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Rethinking the distribution of urban green spaces in Mexico City: Lessons from the COVID-19 outbreak

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ABSTRACT
The COVID-19 pandemic has exposed inequalities that are expected to widen if no action is taken to support the most marginalized populations. One such inequality is the distribution of urban green spaces (UGS), which are essential to pandemic recovery. Cities that aim to be inclusive and resilient should assess whether access to their UGS is equitably distributed among the population and identify the areas where these spaces are most needed. This study therefore examines the equity of access to UGS in Mexico City at the neighborhood level using network analysis. First, access to UGS was identified at a threshold of 300 m, regardless of UGS size. Second, access was differentiated by the functional level of the UGS, which primarily depends on their size, with larger UGS having more extensive catchment areas. The results of this study suggest a deficit of access to small green spaces in most of the neighborhoods of Mexico City, with the neighborhoods with higher rates of poverty showing an even lower average of UGS access. The results further highlight which neighborhoods in Mexico City should receive priority attention and funding for UGS to mitigate the disproportionate effects of public health crises. This is critical for future city planning and may be used as a roadmap for identifying priority neighborhoods in other cities with similar segregation patterns.

1. Introduction

During the global COVID-19 pandemic, quality of life has worsened for people living in densely populated cities, where the risk of contagion is higher (Lehberger et al., 2021; Ugolini et al., 2020). Consequently, urban planners, policymakers, and researchers have sought to determine which measures or policies can help maintain or improve overall health and build resilience amidst the public health crisis (Chwaszcz et al., 2020; Zhang and Ma, 2020). One activity that has had positive effects on residents’ general well-being during the novel coronavirus outbreak is the use of urban green spaces (UGS) (Mayen Huerta and Cafagna; Pouso et al., 2021). Given the restrictions on the use of indoor recreational spaces, UGS became especially important during lockdown periods because they allowed residents to perform physical activities, enjoy natural landscapes, and relax while social distancing, thus making them a highly effective public health tool (Geary et al., 2021; Luo et al., 2021).

Research on UGS and community resilience has shown that these spaces play an essential role in providing comfort to urban residents by serving as safe gathering locations after natural disasters, such as hurricanes and earthquakes (Shimpo et al., 2019). More recently, the growing body of evidence regarding the effect of COVID-19 on health suggests that contact with natural environments has mitigated stress, depression, and anxiety, thereby maintaining, or even increasing individuals’ well-being during the pandemic (Gianfredi et al., 2021; Mayen Huerta and Cafagna, 2021; Ugolini et al., 2021). Contact with nature and frequent use of UGS during lockdown periods have further been linked to improved moods (Luo et al., 2021). However, urban residents often experience unequal UGS access based on their socioeconomic status, race or ethnicity, and age; this contributes to segregation patterns, which can widen existing health inequalities (Wood et al., 2017). Because COVID-19 spreads more quickly in marginalized areas and informal habitats marked by overcrowding and poor hygiene (Corburn et al., 2020), cities that aim to be inclusive and resilient for future pandemics should evaluate whether access to their UGS is equitably distributed and identify the areas where these spaces are most needed.

In Mexico City—a COVID-19 hotspot with over one million cases as of January 2022—the main difficulty in evaluating the equity of UGS access is a lack of information on the distribution of such areas. For
example, several researchers have noted that there is no inventory of the location, surface, or characteristics of the city’s UGS (Checa-Artasu, 2016; Flores-Xolocotzi and González-Guillén, 2010), which limits the development of urban planning policies that would advance more equitable distribution of UGS. Moreover, the city government classifies some paved areas as parks and considers them green spaces, though they lack grass, trees, or vegetation; these areas do not fulfill the restorative functions of UGS, and their classification as UGS contributes to an overestimation of the city’s green space (Curtis et al., 2021; Mayen Huerta and Cafagna, 2021). The lack of information on the geolocation of green areas is a concern in most cities in Latin America, where specific strategies need to be defined at the neighborhood level.

Accordingly, the present research aims to 1) map all UGS in Mexico City; 2) evaluate the city’s distribution of UGS with respect to each neighborhood’s socioeconomic status, differentiating access by UGS size; 3) determine if neighborhoods with UGS access differ in their composition from those without; and 4) identify high-priority neighborhoods, meaning those without access to UGS that also experience overcrowding. The results of this study will reveal which areas and population groups in Mexico City have been most affected by a lack of access to UGS during the COVID-19 pandemic. This information is critical to future urban planning and decision-making.

1.1. Access to UGS

Access to UGS is widely understood as proximity to such public spaces (Koppen et al., 2014; Wolch et al., 2014). The opportunities created by UGS and the ability to enjoy them are restricted by geography (Manaugh and El-Geneidy, 2012). Thus, proximity is a necessary condition for determining which UGS are within reach and how often they are visited, with greater distances often reducing the frequency of use (Peschardt et al., 2012; Shen et al., 2017). During the COVID-19 pandemic, distance to UGS has become one of the main barriers to use, as most urban residents globally experienced mobility restrictions that limit their ability to access distant spaces (Grima et al., 2020).

A burgeoning number of studies on UGS access have found a frequent and significant association between social stratification and the spatial distribution of green spaces in cities that disproportionately affects low-income communities and ethnic minorities (Frey, 2017; Tan and Sam-Sudin, 2017). For example, a study that combined geo-coded household data from the German Socioeconomic Panel with land use data from the European Urban Atlas (Wüstemann et al., 2017) identified substantial disparities in access to UGS in major German cities based on income, education, and age, which, in turn, exacerbated inequalities among health outcomes. Kim and Jin (2018) examined access to UGS through a longitudinal survey conducted in Seoul between 2005 and 2015 and found that high-income residents reported greater access to larger UGS. Another study—a spatial accessibility analysis conducted by Dai (2011) in Atlanta, Georgia—demonstrated that lower-income individuals tended to live in areas with poor access to UGS or were deprived of access altogether. The same study emphasized that green space inequalities predominantly affected Black neighborhoods (Dai, 2011).

Notably, not all studies have found that high-income or non-marginalized groups benefit most from green space access; some have even revealed that highly impoverished areas have greater access to UGS. For example, a network analysis in Texas conducted by Nicholls (2001) concluded that low-income residents had greater access to parks than high-income residents. Similarly, Boone et al. (2009) examined access to UGS in Baltimore through a needs-based assessment and observed that marginalized populations lived closer to green areas. Barbosa et al. (2007) studied access to green spaces along transport networks in Sheffield, England, concluding that low-income neighborhoods had the highest levels of access to UGS. Given these variations in distribution patterns and the distinctive social characteristics of each city, access to UGS must be evaluated on a case-by-case basis. Furthermore, as cities with small UGS and high population density may use biased accessibility metrics, it is crucial to determine access disparities related to UGS size because the environmental, ecological, and social advantages that such spaces provide vary depending on the dimensions of the area in question (Cetin, 2015; Le Texier et al., 2018).

1.2. UGS size: Functional level

UGS are multifunctional by nature (Fluhrer et al., 2021). According to the literature, UGS can supply four types of ecosystem services: 1) provisioning—urban forests can provide food and water; 2) regulating—they moderate air quality, erosion, noise, and climate and can prevent floods; 3) supportive—they facilitate soil formation processes and water and nutrient cycles; and 4) cultural—they provide opportunities for recreation, physical activity, relaxation, and social contact (Nath et al., 2018; Wallace, 2007). Although some academics argue that UGS promote health and well-being regardless of their size (Aselli-Burt et al., 2014; Dravigne et al., 2008), the aforementioned services vary depending on the size of the area, referred to as its functional level (Van Herzele and Wiedemann, 2005). The size of a green area helps to determine its environmental qualities as well as which activities users can perform within it (Le Texier et al., 2018). Moreover, the synergies between UGS benefits increase as UGS size increases (Koppen et al., 2014). Therefore, there is a need for research that explicitly addresses the UGS deficit in cities at different functional levels and provides detailed strategies to cover specific functional level shortages.

Countries including the United Kingdom, the Netherlands, Sweden, the United States, and South Korea have established standards for the provision and distribution of UGS that differentiate catchment areas (also known as coverage areas) for different UGS functional levels (Comber, Brunsdon and Green, 2008; Ferguson et al., 2018). For instance, the U.S. Classification of Parks dictates that people should be able to access a children’s park with an area of 200–400 m² at a maximum walking distance of 400 m from their residence (Gupta et al., 2016). This distance increases to 800 m for neighborhood parks with areas of 2–8 ha (Gupta et al., 2016; Sturm and Cohen, 2014). These standards contrast those suggested by the World Health Organization and England’s Accessible Natural Greenspace Standard (ANGSt), both of which recommend that the nearest hectare of green space should be a maximum walking distance of 300 m from people’s residences (Ergen, 2021; Huang et al., 2017). There is no universal threshold definition for UGS functional levels and their corresponding catchment areas. Nevertheless, most hierarchy guidelines indicate that the catchment area should increase as UGS size increases because people are generally willing to travel farther to access larger parks (Pinto et al., 2021; Shi et al., 2020).

1.3. Study area: Mexico City

The present study focuses on Mexico City—specifically, the urban area of the Federal District, or CDMX, with an area of 60,868 ha (Bravo-Bello et al., 2020). The city is comprised of 16 municipalities and is characterized by acute wealth inequalities, excessive pollution levels, constant flooding, and high population growth rates (Davis, 2010). Similar to many other megacities in the Global South, Mexico City has noticeable segregation and disinvestment patterns; these have raised environmental justice concerns, as the distribution of public services, including UGS, is highly biased against marginalized groups (Brito, Macías et al., 2021; Calderón-Contreras and Quiroz-Rosas, 2017).

Some historians contend that the inequity in Mexico City’s UGS distribution derives from the processes of modernization and privatization in the penultimate decade of the 20th century resulting from neoliberal policies that displaced and alienated marginalized populations from urban spaces and limited their rights (Wakild, 2011). Scholars such as Heynen et al. (2006) have stressed the negative effects of privatizing urban forests, including the gentrification or alienation of low-income communities. The privatization of UGS in Mexico City can...
be largely attributed to the government’s failure to prioritize these spaces in the urban agenda as vehicles of resilience and social well-being (Manuel Navarrete et al., 2019). Historically, the city government has been ineffective in serving marginalized neighborhoods due to its corporate governance approach, with parks in underserved neighborhoods often kept underfunded, overcrowded, and unsafe (Fernández Álvarez, 2012). In the neoliberal context, parks in particular are vulnerable to being lost because they occupy spaces with a potential for profitable development (Acosta García et al., 2020; Walker, 2013). At the neighborhood level, the lack of continuous investment in public services and facilities directly diminishes the possibility of maintaining and creating green spaces, particularly in the city’s poorest neighborhoods (Lee et al., 2022), which is a form of environmental injustice and, during health crises, increases the burden on public health infrastructure. Throughout the 20th century and up to the present, the city’s government has favored gray investments, particularly housing projects (Manuel Navarrete et al., 2019). Because UGS are not considered in the city’s urban development strategies, there is very little information on their distribution and characteristics (Fernández Álvarez, 2012).

Thus far, few urban studies have analyzed UGS distribution in Mexico City with considerations of environmental justice or, more recently, public health crises in which the movement of people is heavily restricted (Moreno-Mata, 2018). The few studies that have been conducted on this topic have examined the availability of UGS as the percentage of green space in a given area rather than accessibility to such areas, yielding results that underestimate the magnitude of the problem given the concentration of green areas in each municipality. For instance, Checa-Artasu (2016) evaluated the availability of green space surfaces in the city and observed that the uneven distribution of UGS in the city has deeply impacted socioeconomically deprived municipalities. Furthermore, Fernández-Alvarez (2017) conducted an availability analysis, illustrating that the southeast municipalities in Mexico City had the lowest UGS availability and the highest poverty levels. Calderón-Contreras and Quiroz-Rosas (2017) examined the total area of green infrastructure in the city using remote sensing techniques and found a significant deficit in the provision of green spaces.

After the coronavirus outbreak, access to UGS became increasingly important in Mexico City as the city government imposed mobility restrictions and opted to close some recreation sites with increased risk of contagion (CDMX Producer, 2020; Mayen Huerta and Utomo, 2021). A recent study conducted by Mayen Huerta and Cafagna (2021) in Mexico City suggests that lack of access to UGS was a key reason for reduced UGS use during the first COVID-19 lockdown (March 2020), with people who lived far away from parks or whose closest green space had closed using such spaces less often. Notably, reduced use of UGS during the pandemic is associated with worse mental health outcomes (Pouso et al., 2021).

An extensive literature review found that no studies have used an access approach to examine UGS distribution in Mexico City or, to the best of our knowledge, in Latin America. Furthermore, no study has specified the sizes of UGS required in specific neighborhoods. The present study will fill the existing research gap regarding access to UGS in Mexico City by mapping all UGS in the city and assessing their pedestrian accessibility through network analyses. Given that there is enough evidence to show that pandemics, such as that of COVID-19, are uncontrollable events that will occur periodically (Rastogi and Singh, 2020), exceptionally detailed studies (such as the one presented here) are of utmost importance to promote urban resilience and preparedness. Replicating this type of study should be a priority in Latin America as it has been deeply affected by COVID and is marked by high income inequality, such that impoverished groups cannot relocate easily and have been unable to travel long distances due to pandemic-related mobility restrictions (Rigolon et al., 2018). Of particular importance, it should be noted that this continent is home to the most urbanized regions in the world (UN-Habitat Producer, 2017).

2. Materials and methods

2.1. Materials

The materials used in this study include the complete inventory of UGS in Mexico City and their corresponding access points, the pedestrian road network of the city, the social lag index, and socioeconomic indicators extracted from the 2020 National Population and Housing Census in Mexico. The present analysis only considers public UGS, as their provision is an essential equity indicator that represents opportunities for contact with nature for people who cannot afford to pay for them (Le Texier et al., 2018). Therefore, cemeteries, abandoned lots, sports grounds (often referred to as deportivos), golf clubs, university gardens, and other green areas that require membership for admission or are subject to specific schedules or activities are not considered UGS in this study.

The UGS polygons and the locations of their access points (where people can physically enter UGS) were generated using a DEM derived from satellite sensing data about ground cover. Through the Green View Index based on Google Street View panoramic images and Google Earth imagery. Google Street View and Google Earth images have been widely used to analyze access to UGS in different cities (Comber et al., 2008; You, 2016; Zhang et al., 2021; Zhang and Zhou, 2018). The presence of vegetation was required for the spaces to be categorized as UGS (Ergen, 2021; Rigolon et al., 2018); thus, open spaces that are called parks but lack vegetation were omitted. Access points were assumed to be located around the perimeter of UGS because most of these spaces can be entered from all directions. This decision also accounted for the perceived visual benefits of the greenery, as there is a growing body of evidence that viewing greenery (an indirect UGS use) can be beneficial to people’s well-being (Triguero-Mas et al., 2015; Zhang et al., 2021).

The road network used to measure pedestrian access to UGS was obtained from BBBike Open Street Maps as a shapefile and later converted to a network format (BBBike Producer, 2019). When taking an equity approach to measuring UGS accessibility, accessible UGS should be defined as those within walking distance so all groups can benefit from them, and so physical barriers are not an issue (Dai, 2011). Furthermore, due to the mobility restrictions implemented during the pandemic, measuring pedestrian accessibility is necessary to estimate whether UGS could be used as a resilience mechanism. Thus, pedestrian accessibility was the only type of accessibility considered in this evaluation.

The social lag index developed by the National Council for Evaluation in Mexico (CONEVAL) was used to classify each neighborhood based on the percentage of its population below the poverty line. This index was created to address the multidimensional nature of poverty; it therefore includes indicators of access to health services and education, assets at home, and the quality and size of the residence. It has five classifications, each of which refers to a certain percentage range of the population living in poverty: Group 1 = [0–18], Group 2 = (18–34], Group 3 = (34–50], Group 4 = (50–70], and Group 5 = (70–100] (CONEVAL Producer, 2019). Table 1 shows the distribution of neighborhoods per municipality according to their rate of poverty. Notably, Group 1 includes nearly 72% of all the city neighborhoods (Group 2: 2.3%; Group 3: 19.4%; Group 4: 0.5%; and Group 5: 6%).

The index information is presented at the urban block level, or AGEB (Basic Geostatistical Area), which is used in this study as a proxy for neighborhoods (see Fig. 1). An AGEB is defined as a physical space bordered by streets, avenues, walkways, or other easily identifiable features in the

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2 Round and square brackets have been used to make the categorization exclusive. The use of square brackets means that the end number is included, and round parentheses indicate it is excluded.
territory with a population of approximately 2500 (INEGI Producer, 2013). Of the 2349 AGEBs located in the 16 municipalities of Mexico City, 2310 were given a poverty level classification and were included in this analysis (see Fig. 1). The 39 AGEBs with no classification either do not contain households or contain so few households that they would be identifiable based on their location. Hence, they were not included.

Using urban blocks as a proxy for neighborhoods has been a common technique in previous access analyses because it provides a higher level of granularity in the results than the use of larger geographical units, such as municipalities (McKenzie, 2014; Talen and Anselin, 2016).

The data extracted from the National Population and Housing Census in Mexico from 2020 included nine indicators at the urban block level: 1) average number of people per room, 2) average years of schooling, 3) percentage of older adults (60+), 4) percentage of Afro-descendants, 5) percentage of indigenous people, 6) percentage of people with disabilities, 7) percentage of people who do not receive social security, 8) percentage of female-headed households, and 9) overcrowding (INEGI, 2021). The definition used for overcrowding is the one established by the U.S. Department of Housing and Urban Development, namely more than one person sharing a room per house (von Seidlein et al., 2021).

Table 1

| Municipality       | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Total |
|--------------------|---------|---------|---------|---------|---------|-------|
|                    | n       | %       | n       | %       | n       | %     | n     | %     |
| Alvaro Obregón     | 146     | 73.7%   | 0       | 0%      | 44      | 22.2% | 0     | 0%    | 198   | 8.6%  |
| Azcapotzalco       | 62      | 60.2%   | 36      | 35.0%   | 5       | 4.9%  | 0     | 0%    | 103   | 4.5%  |
| Benito Juárez      | 102     | 100.0%  | 0       | 0%      | 0       | 0%    | 0     | 0%    | 102   | 4.4%  |
| Coyocán            | 128     | 82.6%   | 16      | 10.3%   | 10      | 6.5%  | 0     | 0%    | 155   | 6.7%  |
| Cuauhtémoc         | 19      | 67.9%   | 0       | 0%      | 7       | 25.0% | 0     | 0%    | 28    | 1.2%  |
| Coyoacán           | 140     | 92.1%   | 0       | 0%      | 11      | 7.2%  | 0     | 0%    | 152   | 6.6%  |
| G. A. Madero       | 218     | 72.9%   | 0       | 0%      | 64      | 21.4% | 1     | 0.3%  | 299   | 12.9% |
| Iztacalco          | 106     | 98.1%   | 0       | 0%      | 2       | 1.9%  | 0     | 0%    | 108   | 4.7%  |
| Iztapalapa         | 243     | 53.5%   | 0       | 0%      | 159     | 35.0% | 4     | 0.9%  | 454   | 19.7% |
| M. Conteras        | 36      | 69.2%   | 0       | 0%      | 14      | 26.9% | 1     | 1.9%  | 52    | 2.3%  |
| Miguel Hidalgo     | 117     | 100.0%  | 0       | 0%      | 0       | 0%    | 0     | 0%    | 117   | 5.1%  |
| Tláhuac             | 37      | 40.7%   | 0       | 0%      | 43      | 47.3% | 1     | 1.1%  | 91    | 3.9%  |
| Tlalpan             | 133     | 74.7%   | 0       | 0%      | 30      | 16.9% | 1     | 0.6%  | 14    | 7.9%  |
| V. Carranza        | 127     | 87.0%   | 0       | 0%      | 18      | 12.3% | 0     | 0%    | 146   | 6.3%  |
| Milpa Alta         | 0       | 0.0%    | 0       | 0%      | 3       | 50.0% | 0     | 0%    | 3     | 0.3%  |
| Xochimilco         | 46      | 38.0%   | 0       | 0%      | 38      | 31.4% | 4     | 3.3%  | 33    | 27.3% |
| Total              | 1660    | 71.9%   | 52      | 2.25%   | 448     | 19.4% | 12    | 0.5%  | 2310  | 100%  |

Fig. 1. Map 1 (left) shows the municipalities in Mexico City; Map 2 (right) shows the neighborhoods (AGEBs) classified by the rate of poverty in Mexico City according to the 2015 social lag index from the National Council of Evaluation (CONEVAL Producer, 2019).
2.2. Methods

2.2.1. Network analysis: Access to UGS within 300 m

A network analysis was conducted in ArcGIS Pro to analyze UGS access within 300 m. This analysis included all UGS identified in Mexico City, regardless of size. Several academics have argued that even very small UGS provide benefits and are needed to promote a population’s well-being (Astell-Burt and Feng, 2019; Fan et al., 2017). This first analysis adopts an accessibility threshold of 300 m, which was the distance employed by Zhou and Kim (2013) in their study of access to parks in Illinois as well as Schipperijn et al. (2010) in their study of access to UGS in Denmark. The Nordic Council of Ministries has also recommended this metric as a maximum distance from one’s home to the nearest green space (Neuvonen et al., 2007), as has the World Health Organization (Ergen, 2021).

Further evidence shows that people’s willingness to walk decreases for distances greater than 300 m (Grahm and Stigsdotter, 2003; Moseley et al., 2013; Nielsen and Hansen, 2007). Moreover, people with restricted mobility, elders, and children—and, more recently, people under pandemic lockdown restrictions—are limited in terms of how far they can walk to UGS (Hornsten and Fredman, 2000; Koppen et al., 2014). These factors further support the decision to use a distance of 300 m from UGS access points along the pedestrian road network as a threshold for this study.

Network analysis was selected as the most appropriate tool for this due to its proven ability to accurately estimate actual walking distances. It considers travel routes instead of Euclidean distances, which are used in overly simplistic buffer analyses and tend to underestimate travel time (Gupta et al., 2016; Koppen et al., 2014; Miyake et al., 2010; Moseley et al., 2013). Once this analysis revealed the service areas for each green space, AGEBs with more than 50% of their area within a service area were given a classification of 1, meaning that people living in that neighborhood had access to UGS within 300 m. Because AGEBs are relatively small, this assumption was determined to be reasonable even for urban blocks that are not completely contained within a service area. The rest of the AGEBs were classified as 0, meaning they had no access to UGS within 300 m. Talen (2013) used a similar approach when assessing equity in a study of access to parks in Colorado and Georgia.

A chi-squared test was then conducted to determine whether there was an association between the rate of poverty and UGS access classification among the AGEBs. To evaluate whether neighborhoods with access are significantly different from those without, Mann-Whitney U tests were also applied to test differences in neighborhood composition. The null hypothesis was that there were no significant differences in the composition of neighborhoods with access to UGS and those without.

2.2.2. Network analysis: Access to UGS according to their functional level

For the second layer of the analysis, access was differentiated according to UGS functional levels, with larger UGS having more extensive service areas. Van Herzele and Wiedemann (2003), among other academics, have advocated for the consideration of different UGS functional levels when analyzing access to UGS, as each level provides distinct benefits (Schipperijn et al., 2010). Three of the four functional levels (children’s, district, and city parks) used in this study were defined following the Accessible Natural Green Space Standards (ANGSt), which is the United Kingdom’s benchmark for green space provision (Ergen, 2021). A fourth scale, the neighborhood park, was introduced following the Classification of Parks in America and Nicholls’ (2001) study of access to parks in Bryan, Texas. The introduction of various functional levels was fundamental to achieving a more accurate representation of which types of UGS are needed in different neighborhoods of Mexico City. (Table 2).

The distances to children’s, neighborhood, and city parks are considered within easy reach when within 5, 10, and 20 min of walking at a moderate pace, respectively. Mexico City’s government advocates for walking and biking as healthy and environmentally friendly modes of travel due to increasing pollution in the city (SEDEMA Producer, 2019), which makes these three catchment areas especially important for the analysis. The walking access metrics of this analysis align with an expert survey carried out by Fan et al. (2017) to evaluate UGS access in Shanghai’s periphery. The majority of urban planning experts surveyed agreed that public transportation should not be considered when measuring access to children’s, neighborhood, and district parks. The distance to the fourth functional level—city parks—corresponds to 5 km, equivalent to a 45- to 60-minute walk. This level was included in the analysis because large UGS improve air quality, which has a clear relationship with public health and is of extreme importance in a city with such high levels of pollution (Kingsley and EcoHealth Ontario, 2019).

Once the service areas for each functional level were identified, AGEBs with at least 50% of their area overlapping with the catchment areas were labeled as 1, and the rest of the AGEBs were labeled as 0. Chi-squared tests were then conducted to examine the interdependence between access to UGS and neighborhood poverty levels at the four functional levels. Similar to the initial analysis of access to UGS within 300 m, Mann-Whitney U tests were used to assess the differences between neighborhoods with access to UGS at the four functional levels and those without access. The null hypothesis was that there were no significant differences between the composition of neighborhoods with access to UGS and those without at each functional level.

2.2.3. Defining high-priority areas

To determine high-priority areas, overcrowding in neighborhoods was included as a dummy variable (one or more people per room = 1, less than one person per room = 0). Next, the areas with no walking access that also experienced overcrowding were identified and highlighted. The European Environmental Agency and the World Resources Institute in Mexico have indicated that the standard maximum distance that people are willing to walk to reach a UGS is 15–20 min at a moderate pace, which equates to approximately 2 km (Brito et al., 2021; Francis et al., 2012; Stessens, Khan, et al., 2017). Therefore, service areas were computed from UGS access points up to 2 km along the pedestrian road network.

The neighborhoods identified in this part of the analysis were marked as areas of particular concern because a lack of contact with green environments during lockdown periods, particularly in areas that experience overcrowding, can lead to increased emotional distress, anxiety, and depression (Gianfredi et al., 2021). Hence, identifying areas that experience both overcrowding and lack of UGS access is vital to improving the social well-being of the city.

3. Results

3.1. Results: Access to UGS within 300 m

In total, 4702 UGS were identified and plotted inside the 16 municipalities of Mexico City. There were 4444 areas that aligned with the surface characteristics of a children’s park, 149 neighborhood parks, 89 city parks, and 54 district parks. In Fig. 2, neighborhoods (AGEBs) with and without access to UGS within 300 m are shown in dark blue and light blue, respectively. The map shows that many neighborhoods with access to UGS within 300 m are in the city’s northwest area, a predominantly mid- to high-income area. Only 4 out of 16 municipalities in Mexico City had more than 50% of their neighborhoods labeled as having access to
UGS within 300 m (see Table 3). These municipalities were Benito Juárez (69%), Cuauhtémoc and Miguel Hidalgo (60% each), and Álvaro Obregón (59%).

Remarkably, 72% (n = 1162) of the neighborhoods in Mexico City do not have access to UGS of any size within 300 m. None of the neighborhoods in Milpa Alta—the most marginalized municipality in Mexico City—have access to UGS within 300 m.

Table 3
Proportion of neighborhoods (AGEBs) per municipality with access to UGS within 300 m by poverty level group in Mexico City.

| Municipality             | Group 1 [0–18] | Group 2 (18–34) | Group 3 (34–50) | Group 4 (50–70) | Group 5 (70–100) | Total  |
|--------------------------|----------------|-----------------|-----------------|-----------------|-----------------|-------|
| Álvaro Obregón           | 44.44%         | 0.00%           | 12.12%          | 0%              | 2.02%           | 58.59%|
| Azcapotzalco             | 14.56%         | 7.77%           | 0%              | 0%              | 0%              | 22.33%|
| Benito Juárez            | 69%            | 0%              | 0%              | 0%              | 0%              | 68.63%|
| Coyocacán                | 31.61%         | 3.23%           | 1.94%           | 0%              | 0%              | 37.42%|
| Cuajimalpa               | 14.29%         | 0%              | 7.14%           | 0%              | 0%              | 21.43%|
| Cuauhtémoc               | 55.26%         | 0%              | 4.61%           | 0%              | 0%              | 59.87%|
| Gustavo A. Madero        | 10.37%         | 0%              | 2.01%           | 0%              | 0.67%           | 13.04%|
| Iztacalco                | 29.63%         | 0%              | 0%              | 0%              | 0%              | 29.63%|
| Iztapalapa               | 8.59%          | 0%              | 1.54%           | 0.22%           | 0.22%           | 10.57%|
| Magdalena Contreras      | 1.92%          | 0%              | 5.77%           | 1.92%           | 0%              | 9.62% |
| Miguel Hidalgo           | 59.83%         | 0%              | 0%              | 0%              | 0%              | 59.83%|
| Tláhuac                   | 5.49%          | 0%              | 2.20%           | 0%              | 0%              | 7.69% |
| Tlapac                   | 23.60%         | 0%              | 1.12%           | 0%              | 0.56%           | 25.28%|
| Venustiano Carranza      | 20.55%         | 0%              | 1.37%           | 0%              | 0%              | 21.92%|
| Milpa Alta               | 0%             | 0%              | 0%              | 0%              | 0%              | 0%    |
| Xochimilco               | 4.13%          | 0%              | 0%              | 0%              | 0.83%           | 4.96% |
| Total                    | 24.46%         | 0.56%           | 2.51%           | 0.09%           | 0.43%           | 28.05%|
the city—were identified as having access to UGS within 300 m. Furthermore, the poverty level Groups 2–5 have very few neighborhoods with access to UGS within 300 m.

To analyze the relationship between a neighborhood’s poverty rate and its residents’ access to UGS, the two variables were cross-tabulated, and a Pearson’s chi-squared test was performed. Fisher’s exact test was also included in the analysis due to the limited number of observations in Group 4 (n = 12). The results of the chi-squared test χ²(4, N = 2310) = 110.71, p < 0.001 indicate that there is a strong significant relationship between having access to UGS within 300 m and a neighborhood’s poverty level group, with the standardized chi-squared residuals indicating that Groups 3, 4, and 5 have a significantly lower proportion of access. Moreover, the results of Fisher’s exact test (p < 0.001) are also statistically significant, which confirms that a neighborhood’s access to UGS in Mexico City is not independent of its rate of poverty.

In addition to the test of independence, the results of the Mann-Whitney U tests suggest that there is a significant difference in neighborhood composition between neighborhoods that have access to UGS within 300 m and those that do not (see Table 4), with all variables being strongly significant except for the percentage of Afro-descendants, which has only moderate significance. Surprisingly, a significantly higher percentage of female-headed households have access to UGS within 300 m, which is not the case in the results of similar studies (Coppel and Wiistemann, 2017).

### 3.2. Results: Access to UGS according to functional levels

**Table 4**

Comparison of neighborhoods (AGEBs) with access to UGS within 300 m and neighborhoods (AGEBs) with no access to UGS within 300 m.

| Access within 300 m | No access within 300 m | Mann-Whitney U test |
|---------------------|------------------------|---------------------|
| Mean                | SD                     | Median              | Mean                | SD                     | Median              | Z       | p-value   |
| Average people per room | 0.711  | 0.193             | 0.660             | 0.842    | 0.190             | 0.850             | 14.809  | 0.000     |
| Average years of schooling | 12.705 | 1.802             | 13.060            | 11.401   | 1.624             | 11.130            | -15.344 | 0.000     |
| Percentage of older adults | 20.07% | 5.79%             | 19.52%            | 16.80%   | 5.54%             | 16.14%            | -11.918 | 0.000     |
| Percentage of Afro-descendants | 2.14%  | 2.20%             | 1.61%             | 2.07%    | 2.54%             | 1.46%             | -2.17   | 0.030     |
| Percentage of indigenous people | 2.13%  | 2.80%             | 1.45%             | 3.13%    | 3.76%             | 2.15%             | 10.355  | 0.000     |
| Percentage of people with disabilities | 5.12%  | 1.87%             | 5.05%             | 5.51%    | 1.80%             | 5.45%             | 4.936   | 0.000     |
| Percentage of people without health insurance | 24.00% | 6.52%             | 23.78%            | 27.56%   | 7.11%             | 27.16%            | 11.795  | 0.000     |
| Percentage of female-headed households | 41.35% | 5.51%             | 41.75%            | 39.72%   | 5.72%             | 39.89%            | -7.101  | 0.000     |

**Average years of schooling** 12.705, 1.802; **Mann-Whitney U test** Z = 14.809, p < 0.001; **city χ²(4, N = 2310) = 162.79, p < 0.001; and district parks χ²(4, N = 2310) = 142.70, p < 0.001. The Fisher’s exact tests were also significant in all four cases (p < 0.001), suggesting a strong significant relationship between access to UGS at the four functional levels and the poverty rate of the neighborhood. The distribution of the nine socioeconomic variables for access versus no access included in the Mann-Whitney U tests shows that there is a significant difference between the two groups of access at a significance level of p = 0.05, except for the percentage of people with disabilities in the district park functional level (see Table 6).

**3.3. Results: High-priority areas**

Fig. 4 depicts the neighborhoods with no access to UGS at any functional level, neighborhoods with no walking access to UGS, and high-priority neighborhoods (no walking access in addition to overcrowding). The three maps highlight similar areas of the city, most of them located in clusters in the south, east, and upper north periphery. Notably, 12.6% of neighborhoods (n = 291) do not have access to UGS within walking distance. This proportion is significantly higher for neighborhoods belonging to Group 3 (7%), Group 5 (66%), and Group 4 (50%) compared with those in Group 1 (7%) and Group 2 (4%).

Seven of the 16 municipalities—Alvaro Obregón (2%), Gustavo A. Madero (6%), Iztapalapa (7%), M. Contreras (13.5%), Tláhuac (4%), Tlalpan (4.5%), and Xochimilco (29.8%)—are home to neighborhoods classified as overcrowded that have no walking access to UGS, representing 4.7% (n = 108) of all neighborhoods in Mexico City. Particular attention should be placed on Xochimilco, which includes 36 overcrowded neighborhoods with no walking UGS access, and Iztapalapa, which includes 31.

### 4. Discussion

The UGS in Mexico City are evidently insufficient and unequally distributed, representing an important socio-environmental problem. This study aims to raise awareness about the magnitude of the lack of UGS access in the city. The research was motivated by previous efforts to analyze UGS distribution in Mexico City, enabling better urban planning decisions when facing public health emergencies such as pandemics. Compared to its predecessors, which explored UGS availability in diverse municipalities across the city, the main strength of the present study is its more fine-grained examination of UGS accessibility at the urban block level. This allowed for identifying the neighborhoods (AGEBs) that could benefit from UGS access at different functional levels within each municipality, showcased by the maps in Fig. 3.

Although identifying priority areas with a high level of granularity is a first step for the design of resilience-focused urban infrastructure in megacities (Talen, 2013), possible barriers to the implementation and enjoyment of these spaces must be considered moving forward. First, UGS must be prioritized in the urban development agenda of the city so resources can be allocated at the municipal level for the maintenance and creation of these spaces. Otherwise, the development of gray spaces over green ones will continue to be favored (Manuel Navarrete et al., 2020).
Moreover, the informal growth of cities in the Global South and the poor state of public infrastructure—such as sewage and water systems and roads—remain critical barriers to developing services such as UGS that promote social well-being (Fluhrer et al., 2021). Thus, detailed information on street characteristics is also needed to guide the creation of new UGS and complement the present study to expand environmental justice in the city (Bravo-Bello et al., 2020).

Concerning the mobility restrictions associated with COVID-19 regulations, analysis of walking access to UGS along with overcrowding conditions at an urban block level can lead to a better understanding of the gravity of spatial inequalities in the city during an epidemic. Recent evidence from Mexico City has demonstrated that during the first pandemic-induced lockdown, people were less willing to travel long distances or use public transportation to reach UGS (Mayen Huerta and Cafagna, 2021). For marginalized communities, members of which typically lack private green space ownership and have limited mobility and access to fewer sources of recreation, the unavailability of nearby UGS amplifies disparities in health and well-being (Boone et al., 2009; Wolch et al., 2013).

Similar to evidence from England and the United States showing that the pandemic has deeply affected low-income groups living in densely populated areas (Larson et al., 2021; Pan et al., 2021), the results of the present analysis suggest that inequities in access to UGS in Mexico City are linked to a neighborhood’s socioeconomic status, with low-income neighborhoods on the periphery of the city being the most affected by the lack of access. This finding raises concerns about environmental

Fig. 3. Neighborhoods’ (AGEBs’) access to children’s (400 m), neighborhood (800 m), city (2 km), and district (5 km) parks in Mexico City.
justice in the city. It is also clear that there are significant differences in the composition of neighborhoods that have access to UGS within 300 m at all four functional levels and those that do not. On average, neighborhoods with access to UGS also have less overcrowding, more years of schooling per household, a higher proportion of elder adults and people receiving social security, a lower proportion of indigenous people and people with disabilities, and a higher percentage of female-headed households. In contrast, the peripheral neighborhoods consist mainly of recent rural-urban migrant youth living on minimum wage, with a high proportion of children and a dense population (Fernández Álvarez, 2012).

In the context of megacities with acute patterns of segregation, such

Table 5

| Municipality         | Access to Children’s Parks | Access to Neighborhood Parks | Access to City Parks | Access to District Parks | Access to at least one functional level |
|----------------------|----------------------------|------------------------------|----------------------|--------------------------|----------------------------------------|
| Álvaro Obregón       | 51.01% 70.20%              | 92.93% 95.45%                | 97.98%               |
| Azcapotzalco         | 31.07% 62.14%              | 75.73% 93.20%                | 97.09%               |
| Benito Juárez        | 82.35% 99.02%              | 81.37% 100%                  | 100%                 |
| Coyocacán            | 40.63% 74.84%              | 91.61% 99.35%                | 100%                 |
| Cuahtemoc            | 7.14% 17.86%               | 50% 96.43%                   | 96.43%               |
| Gustavo A.           | 64.47% 94.08%              | 93.42% 98.68%                | 99.34%               |
| Madero               | 11.04% 32.44%              | 21.07% 97.99%                | 97.99%               |
| Iztacalco            | 37.04% 59.26%              | 44.44% 94.44%                | 95.37%               |
| Iztapalapa           | 11.89% 25.99%              | 36.34% 73.79%                | 92.07%               |
| M. Contreras         | 0% 0%                      | 71.15% 51.92%                | 88.46%               |
| Miguel Hidalgo       | 65.81% 92.31%              | 75.73% 93.20%                | 97.09%               |
| Tlalnepant            | 5.49% 44.38%               | 66.85% 97.19%                | 97.75%               |
| V. Carranza          | 33.56% 76.03%              | 64.38% 89.04%                | 98.63%               |
| Milpa Alta           | 0% 50%                     | 0% 0%                        | 50%                  |
| Xochimilco           | 4.96% 12.40%               | 32.23% 56.20%                | 65.29%               |
| Total                | 29.44% 51.60%              | 58.05% 88.92%                | 95.11%               |

Table 6

| Access No access | Mann-Whitney U test | p-value |
|------------------|---------------------|---------|
| Poverty concentration level | 1.20 1 | 1.86 1 | 12.42 0.000 |
| Average people per room | 0.70 0.66 | 0.85 0.86 | 17.05 0.000 |
| Average years of schooling | 12.80 13.09 | 11.33 11.06 | – 17.72 0.000 |
| Percentage of older adults | 20.51% 20.07% | 16.54% 15.86% | – 14.97 0.000 |
| Percentage of Afro-descendants | 2.20% 1.67% | 2.04% 1.43% | – 3.91 0.000 |
| Percentage of indigenous people | 2.03% 1.45% | 3.19% 2.19% | 11.47 0.000 |
| Percentage of people with disabilities | 5.14% 5.06% | 5.51% 5.44% | 4.64 0.000 |
| Percentage of people without health insurance | 24.09% 23.90% | 27.59% 27.28% | 11.92 0.000 |
| Percentage of female-headed households | 41.78% 42.32% | 39.48% 39.52% | – 10.46 0.000 |
| Poverty concentration level | 1.28 1 | 2.07 1 | 16.24 0.000 |
| Average people per room | 0.73 0.72 | 0.88 0.89 | 18.78 0.000 |
| Average years of schooling | 12.47 12.37 | 11.01 10.77 | – 20.21 0.000 |
| Percentage of older adults | 19.84% 19.38% | 15.44% 14.89% | – 18.65 0.000 |
| Percentage of Afro-descendants | 2.26% 1.68% | 1.90% 1.32% | – 6.15 0.000 |
| Percentage of indigenous people | 2.14% 1.49% | 3.60% 2.63% | 15.58 0.000 |
| Percentage of people with disabilities | 5.32% 5.21% | 5.48% 5.43% | 2.32 0.021 |
| Percentage of people without health insurance | 24.87% 24.41% | 28.36% 28.06% | 13.28 0.000 |
| Percentage of female-headed households | 41.54% 41.84% | 38.69% 38.50% | – 13.65 0.000 |
| Poverty concentration level | 1.41 1 | 2.01 1 | 11.72 0.000 |
| Average people per room | 0.75 0.75 | 0.88 0.88 | 15.88 0.000 |
| Average years of schooling | 12.26 12.06 | 11.08 10.93 | – 15.27 0.000 |
| Percentage of older adults | 18.93% 18.30% | 16.02% 15.33% | – 11.83 0.000 |
| Percentage of Afro-descendants | 2.19% 1.63% | 1.94% 1.37% | – 4.27 0.000 |
| Percentage of indigenous people | 2.32% 1.64% | 3.59% 2.43% | 11.65 0.000 |
| Percentage of people with disabilities | 5.21% 5.13% | 5.66% 5.58% | 6.50 0.000 |
| Percentage of people without health insurance | 25.04% 24.65% | 28.66% 28.22% | 13.32 0.000 |
| Percentage of female-headed households | 41.21% 41.56% | 38.70% 38.69% | – 11.52 0.000 |
| Poverty concentration level | 1.57 1 | 2.46 3 | 11.46 0.000 |
| Average people per room | 0.79 0.79 | 0.97 0.95 | 13.75 0.000 |
| Average years of schooling | 11.95 11.65 | 10.29 10.19 | – 15.18 0.000 |
| Percentage of older adults | 13.15% 13.24% | 18.27% 17.76% | – 13.82 0.000 |
| Percentage of Afro-descendants | 2.08% 1.54% | 2.18% 1.29% | – 2.58 0.010 |
| Percentage of indigenous people | 2.65% 1.81% | 4.50% 3.41% | 10.07 0.000 |
| Percentage of people with disabilities | 5.38% 5.32% | 5.51% 5.32% | 0.44 0.658 |
| Percentage of people without health insurance | 25.89% 25.63% | 31.98% 31.97% | 12.77 0.000 |
| Percentage of female-headed households | 40.36% 40.59% | 38.55% 38.01% | – 5.36 0.000 |
as Mexico City, equitable UGS distribution is even more critical for improving public health due to the connection between UGS access and use and well-being (Dai, 2011; Shen et al., 2017). For example, the results of Ayala-Azcárraga et al. (2019) recent survey of users of nine urban parks in Mexico City suggested that access to UGS is a strong predictor of the use of parks and self-reported well-being. These results are similar to those of a cross-sectional study that analyzed the association between UGS use and subjective well-being in Mexico City, which also suggested a positive association between frequent use and subjective well-being during the pandemic (Mayen Huerta and Utomo, 2021).

Given the psychological distress that lockdown measures can cause, mostly in crowded homes, early evidence has indicated that neighborhoods with access to open spaces or natural environments report better well-being outcomes than those without access (Akbari et al., 2021). Further, the closure of small UGS might amplify the adverse effects of the lockdown among lower-income groups by reducing or eliminating their options for exercising or relaxing outdoors (Mayen Huerta and Cafagna, 2021). For instance, experts have concluded that throughout Europe, the closure of UGS during the COVID-19 pandemic mainly affected low-income residents due to their lack of private green space ownership and cramped quarters, amplifying their mental health struggles (Geary et al., 2021). Considering that most neighborhoods in Mexico City lack access to children’s parks and nearly half lack access to neighborhood parks, the closing of smaller recreational areas critically restricts access to green spaces, predominantly affecting people with limited mobility (Lehberger et al., 2021). Moreover, individuals might feel inclined to travel longer distances to access their closest UGS, increasing the potential risk of contagion (Upolini et al., 2021).

Access to UGS can simultaneously reduce environmental impacts and help cities adapt to environmental variability (Manuel Navarrete et al., 2019). However, as mentioned earlier, access to UGS alone is not enough for users to benefit from them. The state of public infrastructure surrounding UGS is critically relevant to the use and enjoyment of these spaces; a recent study carried out in 11 Latin American cities, including Mexico City, concluded that access to UGS is associated with more social disorder in informal neighborhoods that lack adequate street infrastructure or are perceived as unsafe (Moran et al., 2022). Therefore, while introducing UGS alone in neighborhoods belonging to Groups 4 and 5 might be conducive to better well-being outcomes, additional infrastructure modifications are needed in neighborhoods belonging to Groups 1, 2, and 3 to improve their residents’ quality of life. In particular, given that the neighborhoods identified as high priority are more marginalized, it is of utmost importance to not only introduce UGS in these areas but also to implement multisectoral neighborhood improvement plans targeting road improvements, water availability, safety measures, and measures for efficient garbage collection (Fluhrer et al., 2021). In turn, community participation strategies in the planning and design of green areas are crucial to increasing the accessibility of these spaces and making them less vulnerable to gentrification processes (Lee et al., 2022). Otherwise, the benefits of the green area might not be perceived by the population of these neighborhoods.

Despite its advantage over availability studies, the current project assessed only one dimension of access to UGS. Although proximity—the spatial dimension of access—is the primary predictor of use (Schipperijn et al., 2010; Wolch et al., 2013), it is important to highlight social accessibility (e.g., social restrictions, perceptions, and customs) as another determinant of UGS use (Talen and Anselin, 2016). It is also essential to evaluate UGS quality, which is connected to people’s willingness to use such spaces (Mayen Huerta and Utomo, 2021; Moran et al., 2022; Van Herzele and Wiedemann, 2003; Wolch et al., 2014). To maximize UGS use and improve environmental equity, further research that incorporates social and quality considerations is needed to advance comprehensive urban planning policies to produce a just, resilient, and healthy city. Furthermore, because the surrounding infrastructure affects UGS usage patterns, it is also necessary to prioritize infrastructure improvements in marginalized neighborhoods to address intra-urban inequalities in megacities.

5. Conclusions

This study contributes to an in-depth understanding of spatial inequalities in Mexico City and how UGS service gaps can be filled by highlighting neighborhoods that are particularly vulnerable during pandemic situations. The findings in this study should be of broad interest to urban planners and policymakers seeking to improve resilience and environmental justice in cities worldwide. Although this study is specific to Mexico City and its findings cannot be extended universally, its methodology may serve as a roadmap for evaluating the deficit of UGS at specific functional levels in other megacities in the Global South, which suffer similar patterns of segregation and inequity and have been deeply affected by the COVID-19 pandemic.

As documented throughout this article, the lack of access to UGS in marginalized neighborhoods of Mexico City during the novel coronavirus pandemic has exposed health inequalities that likely exacerbated the effects of the pandemic, shining a spotlight on the resilience strategies embraced by the city. The results suggest that people living in neighborhoods with high poverty rates—which are also the areas in which people are most likely to live in overcrowded homes—were
disproportionately affected by a lack of walkable access to UGS. Furthermore, neighborhoods without access to UGS are those that have, on average, fewer years of schooling and female-headed households as well as higher percentages of people without health insurance, people with disabilities, and indigenous people.

The study results draw attention to the lack of accessibility to UGS in Mexico City, which is more severe than expected and should be prioritized in the city’s urban development agenda, as 72% of the neighborhoods are without access to UGS of any size within 300 m. The results further indicate that access to smaller UGS is severely restricted in Mexico City: only 29% of neighborhoods have access to a children’s park and only 52% are located within 800 m of a neighborhood park. Although new children and neighborhood parks could yield positive results in the short term for neighborhoods with low poverty rates, the creation of new UGS in marginalized neighborhoods must be accompanied by multisectoral policies for neighborhood improvement. Otherwise, the effects of having a park nearby might not be perceived.

Policies and urban planning strategies are needed to support the well-being of individuals and society and counteract the prolonged negative side effects of COVID-19, such as increased levels of stress and anxiety. From now on, the concept of urban resilience must include considerations of well-being and quality of life in emergencies as well as how certain spaces present opportunities to positively affect health, such as UGS. This study may help urban planners better plan for future public health crises. Finally, future research seeking to improve environmental equity and resilience in Mexico City should expand on this study’s findings by integrating them with social and infrastructural limitations and UGS quality measures.

CRediT authorship contribution statement

Carolina Mayen Huerta: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing.

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