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Measuring Accessibility of Green Spaces for the Health and Wellbeing of Inhabitants of the Milan Metropolitan Area

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Abstract: Several studies have recognised the importance of urban green spaces (UGSs) in modern cities. However, the distribution and accessibility of green spaces represent a challenge for the sustainable development of territories in terms of fair distribution, reducing inequalities, and mitigating the effects of climate change, such as urban heat islands and runoff. This research identifies every UGS capable of contributing to people's physical and mental wellbeing in the Milan metropolitan area (MMA), one of the most densely populated areas in Europe. The method allows for the various UGSs to be identified and classified using a comparative approach that considers both formal and informal green spaces through a qualitative territorial analysis and the support of open access databases (satellite and thematic maps). Based on this classification, this contribution establishes an 'accessibility map' of the metropolitan area that determines the actual pedestrian accessibility of a UGS within 300 m. The results show that only 37% of the residential surface of the metropolitan area offers access to a UGS within a five-minute walk. This research aims to identify the most fragile segment of the MMA, which is pivotal for the tree-planting activities sponsored by the Forestami project.

Keywords: urban green spaces; spatial accessibility; environmental equity; informal green spaces

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1. Introduction

Urban green spaces (UGSs) offer a wide range of benefits and contribute to the environmental and urban quality of a city. Many studies have shown the importance of open green spaces in an urban context for both environmental and human health. Direct benefits include positive effects on people's wellbeing, such as temperature regulation [1], pollution reduction [2] and noise mitigation [3]. Green spaces, especially trees, absorb and store carbon dioxide [4] and intercept rainwater, reducing flooding risks by means of positive drainage that reduces the effort required to clean streets and drains [5]. Living in a green neighbourhood also reduces energy consumption and CO_2 emissions due to cooling [6], in light of the fact that planting trees can reduce annual energy use by anywhere between 10 and 50% [7,8].

Further research [9–11] also shows that living in a green neighbourhood and being able to see trees on a daily basis reduces people's levels of stress and physical fatigue. Living close to green spaces promotes physical exercise and reduces obesity levels and risks tied to cardiovascular diseases [12], while promoting social cohesion and interaction between different groups of citizens [13]. Additionally, the presence of UGSs is essential for fragile people, who tend to perceive a much clearer improvement in their lives as a result of regular exposure to nature. Older adults over 65 years of age may feel more supported and less lonely if they live close to open green spaces [14], indicating that such spaces have positive effects on their longevity [15], whilst exposure to greenery can reduce anxiety and depression in young people [16].

Due to the importance of green spaces, it is crucial to consider accessibility as an essential metric in assessing the inclusiveness of a city [17], where the accessibility of open green spaces is measured in terms of time and physical distance and represents the distribution and provision of opportunities and services over a given area [18]. Many studies have focused on determining the accessibility and attractiveness of UGSs [19,20], underlining the importance of their provision and distribution for human health and wellbeing [21,22]. Indeed, UGSs such as parks, gardens, forests, street greenery and areas planted with trees [23] provide multiple environmental, recreational and economic benefits [4,24–27] for people's physical and mental health. Green spaces also provide essential ecosystem services in densely populated cities [28], which strengthen their importance as public goods [29].

Despite their recognised importance, the growing model of urbanisation has increased the fragmentation of these green spaces and reduced their size [30], generating inequalities between different areas and groups of citizens who, as a result, have less access to greenery [31]. This scenario is part of environmental gentrification, a process by which environmental improvements tend to spur gentrification, increasing racial and class inequalities [32,33].

This common phenomenon in denser urban areas has therefore also led to disparities in terms of the perception and use of green spaces, which often end up being planned, designed, and governed by economic and real-estate policies that do not consider their ecological, environmental and social qualities. As a result, urban development redefines green areas, establishing the conditions for gentrification pressure [34] and, subsequently, raising concerns about fairness amongst sustainable planners and designers. Indeed, researchers have shown that immigrants and low-income residents are amongst the worst affected by the redefinition of green spaces [35], highlighting increasing disparities and underlining that the overall availability of greenery in dense contexts is insufficient for satisfying the needs of all citizens.

With the aim of responding to the lack of green spaces in urban areas by promoting a fair and just environment, governments and institutions have defined guidelines [36,37] rooted in the principle of environmental justice, according to which everyone has the right to live in and enjoy a clean and healthy environment [38] (p. 156).

Several studies have explored environmental justice and social equity in the distribution of UGSs and determined their accessibility by identifying the number of green spaces within a 300 m or 500 m radius in a given area and/or city in proportion to the number of residents [36]. Other studies have proposed surveys to explore citizens' perceptions and preferences according to age, gender and ethnicity [39,40], exploring equity in low-income areas.

Following this, Biernacka [41] identified different barriers that affect accessibility of and the availability and attractiveness of UGSs, which include perceived safety, environmental conditions, maintenance and spatial planning features, thus highlighting the importance of making UGSs with a high environmental and urban quality accessible to the public.

Research has established the level of accessibility of parks and gardens, focusing on only the most formal and institutionalised of urban spaces [42] and usually determining accessibility by using UGS centroid or buffer zones [43] or using proximity as the most relevant factor when assessing inclusivity. Others, meanwhile, have determined that spontaneous and informal spaces are just as important as formal ones when it comes to reaching equity goals and meeting the needs of citizens [44].

This article offers a qualitative/quantitative study of UGSs' accessibility in urban and peri-urban areas, identifying the important factors in measuring accessibility with an exploration of the urban and environmental quality of such spaces.

The paper is organised according to the research framework (Figure 1). First, we examine the existing literature on urban green spaces and wellbeing presented in the Introduction with the aim of defining the morphological and physical characteristics that urban green spaces should have in order to contribute to people's health and wellbeing. Second, we define and frame the goals of the research, also exploring the current accessibility methods presented in various studies. To explore the distribution of UGSs that can contribute to people's health and wellbeing, we define a method that is used to draw the accessibility map based on the identification of various types of UGSs. The design solution of the accessibility map is presented at various scales in the Section 3. Finally, as presented in the Section 4, we define important factors to be considered when determining accessibility in a dense metropolitan area.

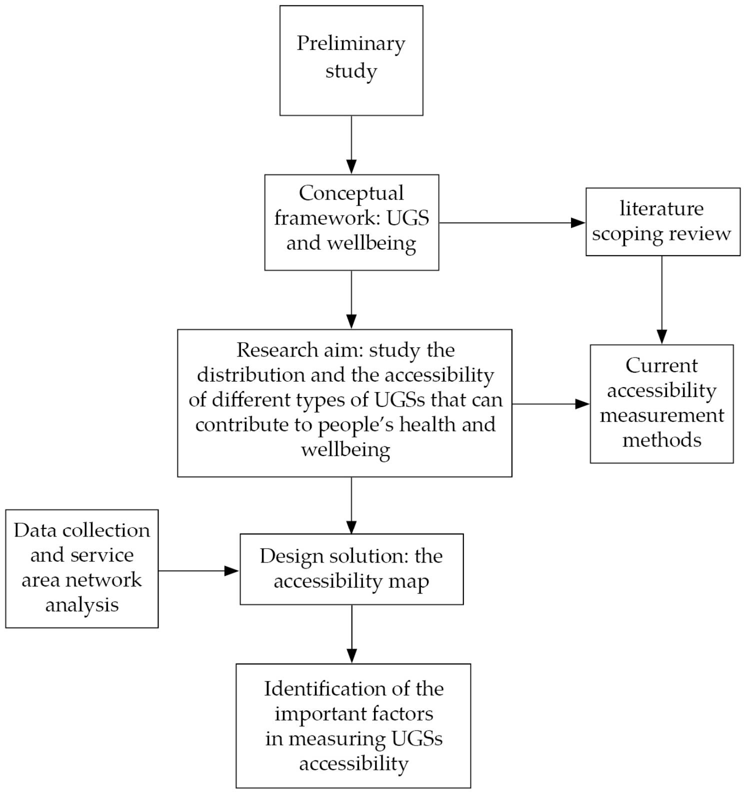

Figure 1. Research framework diagram.

Considering the emerging problem of the equitable distribution of UGSs in metropolitan areas, this paper addresses the accessibility of publicly green spaces in the Milan Metropolitan Area (MMA) by identifying those spaces which can contribute to people's health and wellbeing according to existing literature and guidelines on green spaces and human health. The contributions reflect on the challenges involved in the fair distribution of green spaces in a dense and heterogeneous context, promoting the role of informal greenery in the sustainable development of our cities.

Furthermore, the final goal is to establish a dialogue with local governments and authorities to orient their choices regarding the importance of urban greenery by showing the most vulnerable part of the MMA at various scale, where new sustainable policies and possible funding should be focused.

Hence, the study addresses the following research questions: (RQ1) How are UGSs distributed in the MMA? (RQ2) Which method can be used to measure the accessibility of formal and informal green spaces? (RQ3) What is the current degree of accessibility of those spaces and what are the important elements needed to define it?

2. Materials and Methods

The methodology involved five different steps (Figure 2), starting with data collection on UGSs in the MMA, by classifying them into categories and developing a GIS database that collects different information, yielding an accessibility measurement. Before we undertook this research, there was no existing map of the MMA containing information about UGSs and the characteristics that may contribute to the wellbeing of local citizens. As such, the researchers developed the maps presented in this contribution by overlapping different databases and selecting the features of each UGS based on criteria defined in the existing literature. This identification allowed us to assess the accessibility of UGSs through a network analysis that considered different contextual conditions.

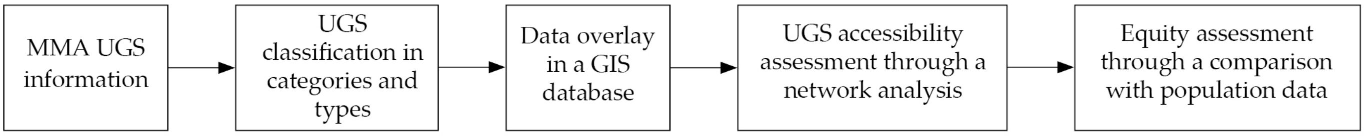

Figure 2. Structure of the methodology.

Finally, the last step involved an analysis of the fairness of distribution and accessibility through a quantitative comparison with population data and distribution.

2.1. Context of the Case Study

The MMA is located in Po Valley in Northern Italy (Figure 3). It is one of the most densely populated areas in Europe, where more than three million people are spread over a total area of 1575.65 km^2 (approximately 6.6% of the Lombardy region as a whole). It comprises 133 municipalities of different sizes and eight homogeneous areas, including the city of Milan itself.

This area has critical environmental conditions, with daily harmful pollutant levels that are four times higher than the World Health Organisation's (WHO) suggested threshold [45], as well as severe heatwaves [46] that are particularly evident in the densely populated central urban areas, where UGSs are often fragmented and small. In the peri-urban context, however, there are large woodlands on the edges of the MMA, whilst most of the area consists of agricultural spaces, sometimes surrounded by rows of trees and paths that run alongside rivers and streams.

This situation highlights the urgency and importance of addressing climate change issues that affect dense urban areas, using sustainable solutions and strategies to protect and enhance the natural environment. Indeed, the varied and heterogeneous green areas within the MMA represent a source of great potential, as well as a challenge for all municipalities in the metro area for designing sustainable interventions to protect their natural capital.

To address the above-mentioned challenges, different institutions, including Milan Municipality, Milan Metropolitan Area, Parco Agricolo Sud Milano, Parco Nord Milano, Fondazione di Comunità, ERSAF, and Polytechnic of Milan, have worked together since 2018 under the Forestami project [47,48]—an ongoing research and implementation project that aims to plant three million trees within the Milan Metropolitan Area to improve air quality and spread the ecological and cultural value of nature. On the local scale, the Forestami project works with each metropolitan municipality through participatory dialogue, identifying the opportunities and potential in the wider area by seeking locations where trees can be planted.

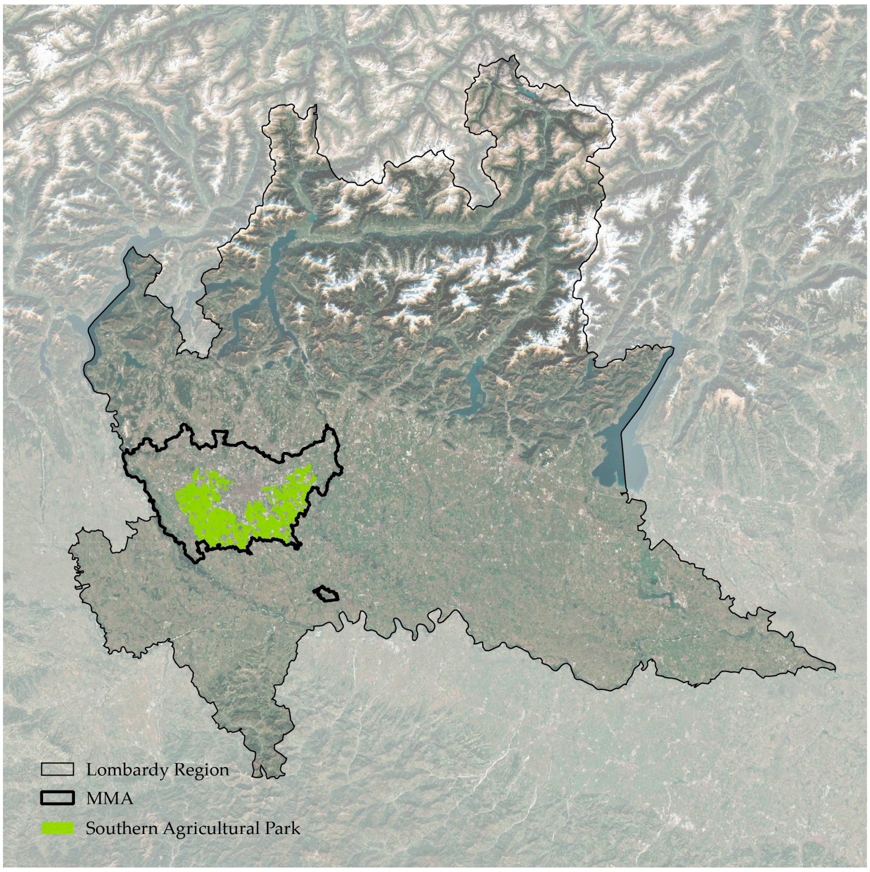

Figure 3. Case study context.

As such, this contribution is part of a complex context in which another project is currently operating; the proposed accessibility map will support the Forestami project, identifying the parts of the MMA that are less accessible and well served as a means of sparking involvement from administrative bodies and institutions in the decision-making process that underpins sustainable urban development.

2.2. Selection Criteria

To develop the accessibility map, we identified all the green open spaces in the metro area, considering their potential accessibility, size, the presence of tree cover and active attendance as essential factors in recognising which UGSs contribute to people's health and wellbeing due to their environmental and urban quality. The four selection criteria were as follows: 1. included sites needed to be publicly and privately accessible; 2. they needed to have a surface area of over half a hectare that allows for practices such as physical exercise or longer breaks; 3. they needed to be actively frequented areas; and 4. They needed to have tree canopy cover of up to 20%.

Notably, we deemed the accessibility of an area to be an essential factor for users to be able to enjoy the environmental and recreational benefits of nature [49].

Regarding size, we followed the guidelines laid out by the WHO, which state that accessibility of public green spaces of at least 0.5–1 hectare should be guaranteed within a linear distance of 300 metres (about 5-min's walk) for all population groups and users [50,51].

The presence of tree canopy cover was established based on the existing literature, which recommends that every neighbourhood should have at least 30% tree canopy cover [52]. Since most of the MMA consists of agricultural land made of tree rows and small wooded areas, we opted to use a lower value, which is more inclusive and contextualised based on the characteristics of UGSs in the MMA; otherwise, the entire southern agricultural territory would have been excluded from this analysis.

Finally, attendance is an essential indicator for evaluating the potential ability of UGSs to deliver benefits because it indicates how often people use a place, who its users are, and what they do there.

We included only the spaces that met all the above-mentioned criteria and opted to exclude—for instance—areas that are inaccessible, degraded or small, or places with very few trees, bearing in mind that accessibility and urban and environmental quality are essential drivers for the wellbeing of both cities and their citizens. As such, the map—developed considering only spaces that are accessible and actively used—offers a representation of how citizens actually use these spaces within the MMA.

2.3. Classification of UGSs

Urban green spaces can be formal, as per the most common definition [23], or informal (informal green spaces—IGSs), playing host to informal practices and spontaneous uses [53]. Within the MMA, formal spaces are clearly defined and organised and include locations such as parks and gardens that are frequently identified as such on maps. IGSs within the MMA, meanwhile, are associated more with the area's peri-urban natural capital, such as forests or agricultural spaces. These spaces are usually undesigned, unplanned, and sometimes unmanaged; they are defined in the land-use database but are not governed by specific rules, as they may contain a variety of spaces and play host to different activities.

Following this selection, open spaces were classified into three categories: (a) parks and gardens, (b) wooded areas, and (c) wooded agricultural areas. Each category contains various types of formal and informal green spaces.

The first category (a) includes parks and gardens, as well as green spaces in urban areas, such as expansive urban parks or neighbourhood gardens, with dimensions of between 0.5 and 10 hectares and an average size of 2.5 hectares. These spaces are usually recognised easily since they are well defined, officially named, and contain a variety of different facilities.

The second category, (b) wooded areas, corresponds to isolated accessible wooded areas, systems of accessible wooded areas, wooded areas bordered by paths, and complex linear systems. Their dimensions vary between 1 hectare for smaller wooded areas—usually located along a system of paths—and over 500 hectares for the complex usable systems that usually contain various kinds of facilities.

The third category, (c) wooded agricultural areas, includes network agricultural spaces and agricultural spaces connected to a ring path. The second and third categories are informal spaces and are difficult to discern using satellite images, as they are regulated by the different ways in which they are used by citizens. They are usually used by athletes such as runners and cyclists, since they have cycle/pedestrian paths as well as country roads running through them, and tend to be surrounded by vegetation, albeit in limited quantities.

2.4. Data Analysis

In developing the map, we deemed administrative fragmentation and land area to be critical drivers due to the numerous urban plans[1]. We superimposed different databases and selected, verified, and individually reshaped each type of geometry in the GIS database. In particular, we selected different open-source databases, as described below, that provide a variety of data on UGSs to develop a new database that compiles this information at different levels.

The identification of the three categories described above and the method applied to develop the database are currently awaiting publication. We sorted our selected sources into the established categories and types to provide information about the position, perimeter, use, and facilities available at the site of each UGS.

The two categories of informal spaces indicated in the database were then completed by adding in the pathways that allow people to enjoy the area. Pathways are useful indications when recognising these spaces, which are usually more complex than formal spaces, and simplify their identification as complex agricultural areas surrounded by woods.

To identify the three categories, we used a variety of open-source data: DUSAF land use, DBT provincial topographical database, Open Street Map, satellite images, existing tree canopy cover, sport tracking applications such as Strava and Komoot, thematic maps of regional and metropolitan parks, and various government plans for the area as a whole.

For each of the spatial features, we assigned a unique identification code (ID), and we collected data about the geographical site (homogeneous zone, municipality, dimensions, name of UGS), the classification of the UGS (source and data, category and type), its features (tree canopy cover, type of facilities available on site) and its primary use (ordinary vs. sports activities) (Table 1).

Table 1. Database information.

Geographical Site					Classification of UGS			Features of UGS		Use
ID	**Zone**	**Municipality**	**Area [ha]**	**Name**	**Source and Data**	**Category**	**Type**	**Tree Canopy Cover**	**Type of Equipment**	**Activities**
1	Milan	Milan	68.31	Parco Porto di Mare	DUSAF April 2023	Urban park	Park	39%	Lighting, benches	Ordinary
2	Sud Ovest	Rozzano	18.58	Parco Baleno	DUSAF April 2023	Urban park	Park	61%	Lighting, benches	Ordinary
3	Sud Ovest	Trezzano sul Naviglio	17.34	Parco del Centenario	OSM April 2023	Urban park	Park	54%	Dog area, playground, kiosk, lighting, benches and tables, bike racks, drinking fountains	Ordinary
……	……	……	……	……	……	……	……	……	……	……
2412	Adda-Martesana	Segrate	0.67	Golfo Agricolo	OSM June 2023	Wooded agricultural area	Network agricultural spaces	20%	…	Ordinary
2413	Sud Ovest	Cusago	2.10	Bosco di Cusago	OSM June 2023	Wooded areas	Wooded areas bordered by paths	90%	…	Ordinary

Accessibility Map

To develop the accessibility map presented in this study, we conducted an isochronal analysis using QGIS and ArcGIS, which offer analytical tools commonly used in many UGS studies [52–54] that are helpful for importing, analysing, and managing various types of georeferenced data.

We used the ArcGIS service area network analysis, through a distance cost analysis using the time necessary to travel from a source. In this analysis, we considered all the intersection points between open green spaces and the pedestrian path network. These points represent entrances to parks, gardens, wooded areas, and agricultural spaces or systems of UGSs, which are highlighted as red dots in Figure 4. Considering that IGSs consist of various singular natural elements such as meadows, wooded areas, rows of trees or shrubs and agricultural fields, it was necessary to consider an entire system of green spaces instead of individual elements. For instance, we reshaped the features of categories

(b) and (c) by creating a complete perimeter to allow the model to calculate the accessibility of an entire group of natural elements (Figure 5).

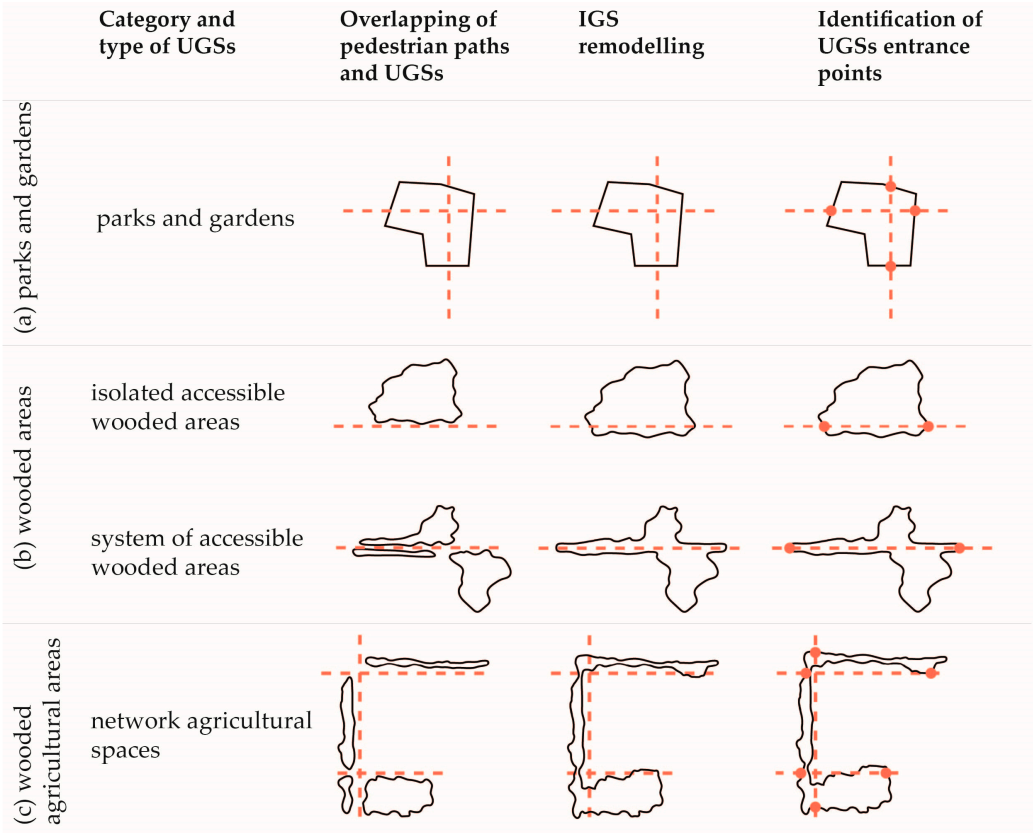

Figure 4. Identification of access points (red dots) to UGSs. The black perimeter represents UGS, and the red lines represent paths.

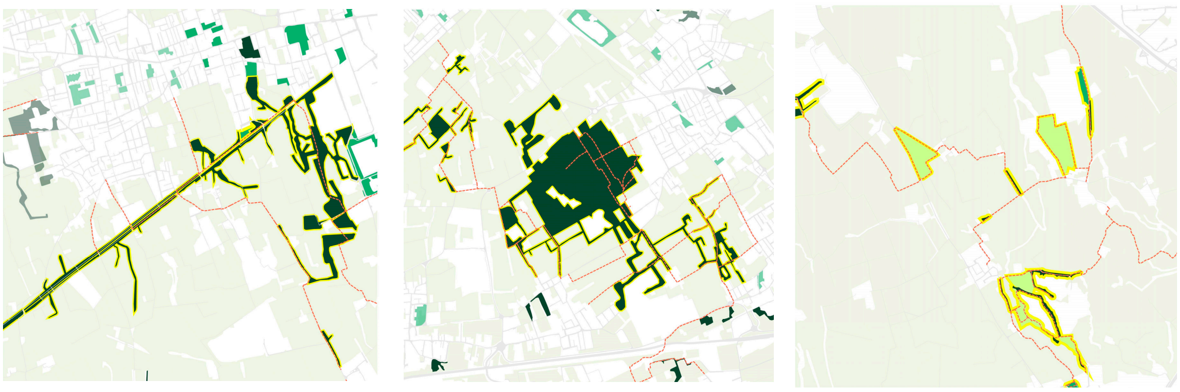

Figure 5. IGS remodelled in a single feature (yellow perimeter) and red pedestrian paths.

The research then continued with an assessment of the network service area at a distance of 300 m along the pedestrian paths. Two accessibility maps were developed, each considering different contextual conditions. The first network analysis showed the accessibility of green open spaces in light of the pedestrian graph for the entire metropolitan city, whilst the second analysis only considered pedestrian paths running alongside vegetation, such as trees or rows of trees.

The second version of the accessibility map considered the average level of tree canopy cover across the MMA, equal to 16.4%, which is low compared to the average for other European cities [55–57]. Due to the critical climate conditions of the metropolitan area, featuring continuous heatwaves and droughts, it is essential to identify which access routes to UGSs can offer people sufficient environmental comfort.

To identify shaded paths leading to UGSs, we cross-referenced the data on tree canopy cover with the pedestrian path network using a true/false matrix based on the proximity of trees to paths (Figure 6). We then accounted for a proximity of 5 m as the maximum distance between pathways and canopy coverage. These criteria restrict the isochronal modelling as the second model avoids routes without trees, or those that are far from trees, with exposure to direct sunlight in the hotter months. As such, this model shows the accessibility of UGSs via paths that run through rows of trees or small wooded areas.

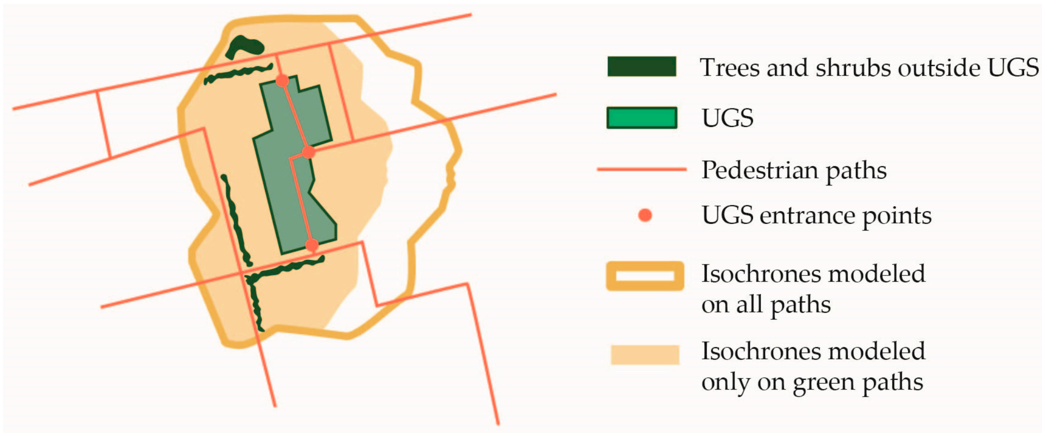

Figure 6. Isochronal modelling.

3. Results

The results presented here show two maps constructed based on the open spaces in the MMA identified above, each representing different levels of accessibility of UGSs. The first accessibility analysis reveals that 37% of the residential surface in the MMA is located within 300 m of the identified green spaces (Figure 7).

Figure 8 shows different segments of the MMA, corresponding to urban, peri-urban and agricultural contexts. The second column shows the accessibility modelled only on the green routes, which form a smaller area than the ones in the first column. Figure 8a illustrates a dense and heterogeneous residential structure with various industrial sections connected to the infrastructures. Open green spaces are fragmented and assigned to the first category, namely parks and gardens. The images show that trees are almost entirely absent in the residential and industrial areas, meaning that they are designed in such a way that the open spaces are not connected accessibly. The urban structure reveals discontinuity in the tree canopy, which is mainly evident when conducting examinations of the industrial and residential areas.

In peri-urban areas (Figure 8b), the tree canopy cover is mainly concentrated in parks, gardens and in wooded expanses within the urban fabric. In this context, the proximity to the Southern Agricultural Park leads to a more significant fragmentation of tree canopy cover, highlighting the absence of trees in most residential neighbourhoods characterised by family houses with private gardens instead of public green spaces.

Finally, Figure 8c represents an agricultural portion of the area in which scattered urban centres are connected by country roads, which are frequently used for outdoor activities such as running and cycling along rows of trees. The UGSs seen here are mainly agricultural green spaces surrounded by rows of trees and wooded expanses, located beside ponds and running paths.

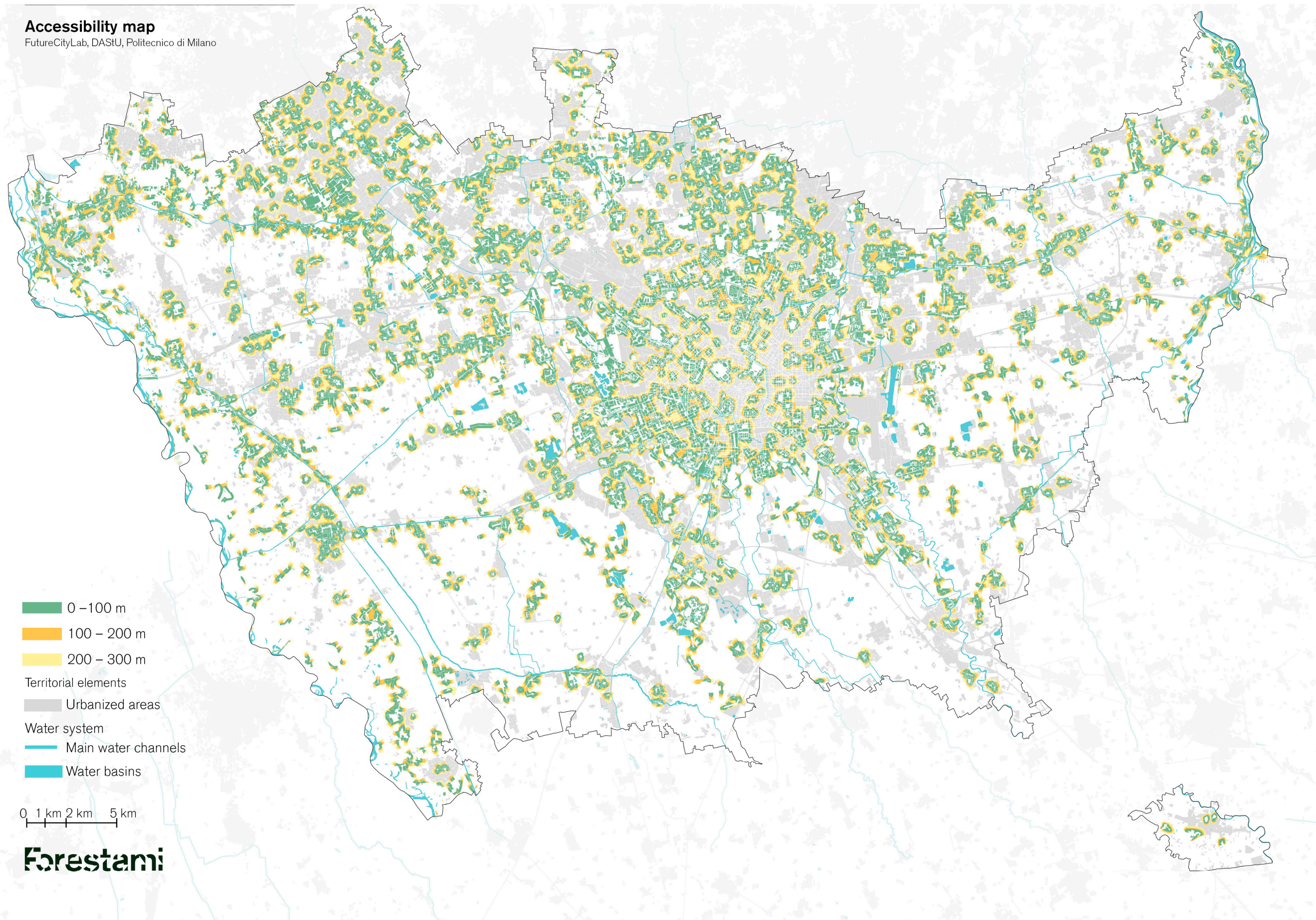

Figure 7. Metropolitan accessibility map.

Comparison Between Homogeneous Zones

The MMA is administratively divided into eight homogeneous zones characterised by geographical, demographic, historical, economic and institutional features. These zones have significantly different green surface values due to the presence of various types of UGSs that make up a range of different landscapes. To analyse the distribution of accessibility within the MMA, Table 2 shows the total size of the UGSs—both formal and informal—for each category identified in homogeneous zones, underlining how the UGS categories are not equally distributed across the area.

Table 2. Total size of UGSs by homogeneous zone.

Homogeneous Zone	Parks and Gardens (a)	Wooded Areas (b)	Wooded Agricultural Areas (c)
Milan	1867 ha	107 ha	47 ha
Adda-Martesana	573 ha	631 ha	86 ha
Alto Milanese	217 ha	2793 ha	30 ha
Magentino-Abbiatense	193 ha	2786 ha	132 ha
Nord Milano	472 ha	35 ha	47 ha
Nord Ovest	430 ha	769 ha	52 ha
Sud Ovest	378 ha	194 ha	89 ha
Sud Est	212 ha	195 ha	72 ha
Total for MMA	4342 ha	7510 ha	555 ha

The results in Table 3 show that the densely populated zones of Milan and Nord Milano have a low ratio of open spaces per inhabitant and good accessibility, mainly offering access to formal spaces, the delta in these zones between the per capita distribution of category (a) and total provision of UGSs reveals a greater presence of parks and gardens.

Despite this provision, the per capita value is less than half the figure established by WHO guidelines, which calls for an ideal value of 50 m^2 of green space per inhabitant [58].

Figure 8. Accessibility within 300 m from UGS access points in different MMA contexts.

The Nord Ovest and Adda-Martesana zones, despite being densely populated, are home to several wooded areas on the edges of the urban fabric, offering a greater variety of spaces. In these zones, too, the per capita values are lower than recommended by the

WHO, highlighting a need to increase the accessible green endowment, thus rebalancing the percentage of the residential surface area that can benefit from the presence of UGSs.

Table 3. Accessibility of UGSs by homogeneous zone.

Zone	Land Area [km^2]	Population (2022)	Parks and Gardens per Capita (a) (m^2/Person)	Total UGS Area per Capita (m^2/Person)	Residential Accessibility (<300 m)
Milan	181.8	1,349,930	14	15	42%
Adda-Martesana	264.95	390,863	15	34	33%
Alto Milanese	215.25	256,801	8	121	32%
Magentino-Abbiatense	360.44	217,470	9	140	34%
Nord Milano	57.88	266,200	18	21	43%
Nord Ovest	135.82	317,515	14	40	39%
Sud Ovest	179.94	239,769	16	27	30%
Sud Est	179.72	176,082	12	25	24%
Total for MMA	1575	3.215 million	13	38	37%

The Magentino-Abbiantense and Alto Milanese zones, on the other hand—which are home to Ticino Park, one of the most important Regional Parks in the metropolitan area—have large informal green areas with a per capita value that are more than sufficient for their residents' needs in terms of green spaces. However, the accessibility analysis shows that this natural capital is often inaccessible or far from the inhabited centre.

The Sud Ovest and Sud Est zones are very similar, as they are located in the South Agricultural Park, which contains a range of small urban formal and informal areas. In this area, the availability of accessible UGSs is mainly determined by the presence of roads and paths that allow inhabitants to make use of green areas, with tree-lined streets, wooded areas and high levels of biodiversity contributing to their urban and environmental quality. As such, the per capita value, whilst lower than the WHO's recommendation, suggests that future improvement can be achieved by identifying new accessible areas.

This comparison shows that the most densely populated areas mainly suffer from a lack of IGSs, despite offering a high degree of accessibility of formal spaces. It also emerges that the formal category of parks and gardens (a) is, broadly speaking, more accessible than the informal categories of wooded areas (b) and wooded agricultural areas (c).

4. Discussion

4.1. State of the Art of UGSs' Accessibility Measurement

In the past, studies on accessibility of specific areas have mainly been concerned with the public and private transport sectors, as well as local and regional transportation [59]. In contrast, a growing number of studies in recent years have introduced the concept of accessibility of UGSs as an essential indicator of equity and inclusiveness in the distribution of green spaces [60].

Research [61] shows that many UGS accessibility analyses conducted to date have been limited. Studies have focused on the accessibility of urban parks and gardens, without considering other types of open spaces [62]. Isochronal calculation often starts from a centroid without considering the actual time that a user would take to reach the centre of the open space [63]. Other studies have limited themselves to evaluating accessibility on the sub-district level [42] without focusing on strategies and proposals for improvement, whilst others still have determined accessibility using green spaces per capita as the key relevant indicator [64].

With respect to Europe, various studies [19,65] have determined the quantitative distribution and accessibility of metropolitan areas by comparing the provision of various types of spaces identified using land cover maps and inhabitants' level of accessibility. The results cannot be easily compared with other studies because of the different UGS criteria applied and the consequent heterogeneity in databases resulting from each UGS selection. For instance, if we compare the results presented here with the results presented by Zepp et al., we see that the MMA has lower accessibility levels than other European metropolitan territories, even when considering smaller UGSs (0.5 ha instead of 1 ha) and expanding the range of inclusion.

This contribution instead yields a qualitative/quantitative accessibility measurement—within 300 m—of UGSs used by the public, expressed with synthetic data and territorial maps. The results are generated from a database that cross-references satellite and thematic data and collects precise, punctual information about each space, whose use (and the frequency of said use) were verified using various databases (such as sport-tracking databases) and our territorial knowledge. The accessibility we present yields the actual accessibility of UGSs.

4.2. Consideration of the MMA Accessibility

When referring to accessibility of green spaces, it is important to highlight that for many years in Italy, the planning of green spaces has followed the parameters established by Italian Ministerial Decree 1444/68, which defined the relevant urban planning standards and set out a minimum of 9 m^2 of green and recreational areas per inhabitant, although it failed to define the type of area. This definition contributed to the development of WHO guidelines on the 9 m^2 per inhabitant as the minimum ratio of green spaces. Although the results presented here comply with the WHO's recommendations and are consequently aligned with the rules established by the Ministerial Decree, the overall ratio for the MMA is significantly lower than the ideal value of 50 m^2, suggesting an urgent need for a change in urban policies pertaining to the design of built space and green space.

Indeed, many residential urban settlements in the MMA have mainly developed formal green areas, designed according to the minimum criteria established in the Decree, and as such do not consider the population's actual needs. Climate change, increasing urbanisation, and health issues have led to a new reflection on the role of open spaces in dense urban contexts, promoting the environmental and recreational benefits of green spaces and allowing more citizens to access green areas, with significant benefits for their physical and mental health.

For instance, in demonstrating the poor accessibility of IGSs, the results presented here suggest improvements in the continuity of connections to various green spaces, such as providing tree-lined roads or developing public country roads that allow access to green open spaces suitable for recreational and sporting activities.

4.3. Relevant Elements and Limitations in Measuring Accessibility

Starting from the state of the art, this contribution demonstrates the complexity and the variety of UGSs, highlighting the importance of studying formal and informal green spaces. With respect to the first research question (RQ1), this study shows that the provision of formal and informal spaces is different in the urban and peri-urban areas of the larger MMA territory. Indeed peri-urban areas have fewer formal spaces, as the undefined, undesigned and less urban spaces provide access to greenery for those living in more agricultural contexts; urban spaces, on the contrary, were found to contain mostly parks and gardens.

With reference to the (RQ2), in order to measure the accessibility, we developed an accurate spatialisation of the UGSs, each defined cartographically and identified by its uses and practices. While the accessibility of formal green spaces is easier to calculate, since such elements are clearly defined and shaped, we remodelled the IGS geometries to consider all the various natural elements as a part of individual features.

Finally, to address RQ3, we stated the degree of accessibility in residential MMAs to provide a result that will be further used to study the sociodemographic characteristics of those areas.

We also identified various elements that, according to this study, are important for defining the accessibility of UGSs in dense metropolitan areas.

Urban environments exhibit considerable heterogeneity in urban and peri-urban landscapes where different situations coexist; in this complex condition, it is necessary to recognise and identify various categories of formal and informal green spaces, which represent the real state of the art of all the green spaces that citizens have access to.

Another aspect to consider is the required accuracy implied to measure accessibility, which must be applied to UGSs' access points and not on the centroid of the area. These operations are necessary to evaluate the travel time, avoiding underestimations [21] and measuring its actual accessibility. Moreover, although it is evident that there is a wide variety of paths that allow access to green space, it is necessary to identify which paths can provide better walkable experiences, such as those that include natural elements that increase environmental comfort in metropolitan areas, which are more vulnerable to climate change. This aspect also relates to the dissemination of this information, which allows people to recognise the importance of green spaces, improve the accessibility of places for pedestrians and enable administrations to increase or develop new projects for spaces and paths that can increase ecological connectivity and improve environmental comfort.

Finally, the relevance of the accessibility measurement is higher if the maps are developed on different scales and various information is gathered on the selected UGS, enabling decision-makers, planners, and politicians to better understand where they should operate.

Although those elements can lead to an accurate accessibility analysis, we must recognise some limitations: as IGSs are mainly defined by the users and the presence of natural and urban quality, such dynamics could vary over time and be influenced by urban policies that affect land use. The identification of such spaces is still challenging because they are connected to extensive knowledge about territorial uses.

Whilst in summer, people may prefer to travel along tree-lined roads that will offer shade from the heat, in winter, people may well opt to walk along roads without vegetation to take advantage of the milder temperatures. As such, it is clear that a single map cannot effectively represent the accessibility of green spaces, as the drivers underlying it can change seasonally or depending on the preferences of the people who access a certain space.

5. Conclusions

This research highlights the importance of addressing the development, management and accessibility of UGSs (and IGSs, in particular) to ensure that all citizens are afforded equal access to them. The indicator we have developed allows us to map and cartographically recognise the parts of the MMA that are underserved, in that they do not have adequate access to green spaces.

However, there is a need for more extensive and detailed research throughout the entire metropolitan area.

If the analysis presented here were developed on the local scale, in particular, it could go into more depth by adding elements that describe users' perception of and preference for certain paths, such as equipment (benches, fountains, etc.) or a sense of safety (lighting, proximity to the urban environment, etc.). We would then expect to look at certain sample areas on a smaller scale—for instance, those where Forestami aims to plant new trees—and consider multiple variables while prioritising remedial measures. These maps could be used as support for urban governmental plans to recognise less-served parts of the territory, where it is necessary to increase the natural capital and improve the accessibility of the existing natural areas through new projects and initiatives.

Use of the accessibility map on a local scale could also encourage reflections on the quality of the different open spaces identified and their perception by different groups of users; in this way, the research could pose the question of how these aspects impact strategies geared towards ensuring environmental justice and social equity [35,66] in terms of both material and non-material benefits [67].

Indeed, the accessibility map we have developed provides an interpretive tool that supports urban and territorial planning to make our cities 'just green enough' [22], decreasing inequalities by allowing all citizens to enjoy existing and future benefits, be they material (better access, improved air quality) or immaterial (wellbeing) [68].

Furthermore, the method implemented here could be applied to other metropolitan cities, thus encouraging further research focused on measuring the qualitative level of accessibility by developing a wider database that identifies similar formal and informal categories and types of UGSs, and considers various types of accessibility, such as that measured using proximity to tree canopy cover.

Given the above considerations, the map aims to support decision-makers, technical experts and politicians, helping to steer policies, projects and funding in the direction of increasing green resources in some of the most fragile situations.

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Notes

[1] Each of the 133 municipalities that comprise the MMA are individually endowed with an urban planning instrument called the Territorial Government Plan. In each plan, each municipality incorporates directions from regional and metropolitan plans, but inserts rules that influence land-use planning at the local scale.

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