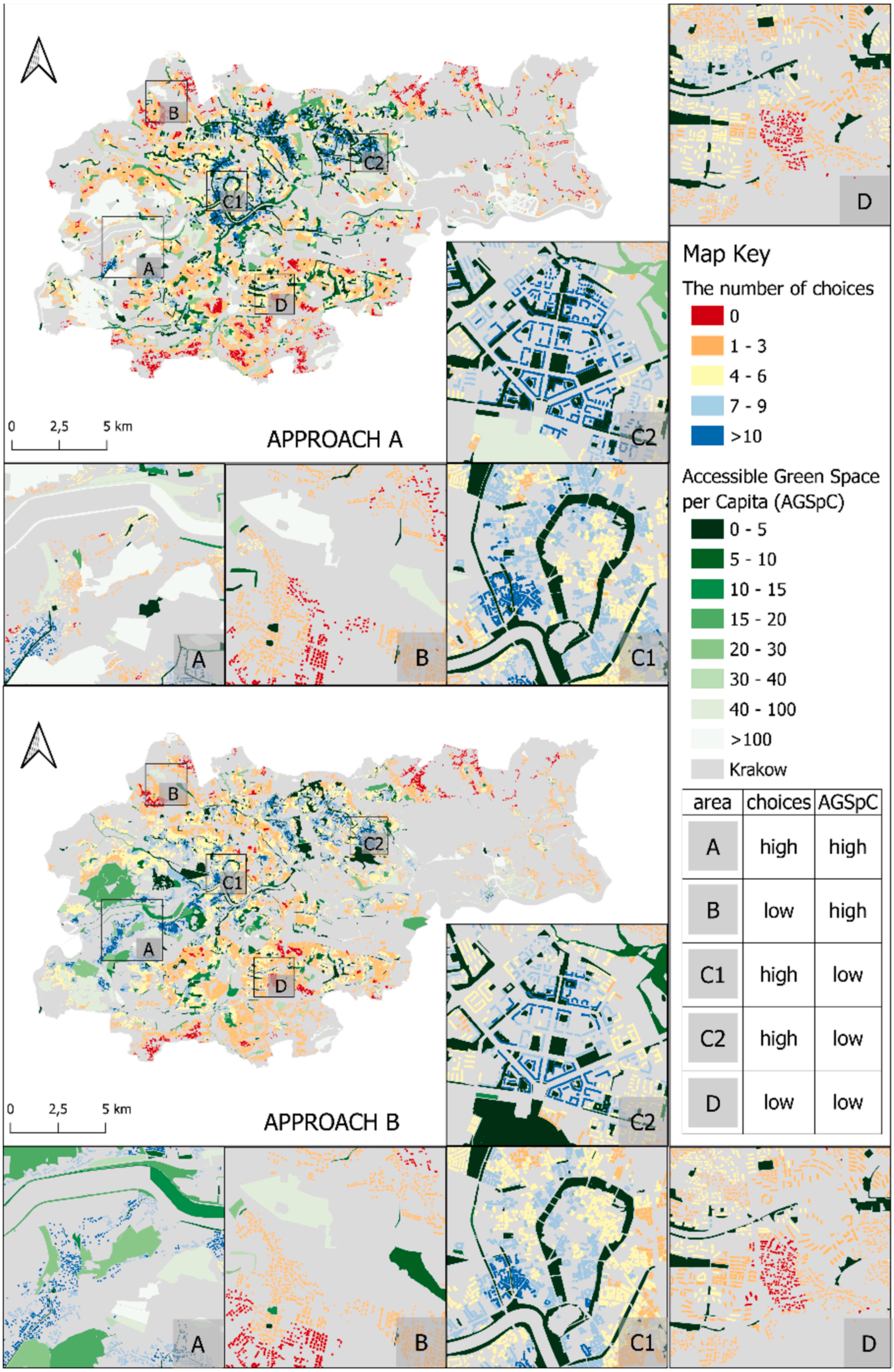


Fig.5. Combined results of the research approaches A and B. Area A – environmentally significant area neighbouring to buffer zone of a landscape park, urban fringe; Area B – various density of urban fabric including terraces housing and single-family houses typical for the urban fringe; Areas C1 and C2 – dense urban fabric: C1 – old town, city centre, C2 – characteristic socialist realist part of the city; Area D – urban tissue undergoing infill development.

on importance. Having equal distribution and just access to UGS is essential for a friendly to live in cities with healthy and benefitting resident's environment (Addas 2023). Both approaches tested in this study revealed that the distribution of UGS and the UGS per capita is uneven in Kraków. Such unevenness in UGS distribution is consistent with other studies conducted both internationally (Fan et al. 2017; Gupta et al. 2016; Kabisch and Haase 2014; A. C. Luz et al. 2019; Pinto et al. 2022; Xue, K., Kepeng, Yu., & Zhang, H. (2023)) and in Poland (Biernacka, Łaszkiewicz, and Kronenberg 2022; Sikorska et al. 2020).

There are also multiple studies that explore the UGS per capita in European cities (Fuller and Gaston 2009), the per capita provision of green space ranged from 3 square meters in selected cities in Spain and Italy to a substantial 300 square meters in selected cities in Belgium and Finland. This points to a trend of increasing per capita green space provision to the north and northwest. However, on average (Maes et al. 2019) it is 18 square meters of publicly accessible urban green space per capita in European core city areas. Also, in other parts of the world various values of UGS per capita are obtained. According to Lin et al. (2019) who used statistical data, the per capita green space with an open space function in China amounts to approximately 8.46 square meters. As highlighted by Xiao et al. (2017) citing the Shanghai statistical yearbooks, the green space per capita in Shanghai increased to 13.1 square meters in 2011, compared with 4.6 square meters in 2000. The value achieved in 2011 falls within the average parkland area in Chinese cities, which is 13.1 square meters per capita (Bureau of Forestry and Landscaping of Guangzhou Municipality 2018). The example of New York City also demonstrates that the amount of accessible urban green space per capita varies significantly, ranging from 7 to 50 square meters, depending on the district (Mustafa et al. 2023).

All of these studies explore the UGS per capita at a scale of a whole city or district and not at the level of an individual UGS or in an accessible distance, but the numbers give an idea on the average values of UGS per capita in other parts of the world. Though sometimes the values for the same unit differ as they are based on various sources and methods. Our research showed that the number of square meters per capita in Kraków varies depending on the size of the green area, its location and the approach used from under 5 square meters to over 100 square meters. The crowdedness of UGS varies depending on the location of the inhabitant. The knowledge on the level of crowdedness is important as crowded spaces trigger negative emotions (Zhang, Qi, and Zhang 2023) which in result may discourage visits and diminish the recreational role of UGS.

We do believe that in order to attempt to find environmental justice at a level of an individual resident a comprehensive approach is necessary and that referring to a number of square meters of UGS per person in a unit as an overall indicator for all unit's inhabitants may be deceptive. In case of Kraków, such approach would give overestimated or underestimated results depending on the chosen location in the city. This may be the case in most cities.

Not only do the AGSpC values vary across the city, but so does the number of UGS choices available to each resident. The quantity of existing UGS may be closely linked to historical factors and the historical development of urban greenery. Historically, the idea that spatial planning in Kraków should include urban green spaces that were supposed to provide recreational areas for the inhabitants started in the 18th century. An essential factor that may have influenced the high number of choices for the Prądnik Czerwony area is the urban planning layout of neighbourhoods from the 1970 s, which included access to parks on the former Dominican gardens along the Sudoł Dominikański stream. On the other hand, in socialist-realist Nowa Huta, the high number of choices is owed to its origins in the concept of a garden city (Zachariasz 2016). In contrast to older urban tissue, housing estates developed after systemic transformation that are still in the process of dynamic development (Olczak et al. 2024) are surrounded by more crowded UGS and have less UGS choices which can be explained by the fact that they have been constructed without urban standards that could bring the ideas of garden city or neighbourhood unit. The study key strength is overcoming the absence of the accurate easily accessible information on the population numbers which is one of the usual limitations of such studies. Semenzato, Costa and Campagnaro (2023) point out that studies dealing with accessibility of green spaces rarely rely on detailed data on population location. In our study, we propose estimating the population based on information about the location, surface area, and number of floors of residential buildings. This type of data is generally more accessible than data directly related to individuals. Specifically, to show the distribution of the population in relation to the distribution of green areas we have decided to estimate the number of inhabitants for each building based on the floor area and average floor area per capita. The total sum of inhabitants of residential buildings from that calculation has amounted to 1 352 848. According to official statistics data there is 801 242 people in Kraków in 2021. Therefore, our calculations seem to be overestimated. However, Kraków is inhabited by many people that are not registered in the official data base as they study or work in the city and even though they live in Kraków they are registered in their hometowns. The number of inhabitants that we have received is confirmed by the data obtained from the water supplies and sewage disposal users, and phone network data, based on which city authorities estimate that there is between 1.2 and 1.3 million people that are living in Kraków (Tymczak 2023). This is also confirmed by the fact that the number of average floor area per capita is counted based on the national census that is obligatory for everybody with no regard to the fact if a person is registered in a city or not. Sound estimation of the actual population of analysed area is important for obtaining a valid answer to the question of the availability of green area in a city. If we would apply the official number of inhabitants, we would obtain 46 square meters of UGS per capita per whole city. With our estimation we have come to a number of 27 square meters per capita on average in Kraków.

5.2. Comparison of methods

The multitude of literature on UGS accessibility is usually concerned with the use of chosen standard to check the accessibility of chosen test area. Our research is testing two approaches to show if the choice of various standards matters for the research outcomes. First approach omits the factor of UGS size, and the second is size sensitive. The research was made for diverse urban fabric of the test city of Kraków. Therefore, it presents the detailed results for dense city centre as well as low density urban fringe. All accessible urban green areas were considered in contrast to many studies reflecting only on the accessibility of urban parks.

Accessible distance used for the research impacts the results of the research. Results vary between the two approaches which shows that if we use accessible distance of 300 m for all green spaces, we will miss some patterns that may occur in the city. The idea of having a green area in a proximity of 300 m is very reasonable but while researching the accessibility we need to pay attention to more holistic impacts that green areas may have to the whole city fabric. On the one hand our approaches go deeper as we analyse separately each green area but on the other hand, we have also discovered bigger patterns and inequalities.

In the 300 m approach, larger parks are seemingly providing more UGS per capita. However, this approach may not show the whole impact of larger green spaces. If an UGS is popular the approach using 300 m does not show possible pressures on the park. Therefore, we would recommend either comparing the two approaches for a research area or using only method with buffers generated according to functional scale division of UGSs to assess the accessibility and population pressure.

Using size sensitive approach for UGS accessibility research is important, as evidence shows that larger UGS offer more space for recreation, alleviate concerns about overcrowding, and provide a greater sense of comfort. Mustafa et al. (2023) demonstrated that respondents living near larger green spaces were less likely to report concerns about overcrowding. Therefore, large green spaces are especially important, particularly given that the perception of overcrowding is subjective. While our results don't provide exact values to distinguish between overcrowded and non-overcrowded UGS, they do enable the assessment of the level of crowdedness in a particular UGS.

In their study, Mustafa et al. (2023) also identifies four patterns related to the spatial accessibility of green spaces and UGS per capita, but they generalise these patterns to the ZIP code level. Our findings show that these patterns differ significantly even at the level of individual buildings, so generalising to the ZIP code or neighbourhood level could be misleading.

5.3. The limitations of the study

No study comes without limitations and here is a brief discussion of the ones we have identified in ours. We will firstly note the type of green areas that were included in the analysis: we have considered all existing green areas within the city, rather than focusing on areas already designated as recreational. This likely resulted in a somewhat higher number of UGS square meters per capita, as it might have included less controlled green areas too.

Secondly, we note that the study is limited to the borders of Kraków. This means that, some areas on the outskirts of Kraków that have low accessibility and low number of choices may in fact have access to green areas. But this access may be provided by neighbouring municipalities. Moreover, we have excluded agricultural areas in the vicinity of the city from our analyses. In some cases, such areas may serve as complementary to UGS. This statement, however, needs more exploration to determine what roles if any do various agricultural areas play in complementing UGS city functions.

It is also important to mention that this spatial analysis like all spatial analyses is an approximation that depends on the quality of the data and the methods. To make it as implementable as possible, we have used buffers instead of service area. As we have noticed that using service areas is burdened with taking many subjective decisions related to the parameters used in the algorithm such as adopting the starting points of the routing or choosing the types of roads for the analysis in the existing routable road network layers. Buffer analysis is simple, therefore, it is easily understandable and implementable by the planners, and it may be independent of the existence of a routable road network layer which increases its comparability while implementing it in various cities.

The study does not include possible temporal changes and various seasonal and daily uses. We have to note that the values of AGSpC that we receive are potential. As only the inhabitants are taken into account and UGS may also host people living elsewhere or it may be used differently according to season or a day of a week. A promising direction for future research would be to incorporate temporal changes as well. However, we believe that the availability of sufficient green space in a city is important independently of its use. As green spaces have many positive impacts such as improving the air quality and lowering the city temperatures.

The study is quantitative and as it does not take into account the inhabitants' perception of UGS or their preferences. While the scope of our research is UGS spatial accessibility, considering additional aspects such as perceived accessibility would contribute to a more comprehensive understanding of UGS just access.

6. Conclusion

The proposed method effectively demonstrates the number of UGS choices of an individual building and capacity of an individual green space. Answering the first research question we have concluded that the AGSpC values in the city range from under 5 square meters to over 100 square meters per capita. As per second research question, the number of UGS choices falls between none and over ten per residential building.

To answer the third research question, we have compared two methods based on two common in literature principles that we implement at a detailed level of each individual UGS. Our research shows that the decision to use various accessible distances influences the results of UGS accessibility analysis. We suggest that UGS accessibility should be verified as a combination of UGS buffer areas and the number of UGS choices. Moreover, we would like to stress that size sensitive methods introduced by Van Herzele and Wiedemann (2003) may be more adequate to complex urban fabrics. Approaches that we have proposed, especially the approach B, based on size sensitive AGSpC can be an easy tool to measure inevitable UGS supply changes occurring with the development of new residential and commercial zones in the cities. However, to monitor and compare the accessibility between various urban areas the simple 300 m approach A may be also useful. The study was conducted in the city of Kraków and to implement the methods in other cities it would be necessary to collect comparable data for the future study areas first. The recommendation to use a certain number of meters per capita has managed to capture the attention of many researchers. It became popular, widely cited in the literature and it is also used in urban greening strategies. Therefore, we believe that such measure may in fact provide meaningful easy to implement information resonating with the stakeholders and the public. Moreover, it could facilitate citizens' choices of residence and assist local authorities in delimiting areas in which UGS accessibility requires attention.

Our study presents a useful tool for decision makers and spatial planners. Knowledge on UGS crowding and accessibility is important in regular planning practices. Number of square meters per person is a widely accepted measure, however there are no guidelines on the implementation of this measure. We hope that our study helps not only planning but also picking preferred method for decision makers and other authors alike. As we show the difference in the results with two approaches which may give some additional insights to exploring UGS accessibility and crowding.

Funding

The research was carried out as part of the project entitled: "Investigating the Role of GREENery to Improve Climate Resilience, Water, Soil and Air QUALity in Dense Urban Fabric (GREENQUAL)", which received funding from The National Centre for Research and Development (NCBR), in EIG CONCERT-Japan Programme, Call no. 10, under grant agreement no.: EIG CONCERT-JAPAN/10/69/GREENQUAL/2024. This project has received funding from the European Interest Group (EIG) CONCERT-Japan which is an international joint initiative to support and enhance science, technology and innovation (STI) cooperation between the European region and Japan.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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