

Towards a High-Fidelity Assessment of Urban Green Spaces Walking Accessibility

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Abstract. Urban Public Green Spaces (UPGS) *available at walking distance* are a vital component of urban quality of life, of citizens' health, and ultimately of the right to the city. Their demand has suddenly become even more ostensive due to the measures of "social distancing" and the restrictions of movement imposed in many countries during the COVID-19 outbreak, showing the importance of the public urban parks and green open spaces located near homes and accessible by foot. Hence, the idea of "green self-sufficiency" at the local, neighbourhood and sub-neighbourhood level has emerged as a relevant objective to pursue. For this purpose, we have constructed a high-fidelity evaluation model to assess the walking accessibility of UPGS at the highly granular spatial scale of street network nodes. The evaluation procedure is based on a novel index constructed around the concept of distance-cumulative deficit, scoring nodes with respect to all the available UPGS within their catchment area of slope-corrected walking distance of 2 km. To showcase the possible outputs of the evaluation procedure and their exploratory analyses, we present an application on the city of Cagliari, Italy. In doing that, we argue that the proposed evaluation approach is an advancement over the traditional (density-based) approaches of assessment of green area availability, and that it provides an intuitive, flexible and extendable tool useful to better evaluate and understand the current and the potential accessibility of urban green space, and to support urban planning, policy making and design.

Keywords: Urban Public Green Spaces · Accessibility · Walkability · Evaluation model

1 Introduction

The rapid and intensive urbanisation of the last decades adversely affects the environment, impoverishes ecosystems, causes climate change and major problems in citizens' health and quality of life. In light of these impacts, Urban Public Green Spaces (UPGS) are increasingly recognised as essential elements for improving urban quality of life, especially in the large and medium size cities where the densification process causes a loss of green space per capita and, consequently, a decrease in daily exposure

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for many citizens [1–3]. According to the "three pillars of sustainable development", the UPGS provide an array of services and potential benefits, from the environmental, social, and economic standpoints [e.g. 4–8]. This view has been strengthened recently by the principles of the UN's *New Urban Agenda* [9] and the Sustainable Development Goals [10], and in particular by the Goal 11 to "build cities and human settlements inclusive, safe, resilient and sustainable", which states the objective «to provide universal access to safe, inclusive and accessible, green and public spaces» by the year 2030 (SDG 11, Target 11.7).

This objective has suddenly become even more apparent and vital due to the "social distancing" measures imposed in many countries during the COVID-19 pandemic. As observed by the 2020 special report on *Parks and the pandemic* published by the Trust for Public Land, during the pandemic crisis the role of the close-to-home parks and green spaces has proven crucial for the community wellbeing, but at the same time «the pandemic highlights that in too many communities, access to the outdoors is considered a privilege when it should be a right» [11: 2]. Notwithstanding the waning of the acute phase of the pandemic in many places at the time of this writing, accompanied by the relaxation of stringent restrictions on movement, the experience has left scars, will likely produce durable changes, and has rekindled a debate on the spatial reorganisation and distribution of activities in cities.

The 2018 Working Paper of the European Union *A walk to the park? Assessing access to green areas in Europe's cities* [12] reports the results of a recent study conducted in a sample of 400 cities that assessed the total surface of green areas that can be reached within 10 min walking time. The findings show the differences in the distribution of the green accessible areas between cities and, within cities, between different neighbourhoods. Similarly, numerous other recent studies underline the uneven distribution and accessibility of green areas within cities, and how this condition generates notable socio-spatial inequalities [13–16]. It follows that an equitable accessibility of UPGS is one of the main objectives to be addressed to develop more secure, fair, and sustainable urban development patterns.

Among the necessary directions of work to pursue this goal and to support a better UPGS provision, one is the advancement of evaluation models and operational assessment tools. The conventional planning practice usually employs indicators of density, i.e. the per capita availability of green spaces within predetermined areas (zones, neighbourhoods), as factors of city's liveability [2]. Along this approach, different standards were established in the past by the regional planning and regulatory agencies; for example, in Europe the standard ranges from 6 to 50 m^2 per person [17, 18]. Numerous studies have been conducted to measure and assess such densities at the neighbourhood and urban scale, employing different methods and data sources, from those using remote sensing coupled with GIS [19–23] to those, more recently, taking advantage of the freely available geographic data such as OpenStreetMap [e.g. 24–26].

However, such density-based measures may be spatially imprecise, may fail to capture the differences in scale and nature of different green areas, and risk concealing important constraints and factors limiting the real capability to access the green areas. Indeed, the per capita availability does not provide enough precise and adequate information on the effective accessibility of public green spaces and on which urban areas and citizens can best benefit from the available UPGS.

More accurate analyses go beyond mere indicators of densities, and evaluate the UPGS accessibility taking into account different modes of transportation to reach those spaces [27–29] and different functional levels of public green spaces related to different uses which these fulfil at different scales, from neighbourhood to metropolitan, typically based on the green space size [30–32]. Furthermore, there are various attempts to establishing typologies of parks and green areas, each related to different walkable catchment area and on distance-decay functions associated with distinct types of parks [27, 31, 33–35].

Furthermore, to assess the accessibility, many evaluation models employ an inadequate representation of the key variable of distance/proximity [36]. Among these, the Euclidean buffer (the minimum as-the-crow-flies distance between points of origin and destination) is still frequently adopted [e.g. 30, 37–40]. As Unal et al. [41] note, this approach shows at least three critical elements. First, it uses circular buffer zones, created around all destination points, without considering the effective street connectivity and the distance that must be crossed along a transportation network (walking routes). In this way, it does not account the impedance elements, such as barriers (e.g. rivers, railways) and terrain characteristics (slope) that may alter the acceptable distances. Second, it considers all parks as open spaces, fully accessible along their boundaries without consider the effective access points. Third, by measuring the distance from the centre of the park it does not allow to consider irregular park's shapes, leading to an inaccurate representation of the site catchment zone.

Some studies are based on street network analysis which should provide a more realistic representation of the available access routes [e.g. 37, 38, 42], access points [e.g. 43, 44] and impedance elements [e.g. 45, 46].

However, most of the cited studies do not consider all these elements simultaneously. Therefore, the main purpose of this paper is to propose a high-fidelity evaluation model, and the respective UPGS capability index, designed to overcome limitations mentioned above. The model produces evaluations (scores) at every street node, effectively obtaining assessments at the micro-urban level. It employs a novel index based on the cumulative computing of the UPGS deficit at different distances. To test and showcase the effectiveness of the evaluation procedure, we conducted an application on the city of Cagliari (Italy) which we present here as a case study.

2 Evaluation Model

2.1 Definition

For assessing the level of capability to access UPGS, we have devised a novel index based on the idea of "distance-cumulative" deficit. Intuitively, the model is grounded on a normatively predefined benchmark establishing the cumulative amount of green areas deemed as sufficient *at each* distance from the node in the street network under evaluation. By comparing these benchmark levels with the observed availability of green areas at different distances from the node, the model assigns the index value from 0 (minimum) to 1 (maximum level of capability).

In our application, the index is computed at every node of the street network, producing highly detailed and spatially granular evaluations.

To compute the UPGS *distance-cumulative deficit index* (UPGS-DCD index), the required data are:

- the set of the available UPGS (in short parks) together with their access points and sizes in terms of surface area (for simplicity, the size is assumed as a proxy of the salience and the level of services provided by the parks);
- the graph of the street network, with the set of nodes, for which the shortest-path distances from all the available parks are preliminarily computed; importantly, to add to the fidelity of the modelling, the walking distances have been corrected for slope (following the procedure suggested in [47]), modelled as a dilation of distances increasing with the steepness of the path.

Given a sequence of n available parks ($i = 1, \ldots, n$) – each with surface area p_i, at the walking distance δ_i from the node – indexed in non-decreasing order of distance (i.e. $\delta_i \leq \delta_{i+1}$), we define the *distance-cumulative curve* (DCC) of park areas at the distance $\dot{\delta}$ as:

$$C\left(f\left(\dot{\delta}\right)\right) = \sum_{0 \leq \delta_i \leq \dot{\delta}}^{n} s(p_i)$$

where:

- $f\left(\dot{\delta}\right) \in [0, 1]$ is a distance scale transformation function which, besides rescaling distances from 0 to 1, allows for modelling of possible decay with distance of park's salience for the residents at the origin node;
- $s(p_i)$ is an area transformation function which, besides possible measurement scale conversions, allows for modelling of variable park unit-area salience depending of the park's size (the form of f and s may both also depend of the purpose and scope of the specific application and evaluative question addressed).

We further define a *benchmark distance-cumulative profile* (BDCP) $X(f(\delta))$, which designates the benchmark value of the distance-cumulative park area at each distance, deemed to be fully adequate to satisfy a (normatively defined) required level of UPGS availability. Hence, being the benchmark distance-cumulative profile the upper-limit frontier at each distance, beyond which any further cumulative availability is irrelevant for the sake of computing the deficit index, we can define a *trimmed version of the distance-cumulative curve* (tDCC) as:

$$\bar{C}(f(\delta)) = \begin{cases} C(f(\delta)), & \text{if } C(f(\delta)) \leq X(f(\delta)) \\ X(f(\delta)), & \text{if } C(f(\delta)) > X(f(\delta)) \end{cases}$$

Having established the above, we define the UPGS *distance-cumulative deficit index* (Δ) geometrically, as the area between the BDCP and the tDCC divided the entire area under the BDCP. That is:

$$\Delta = \frac{\int_o^1 [X(f(\delta)) - \bar{C}(f(\delta))] d\delta}{\int_o^1 X(f(\delta)) d\delta}$$

The logic of this index can perhaps best be understood with a visual example. The following Fig. 1 represents the distance-cumulative profile for a node in our dataset.

The distance-cumulative curve (DCC) indicates the cumulative park area (transformed by the function *s*) of all the UGPS at the (scale-transformed) distances from 0 to 1. The bisecting diagonal line represents the predefined benchmark profile (BDCP). Given this profile, the resulting trimmed DCC (tDCC) is shown as the thicker dashed line. The difference between the benchmark profile and the tDCC gives rise to the two "deficit" areas marked in the figure. Thus, following the definition from above, the value of the *distance-cumulative deficit index* Δ is the sum of the two deficit areas divided by the total area under the benchmark profile (which equals 0.5 by definition). In the example in Fig. 1, this calculation yields approximately $\Delta = 0.92$.

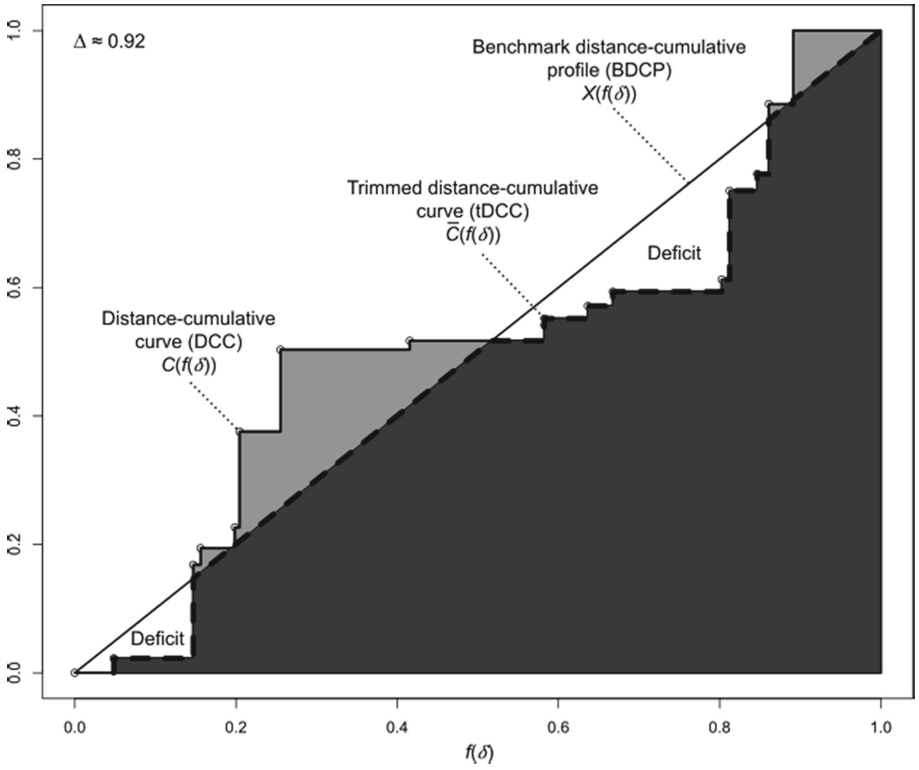


Fig. 1. Distance-cumulative deficit index, a geometrical illustration.

2.2 Specification

For the example application on the city of Cagliari presented in this paper, we have established the maximum walking range of 2 km, or roughly 20 min on a moderate pace. To model the distance decay, assuming the maximum walking distance at which we consider a green area reachable by foot of $\delta_{\max} = 2000\,\text{m}$, we have used the following distance scale transformation function:

$$f(\delta) = \sqrt{\frac{\delta}{\delta_{\max}}}$$

Assuming the area threshold of $p_{\max} = 10\,\text{ha}$ (hectares) as yielding the maximum possible benefit for a single park (i.e. beyond which we assume no additional benefit from a single park area), for the area transformation function we employ $s(p) = (p/p_{\max})^2$. Finally, for the BDCP, we posit $X(f(\delta)) = f(\delta)$. These specifications have yielded the results for the node in Fig. 1.

As the final phase in the assessment procedure, the values computed at each node get interpolated to obtain a value at each point in urban space.

3 Case Study

Cagliari, with about 150.000 inhabitants, is the largest city of the island of Sardinia (Italy) and among Italian cities with the largest green and blue coverage. Green and blue spaces, in fact, occupy 55 of 85 km^2 of the total surface, about 65% of the entire territory. In this study we consider the Urban Public Open Spaces, referring to the urban parks and open public spaces freely accessible for everyone during entire year. In this respect, we considered the Poetto seafront, the Cape Sant'Elia and the San Bartolomeo Hill because they represent two areas of environmental and landscape value, variously used by people who live in or close to them, but also by the inhabitants of other neighbourhoods and wider territory. Vice versa, some types of green spaces, mainly private, informal, or abandoned area, have been excluded from the dataset.

Figure 2 show the UPGS distribution across 31 city neighbourhoods (Q1. Castello; Q2. Villanova; Q3. Marina; Q4. Stampace; Q5. Tuvixeddu-Tuvumannu; Q6. Is Mirrionis; Q7. La Vega; Q8. Fonsarda; Q9. Sant'Alenixedda; Q10. San Benedetto; Q11. Genneruxi; Q12. Monte Urpinu; Q13. Monte Mixi; Q14. Bonaria; Q15. Sant'Avendrace- Santa Gilla; Q16. Mulinu Becciu; Q17. San Michele; Q18. Barracca Manna; Q19. Is Campus - Is Corrias; Q20. Villa Doloretta; Q21. Monreale; Q22. S. Giuseppe, S. Teresa, Parteolla; Q23. Is Bingias–Terramaini, Q24. Monteleone - Santa Rosalia; Q25. Quartiere Europeo; Q26. CEP; Q27. Poetto - Medau su Cramu; Q28. La Palma; Q29. Quartiere del Sole; Q30. Borgo Sant'Elia; Q31. Nuovo Borgo Sant'Elia).

There are many small and medium size open green spaces and nine large urban parks (P1. San Michele; P2. Monte Claro; P3. Terramaini; P4. Monte Urpinu; P5. Molentargius; P6. Anelli; P7. San Bartolomeo Hill; P8. Cape Sant'Elia; P9. Poetto Seafront), mainly concentrated in the southeast areas of the city.

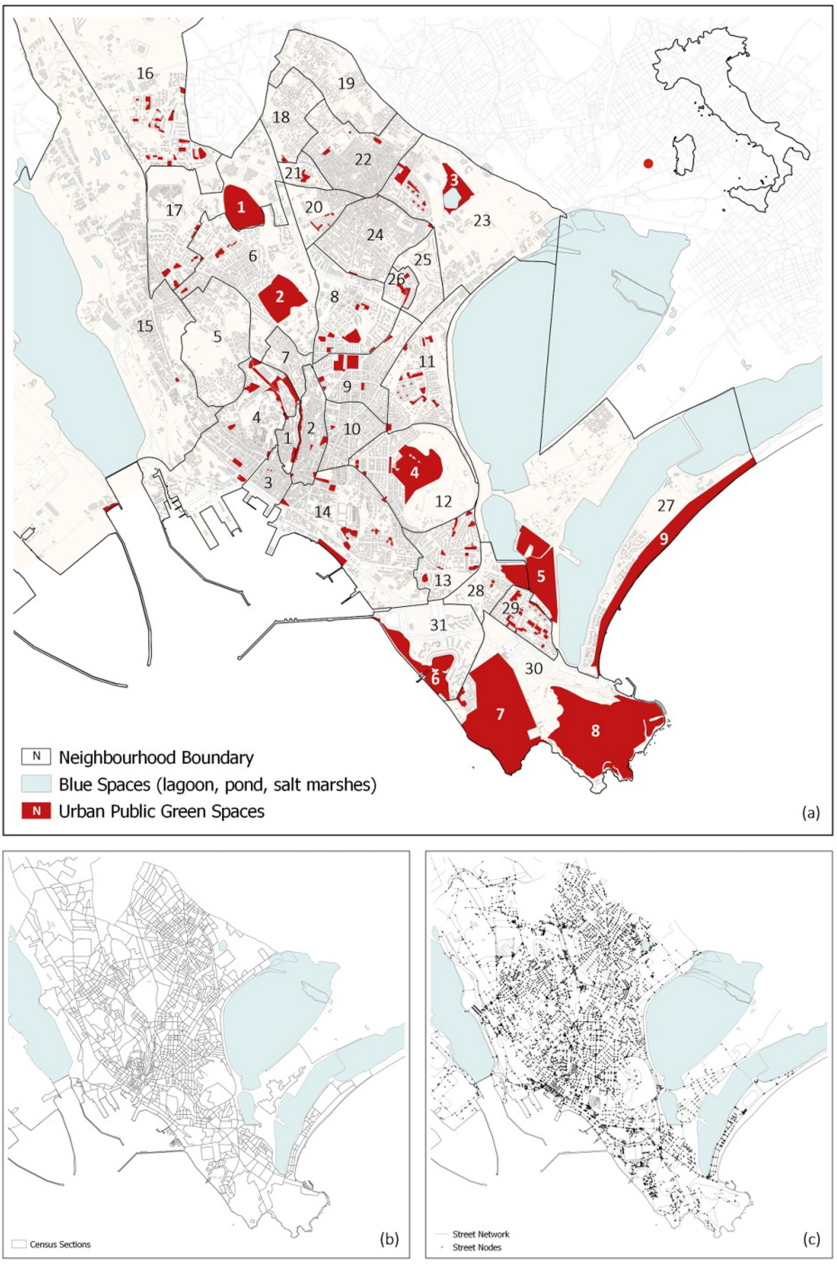


Fig. 2. The distribution of Urban Public Green Spaces in Cagliari and the boundaries of the 31 city neighbourhoods (a); Population Census Tracts (b); Street Network with the over 6.500 Street Nodes used in the assessment.

The data for the assessment were collected from various sources and further processed as follows:

- the city's street network was obtained from the OpenStreetMap (OSM), using urban roads, walking pathways and all the available street nodes (Fig. 2c);
- the geographical distribution of the UPGS and their related data were digitised starting from the OSM data and verified by comparing the satellite imagery (Google Earth), to check, and, if necessary, to correct the discrepancies between the OSM classification and the ground truth;
- UPGS access points were digitised starting from the OSM data and manually corrected using Google Earth imagery for validation;
- the geographic distribution population was obtained from the Italian National Institute of Statistics (ISTAT) 2011 residential population census.

3.1 Results

The geographical distribution of the UPGS *distance-cumulative deficit* index calculated for the city of Cagliari is shown in Fig. 3.

The index has shown a notable variability for the 31 city neighbourhoods (Figs. 3 and 4). The highest score is obtained from the neighbourhoods located in the south-east area of the city (N30, N27, N31) where the spatial proximity to the large parks corresponds to a high accessibility, due to the fact that the majority of UPGS analysed have open access (P6, P7, P8, P9), and that the relatively flat terrain allows for easy pedestrian mobility. A similar observation can be made for the more central neighbourhoods (N12, N7, N9), which are also located near large urban parks (P2, P4) and where the increase in the terrain slope is compensated by the greater choice offered by various parks of different sizes situated in the surroundings. Three of the 31 neighbourhoods analysed (N8, N11, N13) show a large variability in the scores. In particular, the index value of N8 and N11 varies from 0.30 to 0.50 points. The northern area of these two neighbourhoods shows a lower score than the southern one, due to the presence of a large road infrastructure which represents an impediment to pedestrian accessibility, and to the scarcity of open public green areas in the surrounding urban tissues. A similar condition characterises N13 where the road infrastructure is located to the south of the neighbourhood.

The lowest values of the index were assigned to the neighbourhoods located in the north western suburbs of the city (N16, N15, N4, N5) and in the peripheries of the Pirri municipality, in the north-west urban areas, at the borders on large road-infrastructures (N18, N19, N21, N20, N24, N25, N26).

The four neighbourhoods of the historic centre (N1, N2, N3, N4) have markedly different index values, largely dependent on the different type-morphological characteristics and terrain slopes. In decreasing order of score, N2 has the highest values especially in the northern area, where there are numerous public open green spaces; N1 has good scores for the presence of a system of green areas along the north-eastern

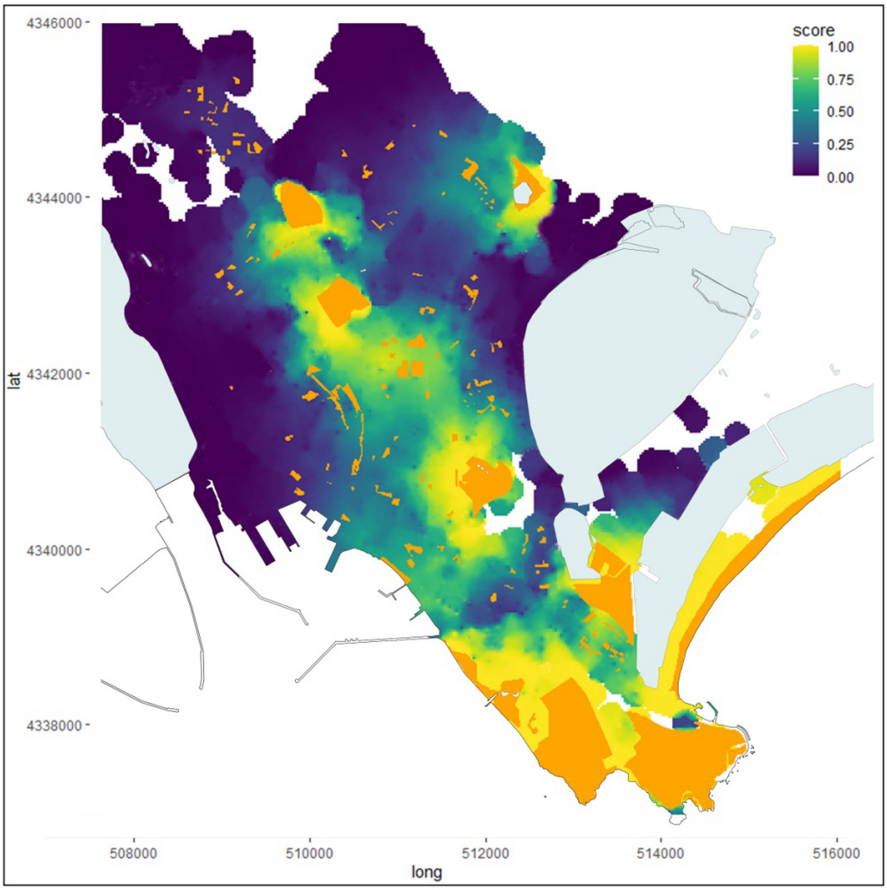
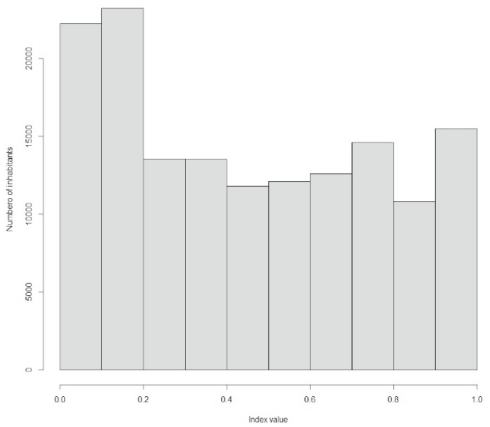


Fig. 3. UPGS-DCD Index: a geographic overview.

rampart/bastion; low indices values of N3 are affected by the scarce endowment of UPGS and by the great distance from large urban parks; finally, N4 shows low indices values especially in the peripheral areas, outside the boundary of the historic centre, also due to the impediments related to the terrain slope which make accessibility to the surrounding large urban parks more difficult (Fig. 5).

The analysis of the index values in relation to the residential population has shown (Fig. 4) that approximately 45,396 inhabitants out of the 149,855 total (30%) live in urban areas characterised by a very low index value (<0.2), while only about half of that, 26,303 people (17.5%), live in areas with a high index (score between 0.8 and 1). Most of the population 78,156 (52.5%) live in areas with intermediate values (score between 0.2 and 0.8). For the purposes of the analysis, it is important to note that some of the neighbourhoods with low index score are among the most densely populated (N16, N17, N4; N18, N19; N26 and the part of N13 with low score).



Index value range	N. of inhabitants
0.0 – 0.2	45.396
0.2 – 0.4	27.073
0.4 – 0.6	23.899
0.6 – 0.8	27.184
0.8 – 1.0	26.303

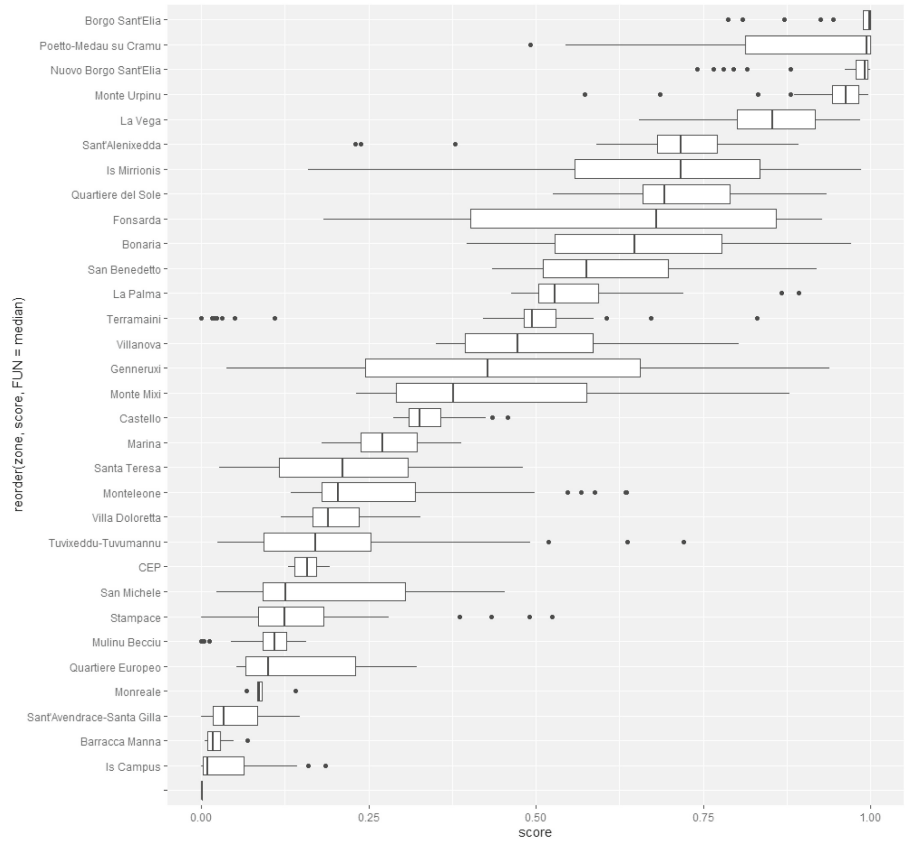


Fig. 4. Distribution of the UPGS-DCD index values among the city population (above) and within each neighbourhood.

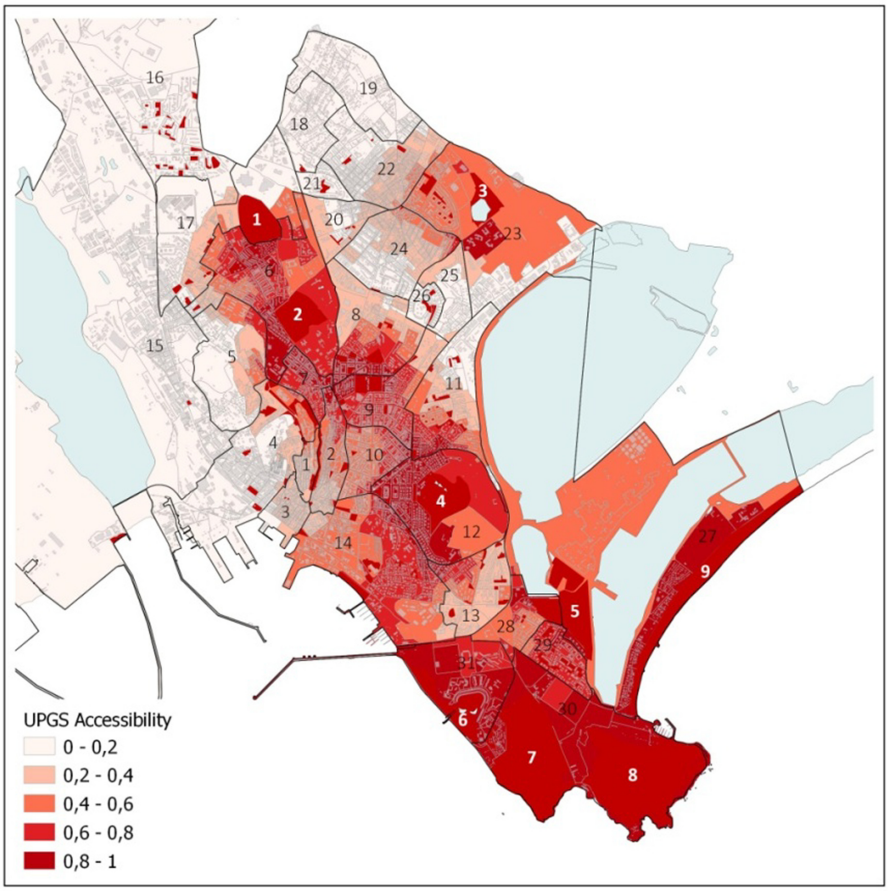


Fig. 5. UPGS-CD Index: map of the calculated values for each census tract (the numbers indicate the neighbourhoods and major parks, according to the Fig. 2).

4 Conclusions

The evaluation model and the related assessment procedure presented in this study allow to assign a UPGS capability index to each node, evaluating its pedestrian connectivity with the set of available public green spaces. The model is based on the idea of UPGS distance-cumulative deficit, and was developed specifically to obtain a better, more detailed and a high-fidelity understanding of different degrees of UPGS accessibility at a spatially granular level, allowing subsequent aggregation at the neighbourhood level for comparison.

The application on the city of Cagliari showed that the neighbourhoods have a high internal variability in accessibility characteristics, which can easily be overlooked by the traditional evaluation procedures. For instance, as can be seen results in Fig. 3, nodes and areas apparently close to large urban parks may obtain low index value due

to the presence of impedance elements such as the high terrain slop, lack of nearby park access/entrance points, or due to inadequate street connectivity. These differences are also found within the same neighbourhood, so policies aimed at improving the distribution and accessibility of UPGS cannot be exclusively based on neighbourhoods boundaries, but must work on multiple scales, from strictly local, at the sub-neighbourhood and block level, to wider spatial scenarios, at the city and metropolitan scale.

The results from the Cagliari case study also show the areas with the lowest index values, suggesting places for planning interventions to reduce inequalities across the city. Many of these UPGS-deprived areas are located in the most peripheral areas of the city, characterised by a discontinuous urban fabric, with many abandoned open spaces, which could be usefully converted into public green areas in order to increase the level of UPGS accessibility.

A way in which the proposed evaluation model can also prove useful is in creating different evaluative scenarios by modifying reference values and parameters (such as the maximum distance, the distance decay and the park-size-transformation function, among others), in order to take into account other modes of transportation and different uses by different groups and profiles of users (e.g. children, senior citizens). Finally, as a simulation tool, the evaluation model can be used to assess the impact of many kind of urban interventions to which the traditional approaches are insensitive, such as adding new park entrances, removal of barriers, improvements of street connectivity, among many others. Hence, although there are still steps to be made, with these possibilities in mind we believe that the proposed approach is a promising candidate to grow into a useful planning and urban design support at different scales of intervention.

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