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Identifying pharmacy gaps: a spatiotemporal study of multimodal accessibility throughout the day

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Abstract

Background Accessibility to community pharmacies is crucial for ensuring timely access to medications and essential health services. While accessibility to community pharmacies is critical, disparities driven by temporal and spatial factors persist, resulting in inequities in healthcare access. This study aims to comprehensively assess spatiotemporal and multimodal accessibility to community pharmacies in Lisbon, highlighting the influence of transport modes and time of day on accessibility disparities.

Data and methods The study employed a methodology that considered five daily time slots and two modes of transport—walking and public transport—to evaluate accessibility to community pharmacies. Data was sourced from road and pedestrian networks, Google API, and GTFS data. Descriptive statistics and spatial analysis were utilized to assess travel time and accessibility disparities across different regions of Lisbon. The analysis focused on both the percentage of residents able to access pharmacies within 10 min and the total number of pharmacies accessible.

Results ndings reveal significant temporal variations in accessibility, with public transport consistently improving access compared to walking. Accessibility peaks in the evening (6–7 PM), when 83.3% of residential buildings are within a 10-min walking distance of a pharmacy, and 92.7% are reachable by public transport. In contrast, early morning hours (4–5 AM) show the lowest accessibility, with only 8.9% of buildings accessible by walking and 16.1% by public transport. During the daytime (8–9 AM), notable disparities emerge across the city: public transport enhances access in the southwest, northwest, and central areas, while limited pharmacy opening hours constrain accessibility in the north and southeast, where only 108 of 258 pharmacies are operational. Finally, travel time to pharmacy services for city residents highlight significant spatial and temporal disparities in pharmacy accessibility, emphasizing the role of transport modes and service hours in shaping urban healthcare access.

Conclusions This study underscores the importance of addressing both temporal and spatial factors to ensure equitable accessibility to community pharmacies. The findings suggest the need for targeted policies to improve public transport services during off-peak hours and to extend pharmacy operating hours. Future research should focus on comparative studies across different urban contexts and incorporate more granular data to better understand accessibility to urban services.

Keywords Multimodal accessibility, Spatial equity, Travel times, Public transport supply, GTFS

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Background

In the context of public health promotion, access to healthcare facilities and services specifically, geographical accessibility determined by travel time (or distance), is widely recognized in the literature as a key social indicator for public health assessment [15, 28, 32]. Indeed, physical accessibility has been shown to influence the utilization of healthcare services, with the distance between one's residence and healthcare facilities being strongly correlated with both healthcare usage and disease burden [2, 19]. Among the various types of healthcare services, community pharmacies play a unique role in delivering healthcare to the population due to their strategic geographical distribution across both urban and rural areas. They also operate with fewer barriers to access compared to other healthcare facilities. Unlike hospitals or clinics, community pharmacies typically do not require appointments, making them an essential and readily available resource for immediate healthcare needs. Beyond pharmaceutical services (e.g., dispensing medications), community pharmacies offer a wide array of public health services, such as user counseling, infection screening tests, and immunization programs [19, 34, 44, 47]. Additionally, they promote wellness campaigns and preventive health programs, further reinforcing their role in public health.

Despite the extensive body of research on accessibility to healthcare facilities—including studies focused on pharmacy accessibility—many earlier studies predominantly evaluate accessibility based on a single transportation mode, such as walking or car travel [19, 37, 38, 51]. While recent research has increasingly adopted multimodal approaches to assess accessibility to urban amenities [6, 24, 43], most healthcare-related studies continue to prioritize hospitals and primary care centers [8]. Relatively few studies have examined how public transport and walking—two key modes of mobility for vulnerable populations—impact access to community pharmacies. This is primarily due to data limitations on pharmacy locations and transportation infrastructure.

Notably, buses and metro systems serve as primary modes of transportation in urban areas [29], providing practical options for accessing pharmacies in non-emergency situations. This makes assessing accessibility via transit systems particularly relevant. Research on public transport accessibility has advanced significantly in recent years, leading to the development of comprehensive street network datasets that integrate pedestrian pathways [49, 54], bus routes [42], rail transit systems [16, 53], and bicycle paths [12]. While many studies continue to focus on single-mode networks [27], relatively few incorporate multiple transportation modes—an essential factor in capturing the complexities of multimodal mobility in urban environments [8].

Even in contexts where pharmacy locations are regulated to ensure equitable spatial distribution, accessibility remains influenced by disparities in transport availability and individual mobility constraints. Multimodal accessibility is particularly relevant as it accounts for the diverse ways in which individuals navigate urban areas—especially in cases where private transport is unavailable or during off-peak hours. This perspective is crucial for identifying hidden inequities in spatial and temporal access to urban services, ensuring that regulatory efforts effectively translate into real-world accessibility—particularly for vulnerable populations such as the elderly or those with limited mobility [4, 33].

The limited focus on spatiotemporal accessibility in pharmacy accessibility research has resulted in gaps in understanding how access varies across different times of the day, transport modes, and urban contexts. These gaps hinder efforts to effectively identify areas where pharmacy accessibility is insufficient and to address persistent pharmacy inequities [7]. In the literature, the term "pharmacy deserts" refers to geographic areas where access to community pharmacies is inadequate—either due to the absence of nearby facilities or restricted operational hours that limit timely access to medications and services [41]. Addressing these challenges requires a nuanced, spatiotemporal analysis to enhance the equity of healthcare service provision [11, 37].

This knowledge gap has become even more pronounced following the global pandemic, which has introduced new challenges to healthcare accessibility. Individuals often experience difficulties accessing pharmacies due to limited operational hours or personal scheduling constraints, which vary throughout the day. Research in other domains has emphasized the importance of aligning service operating hours with public transport availability. For instance, Langford et al. [23] examined the relationship between bank opening hours and bus timetables, Neutens et al. [36] investigated accessibility to supermarkets based on transit schedules, and Delafontaine et al. [10] analyzed the accessibility of public service facilities in Belgium in relation to their operating hours and available transport modes. These studies highlight the significant influence of temporal constraints on accessibility across various services.

Despite this growing body of evidence, research on community pharmacies remains underdeveloped in the context of spatiotemporal accessibility. Additionally, there has been little focus on the role of different transportation modes—particularly public transit systems—which are essential for populations that lack access to private vehicles in urban areas [4, 11, 36]. This underscores the need for innovative methodologies to identify pharmacy accessibility gaps and evaluate multimodal accessibility throughout the day.

Accordingly, the objectives of this study are to: (i) Identify areas with significant pharmacy accessibility gaps at different times of the day, using two transport modes: walking and public transport; (ii) Assess disparities in community pharmacy accessibility by analyzing the spatial and temporal variations between walking and public transport access across Lisbon; and (iii) Evaluate how spatiotemporal accessibility to pharmacies impacts the number of city residents reached at different times of the day, highlighting variations in accessibility between daytime and nighttime periods.

For this study, we define a pharmacy gap as an area where a significant portion of the population cannot access a pharmacy within a 10-min travel time, accounting for spatiotemporal variability in operational hours and public transport availability. This definition integrates both spatial and temporal dimensions, reflecting the real-world constraints that residents face in accessing pharmacy services.

The main contributions of this study are twofold: First, it evaluates multimodal accessibility by integrating walking and public transport data. Second, it adopts a temporal-geographic approach to assess pharmacy accessibility across different times of the day, considering both public transport availability and pharmacy operational hours. Our study builds on previous research by adapting similar methodologies to assess spatiotemporal pharmacy accessibility, thereby addressing a critical gap in healthcare accessibility studies. Furthermore, this study demonstrates the added value of incorporating multimodal and temporal dimensions into accessibility assessments, compared to traditional approaches that often rely on static, single-mode, or Euclidean distance-based measures. Although we did not directly compare our results with these traditional methods, our findings illustrate the importance of integrating real-world dynamics—such as public transport schedules and pharmacy operating hours—into healthcare accessibility assessments. This approach provides a more comprehensive understanding of accessibility disparities, particularly in the context of community pharmacies.

The remainder of this paper is structured as follows: Sect. "Data and methods" describes the study area, data sources, and methodology. Sect. "Results" presents the results. Sect. "Discussion" discusses key findings, their implications for policy and practice, and study limitations. Finally, Sect. "Conclusion" concludes with a summary of contributions and recommendations for future research.

Data and methods

Study area

The study area of this research is Lisbon, the capital of Portugal, renowned for its advanced urban development. The Lisbon municipality covers approximately 100 km^2 and is divided into 24 parishes (Fig. 1). It exhibits significant social diversity and holds relevant national importance. According to the National Institute of Statistics (INE), Lisbon's resident population has been steadily declining since 1981. In 2021 Lisbon had about 545.142 inhabitants [20], of whom about 23% were 65 years old or older, making it one of the Portuguese municipalities with highest proportion of elderly residents. These demographic characteristics make Lisbon an important case study for assessing accessibility to essential healthcare services, particularly for older populations. Additionally, Lisbon's population is concentrated in its historic residential districts, with urban expansion along major thoroughfares connecting neighboring municipalities.

Lisbon boasts a well-established transportation network encompassing diverse modes of travel. It is served by a varied transport network including the subway, trams, buses and trains. Indeed, the city center is connected to the upper and eastern districts, as well as some suburbs that are part of the Lisbon metropolitan area, by Lisbon's subway system. This system consists of four lines and 50 stations, providing multiple interchange stations with other transport modes. Additionally, local and commuter bus services operate across the municipality, connecting both intra-city locations and neighboring municipalities. Two main commuter train lines connect the municipality of Lisbon to neighboring municipalities within the district. Finally, several ferry routes connect Lisbon to the municipalities on the southern bank of the Tagus River.As a result, residents across different areas rely on various transportation options to access healthcare facilities, leading to distinct traffic patterns and varying travel times.

Study framework

The study framework includes four main stages: (1) collection and pre-processing of spatial data, (2) overall accessibility measurement, (3) accessibility disparity measurement, and (4) accessibility analysis for city residents (Fig. 2). To measure the impact of public transport schedules and pharmacy operational hours on accessibility, we considered five time slots throughout the day: Morning (8–9 AM), Afternoon (1–2 PM), Evening (6–7 PM), Late Night (11–12 PM), and Early Morning (4–5 AM). These time slots were selected to ensure a uniform temporal evaluation, capturing variations in accessibility throughout the day and highlighting the role of public transport availability in identifying temporal gaps. The

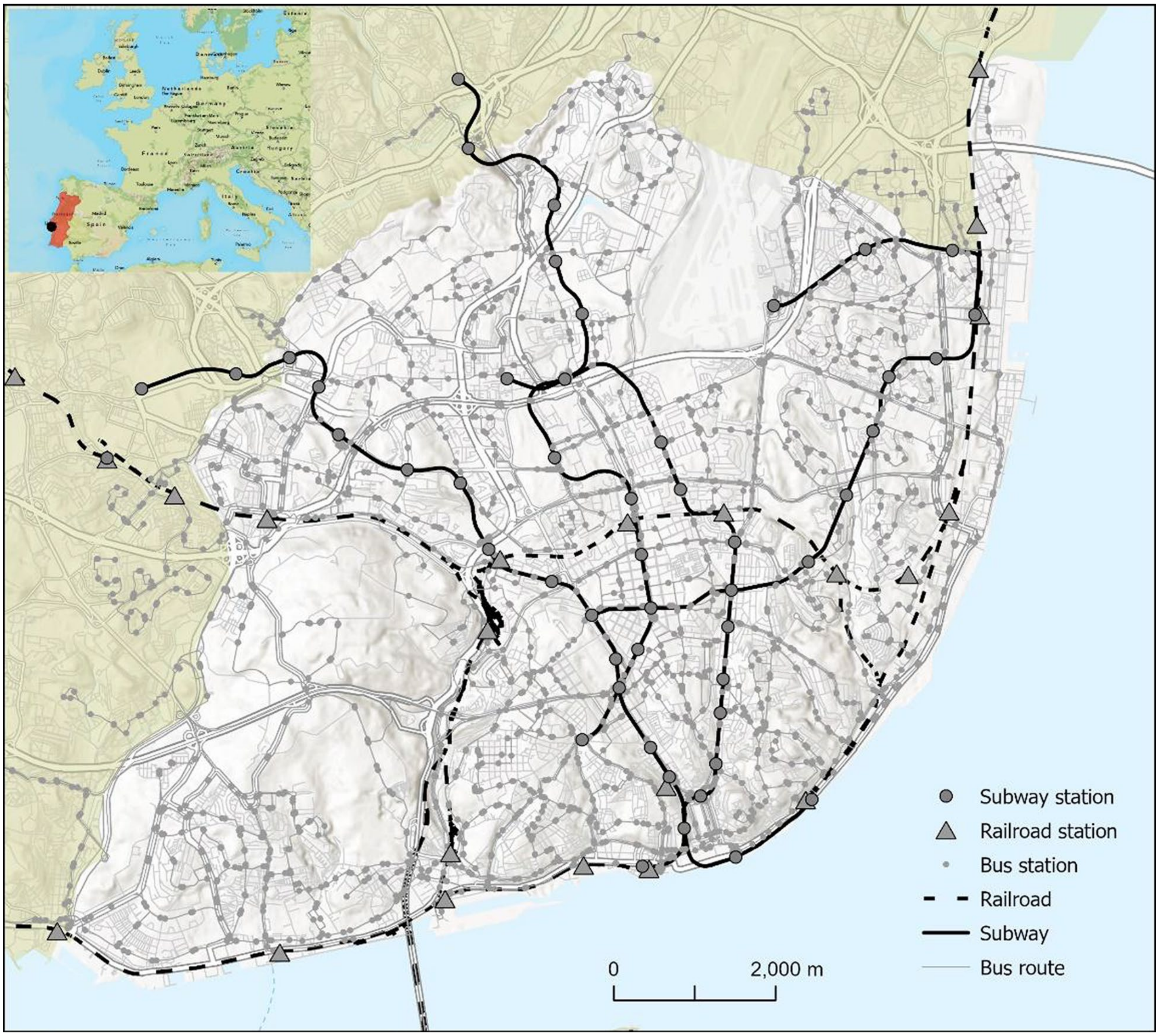

Fig. 1 Study area

chosen slots align with public transport schedule variations and Portuguese regulations (Portaria n.º 277/2012), which define the standard operating hours for community pharmacies in Portugal. According to these regulations, community pharmacies must operate for a minimum of 44 h per week, with the following standard hours: Monday to Friday: Open from 10 AM to 1 PM and from 3 to 7PM. Saturday: Open from 10AM to 1PM.

This study focuses on walking and public transport as the primary modes of accessibility to pharmacies. These modes were chosen due to their relevance for the general population in Lisbon, particularly for vulnerable groups, such as the elderly and individuals without access to private vehicles. Private transport was excluded from the analysis, as the study aims to assess equitable accessibility, which is more closely associated with public and non-motorized transportation modes.

Data collection and pre-processing

For this analysis, a hexagonal grid approach was employed to assess pharmacy accessibility across Lisbon. Hexagons were chosen as the spatial unit due to their spatial efficiency and ability to minimize edge effects, which are common in square grid systems [3]. Unlike square grids, hexagonal grids ensure uniform distances between centroids, allowing for more consistent and precise accessibility measurements [31]. The regular grid structure of hexagons enhances spatial distribution

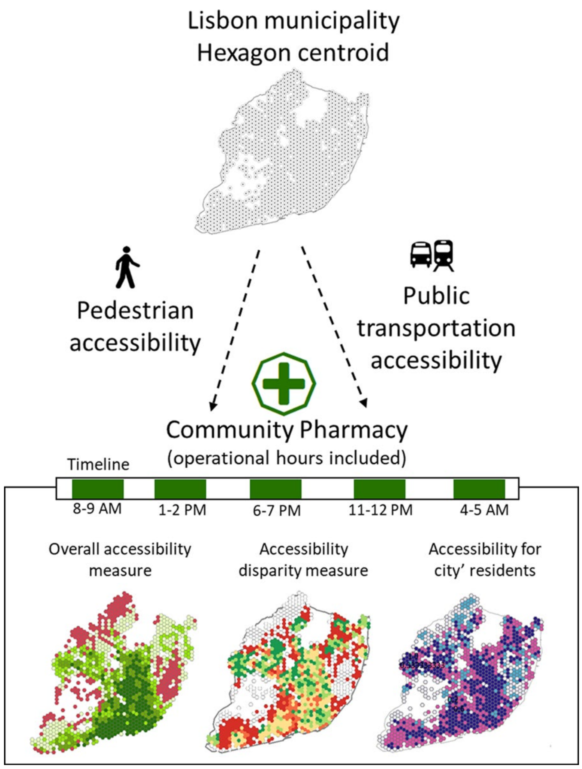

Fig. 2 General framework

analysis while maintaining computational efficiency. This approach has been increasingly adopted in accessibility and spatial equity studies due to its ability to capture spatial patterns with greater accuracy [25, 26].

To approximate pharmacy demand, this study utilized population distribution data at the hexagonal grid level, assuming that all residential buildings contribute equally to potential pharmacy service demand. A regular hexagonal grid was generated with centroids spaced 150 m apart, resulting in hexagons of approximately 58,457 m^2 each. The centroid of each hexagon (n = 50,342) was considered the starting point (origin) for the accessibility analysis. However, to focus on populated areas, only hexagons containing residential buildings were included in the analysis (n = 1,549), excluding non-residential areas such as Lisbon Airport, green spaces like Monsanto Forest Park (a 10 km^2 park in the westernmost part of Lisbon), and other non-residential zones (Fig. 3).

Hexagon-based measurements are widely recognized as effective in walkability studies [26]. The hexagonal shape provides a more accurate representation of walkable areas than other geometric models [52]. Moreover, shorter walking distances are essential for ensuring access to healthcare services, particularly for elderly populations [35]. Research suggests that distances under 200 m are highly walkable, facilitating better health outcomes by improving access to medications and essential healthcare services [1]. Therefore, a 150-m spacing between hexagon centroids was chosen to balance spatial resolution and computational efficiency, allowing for detailed spatial variability in accessibility while keeping computational demands manageable [21]. This scale significantly reduces the number of starting points while ensuring an accurate estimation of distances between residential buildings and the nearest community pharmacy. Data on residential buildings was obtained from the Lisbon City Council, ensuring accuracy and relevance for this study.

In Portugal, community pharmacies serve as the primary providers of prescription and over-the-counter medications, operating under strict regulations to ensure equitable access to pharmaceutical services. While some supermarkets include pharmacy outlets, their presence is limited, and they were excluded from this analysis due to their secondary role in medication provision. The spatial distribution of pharmacies in Lisbon is relatively widespread, with a total of 258 pharmacies serving the municipality (Fig. 3). These pharmacies are concentrated in central areas with higher population densities, whereas peripheral areas exhibit lower densities. This distribution pattern reflects Lisbon's urban structure, with pharmacies primarily located in historic residential districts and along major thoroughfares that connect neighboring municipalities.

The pharmacy dataset used in this study was obtained from the Lisbon City Council and the Google Maps Places API, providing detailed georeferenced locations and operational hours to ensure high accuracy for spatial analysis. While the dataset reflects the most recent available information, potential discrepancies due to changes in pharmacy operations or public transport schedules remain a limitation of this study.

Overall multimodal accessibility

This study employed a travel time threshold-based measure of accessibility, evaluating the percentage of centroids representing residential buildings that could access at least one pharmacy within 10 min. This approach was chosen to assess spatiotemporal and multimodal variations in pharmacy accessibility.

To calculate both pedestrian and public transport travel times, we used ArcGIS Pro software along with Python programming toolboxes. The road network dataset was sourced from Navteq, and a walking-to-transit transfer speed of 4.8 km/h was assumed, following Farber et al. [13]. Specifically, pedestrian travel time was calculated based on "Walking Time", using the ArcGIS Pro Online network analysis service street network.

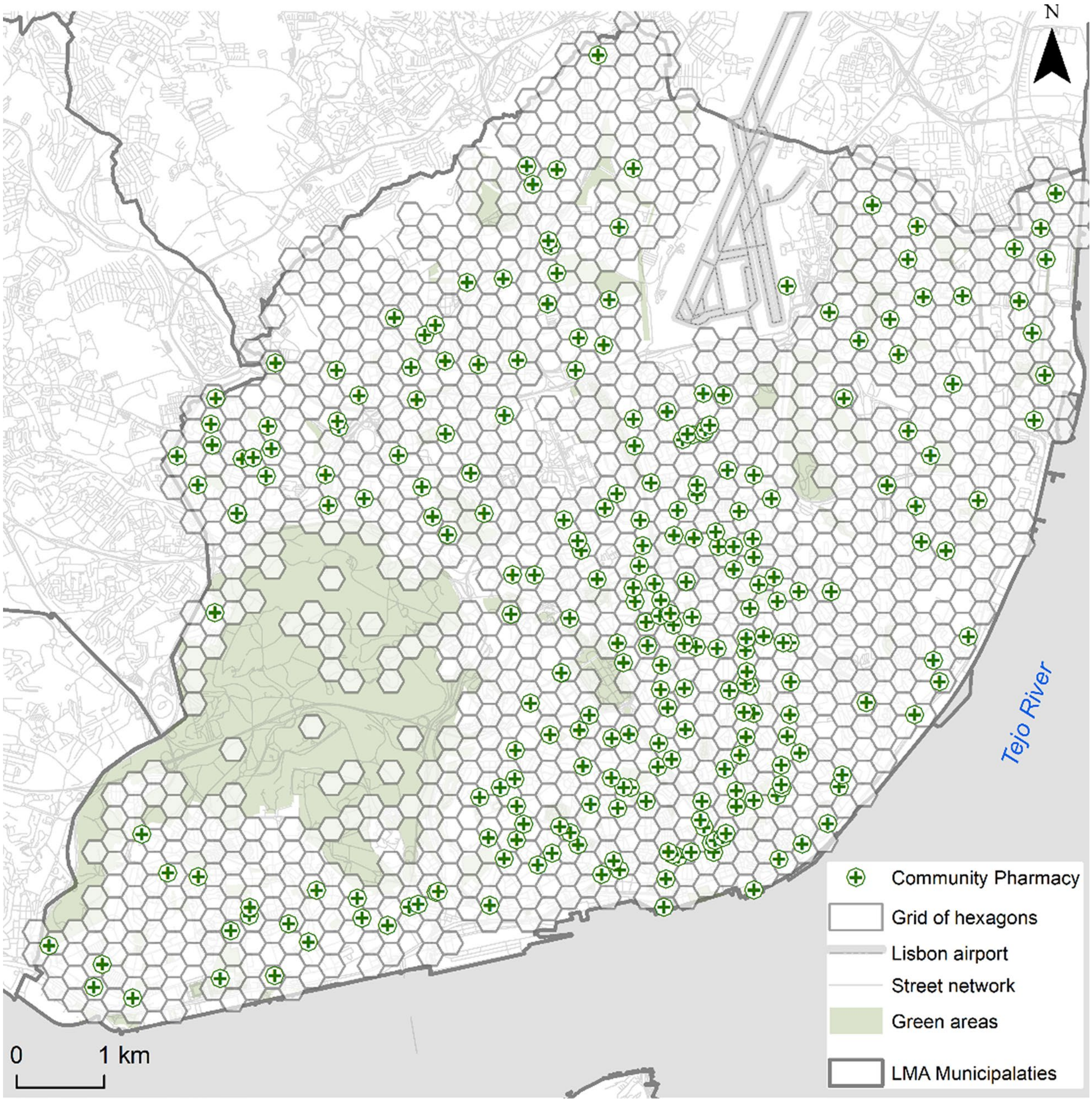

Fig. 3 Regular grid of hexagons and community pharmacies (n = 258) spatial distribution

The public transport data used in this study was sourced from the General Transit Feed Specification (GTFS) via the city's open data portal (https://dadosabertos.cm-lisboa.pt/dataset?res_format=GTFS), which provides detailed information on scheduled public transport services, including routes, stops, and timetables. While GTFS is a standardized and reliable dataset for accessibility analysis, it reflects scheduled rather than actual travel times. As a result, variations in service reliability due to delays, traffic congestion, or operational issues may affect real-world accessibility, particularly during peak hours or in highly congested areas.

Because travel time varies significantly throughout the day [13] and depends largely on public transport frequency and individual departure times [45], we calculated public transport travel times using a temporal resolution of one minute. To minimize dependency on exact departure times, the travel time for public transport corresponds to the average travel time within each time interval considered (computed as 60 calculations per hour).

Given the hierarchical role of community pharmacies as the most frequently accessed type of healthcare service, we established a 10-min travel time threshold as the accessibility cutoff. This threshold was defined based on the relatively homogeneous distribution of community pharmacies across Lisbon and their spatial correlation with population distribution [37].

Multimodal accessibility disparity

To evaluate the multimodal disparity in accessibility to community pharmacies, either ratio or dissimilarity indicators can be used. Given the greater ease of interpretation of the accessibility gap [48], this approach was chosen, obtained through the following expression:

$$AD_{ipq} = AG_{ipq} = \frac{A_i^p - A_i^q}{A_i^p + A_i^q} \tag{1}$$

where AD_{ipq} is the accessibility disparity of place i between modes p and q, AG_{ipq} is the accessibility gap of place i, A_i^p is the accessibility of place i considering the travel mode p, and A_i^q is the accessibility of place i considering the travel mode q. Thus, accessibility was measured by calculating the number of different pharmacy services reachable from the hexagon centroids, while disparity was calculated as a gap, which varies between -1 and 1, where 0 indicates parity.

City residents' multimodal accessibility to community pharmacies

This analysis evaluates community pharmacy accessibility by estimating the actual number of city residents impacted by spatiotemporal variations. Unlike the overall accessibility assessment, which used residential building centroids, this approach focuses on population distribution within the study area. It provides insights into how accessibility variations affect residents during both daytime and nighttime periods.

The analysis integrates demographic data, travel times for walking and public transport, and pharmacy operational hours. To estimate the spatial distribution of city residents, we used census data from INE [20], which includes the number of individuals per dwelling, derived from census statistical subdivisions (e.g., census blocks), and geo-referenced data on residential buildings. The total population within each hexagonal grid unit was calculated by multiplying the number of individuals per dwelling by the number of dwellings in each building. To prevent population overestimation due to building overlaps, we assigned each building's total population to the hexagonal grid unit containing its centroid. We opted for the centroid-based assignment method instead of area-weighted interpolation to ensure that each building's population was uniquely allocated to a single hexagonal grid unit. This approach minimizes the risk of double counting when buildings intersect multiple hexagons and maintains spatial consistency across the study area.

The methodology detailed in the previous sections was then applied to calculate accessibility, incorporating travel times for walking and public transport, pharmacy operational hours, and population distribution across the hexagonal grid. To mitigate potential spatial misalignment between census statistical subdivisions (e.g., census blocks) and the hexagonal grid, we first aggregated population density values at the finest available census unit before assigning them to grid cells. This step reduced discrepancies caused by differences in spatial scales between administrative boundaries and hexagonal tessellation.

Results

Overall multimodal accessibility

Table 1 presents data on the percentage of residential buildings with access to at least one pharmacy and the total number of pharmacies accessible from these origins, evaluated for both walking and public transport (PT) across different times of the day. The results reveal significant variations in accessibility depending on the mode of transport and the time of day. Public transport consistently provides better accessibility than walking, as evidenced by the higher percentage of origins with pharmacy access and the greater mean number of pharmacies reached.

Accessibility is highest in the evening (6–7 PM), with 83.3% of residential buildings within a 10-min walking

Table 1 Accessibility to community pharmacies in Lisbon

	% of origins which can access at least one pharmacy			Total pharmacies accessed from origins	
	Walk	PT	Walk-PT Difference (%)	Walk (Mean)	PT (Mean)
8–9 AM	54.2	76.3	**− 22.1**	1.7	5.3
1–2 PM	**79.8**	90.8	− 11	3.8	9.4
6–7 PM	**83.3**	92.7	− 9.4	4.0	10.2
11–12 PM	20.5	40.5	**− 20**	0.3	0.8
4–5 AM	8.9	16.1	− 7.2	0.1	0.3

Bold values indicate the highest average spatiotemporal accessibility disparity observed among the selected time intervals distance of a pharmacy and 92.7% when using public transport. Conversely, accessibility is lowest in the early morning (4–5 AM), with only 8.9% of residential buildings accessible by walking and 16.1% by public transport. Late-night accessibility (11–12 PM) is also notably limited compared to other times of the day.

Regarding the total number of pharmacies accessed, public transport significantly enhances accessibility, particularly in the evening (mean of 10.2 pharmacies) and afternoon (mean of 9.4 pharmacies). Walking provides access to fewer pharmacies overall, with a maximum mean of 4.0 pharmacies observed in the evening. These findings underscore the critical role of public transport in improving pharmacy accessibility, particularly during peak hours.

Figure 4 illustrates pharmacy accessibility at different times of the day, highlighting both the distribution and the number of community pharmacies accessible within specified time slots. The maps reveal disparities in pharmacy accessibility across Lisbon's neighborhoods, particularly in areas with limited public transport coverage. A color gradient from red (0 pharmacies) to dark green (> 10 pharmacies) visually represents the concentration of accessible pharmacies, providing a clear depiction of accessibility levels.

Central Lisbon exhibits the highest accessibility throughout the day, particularly when using public transport. Northern and southern areas of the city demonstrate moderate accessibility, which improves significantly with public transport but remains challenging during late-night (11–12 PM) and early-morning (4–5 AM) hours. Eastern and western Lisbon follow similar patterns, with public transport greatly enhancing accessibility.

The evening period (6–7 PM) stands out for consistently high accessibility, with large areas in the city center and inner-city districts displaying a predominance of dark green, indicating access to multiple pharmacies. In contrast, late-night and early-morning periods are characterized by limited accessibility, with most areas appearing in red, indicating minimal or no access to pharmacies during these times.

Spatiotemporal accessibility disparity between travel modes

Table 2 presents descriptive statistics for spatiotemporal accessibility disparity at various times of the day, providing a detailed overview of pharmacy accessibility disparities. The late-night period (11–12 PM) exhibits the highest average and median accessibility scores, indicating relatively better overall accessibility to pharmacies. However, the high standard deviation suggests significant variability, with some areas experiencing excellent accessibility, while others face substantial limitations. In contrast, the evening period (6–7 PM) demonstrates consistent accessibility, as evidenced by the lowest standard deviation, reflecting a more uniform distribution of pharmacy services. Meanwhile, the early morning period (4–5 AM) shows the highest variability and a lower median score, highlighting pronounced disparities and very limited access in certain areas.

Figure 5 illustrates the density of pharmacy accessibility across Lisbon at various times of the day, using a color gradient from green (0–0.20) to red (0.81–1.00) to depict the proportion of community pharmacies accessible within 10 min by walking or public transport. During the daytime period (8–9 AM), notable disparities emerge in the southwest, northwest, and central areas, where public transportation enables pharmacy access within 10 min. However, certain northern and southeastern areas lack adequate accessibility due to limited pharmacy operating hours, with only 108 out of 258 pharmacies open during this time. At night (11–12 PM), accessibility challenges are widespread, with a significant portion of Lisbon lacking 10-min access to pharmacies by either walking or public transport. Only 21 pharmacies are accessible via public transport, and eight by walking during this period. In contrast, the afternoon period (1–2 PM) shows minimal disparities, with most of Lisbon achieving 10-min accessibility by either mode. However, specific areas, such as Monsanto in the southwest and regions in the northwest, still experience limited access during this time. Additionally, northern border areas consistently exhibit limited accessibility to pharmacies across all analyzed periods.

City residents multimodal accessibility to community pharmacies

Table 3 presents descriptive statistics for travel time to pharmacy services for city residents, highlighting variations in accessibility by walking and public transport within a 10-min threshold across different times of the day. The results reveal significant disparities in accessibility depending on the time of day and mode of transport. The evening period (6–7 PM) demonstrates the highest accessibility for walking, with 532,637 residents (94% of the population) able to reach a pharmacy within 10 min. Conversely, public transport achieves its highest accessibility during the morning period (8–9 AM), enabling 556,893 residents (98%) to access pharmacies within the same timeframe, ensuring widespread reach during peak hours. In contrast, the early morning period (4–5 AM) exhibits the lowest accessibility for both modes of transport. Only 73,421 residents (12%) can access pharmacies within 10 min

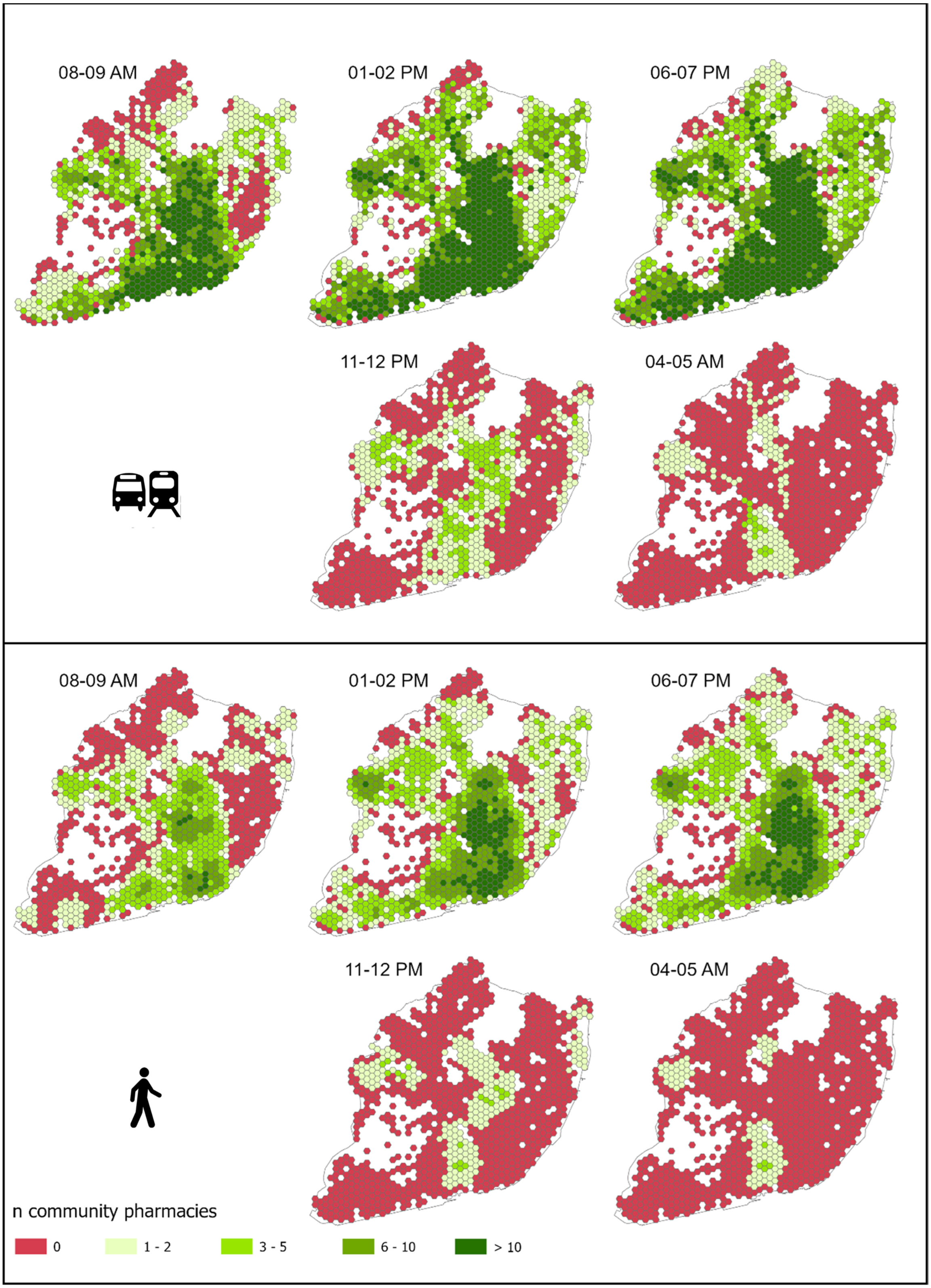

Fig. 4 Number of community pharmacies accessible within 10 min by Public transport (top), and walking (bottom) throughout the day

Table 2 Spatiotemporal accessibility disparity descriptive statistics

	8–9 AM	1–2 PM	6–7 PM	11–12 PM	4–5 AM
Average	**0.56**	0.44	0.44	**0.60**	0.48
Median	0.54	0.43	0.44	0.60	0.33
STDEV	0.35	0.30	0.29	0.42	0.47

Bold values indicate the highest average spatiotemporal accessibility disparity observed among the selected time intervals

by walking, while 108,097 residents (19%) can do so using public transport. These findings highlight the significant impact of spatiotemporal factors on pharmacy accessibility, particularly during off-peak hours, when both operational and transit services are limited.

Discussion

Importance of pharmacy accessibility

Community pharmacies serve as a vital resource for medications and essential health services, forming a cornerstone of public health accessibility worldwide. Pharmacists are increasingly recognized as integral members of primary healthcare teams, providing services that extend beyond medication dispensing. These services include medication management, prescription renewals, and counseling on health behaviors such as smoking cessation and cardiovascular screening [40, 47]. Ensuring equitable spatiotemporal accessibility to pharmacy services is therefore critical for timely healthcare delivery and improved public health outcomes.

This study introduced a comprehensive methodology that integrates five daily time slots and two transport modes—walking and public transport—to assess temporal and multimodal accessibility to community pharmacies in Lisbon. By leveraging spatial data from road and pedestrian networks, Google API, and GTFS datasets, the study provides an in-depth understanding of how transport modes and time of day influence pharmacy accessibility in an urban setting. This approach offers a more accurate representation of real-world conditions,

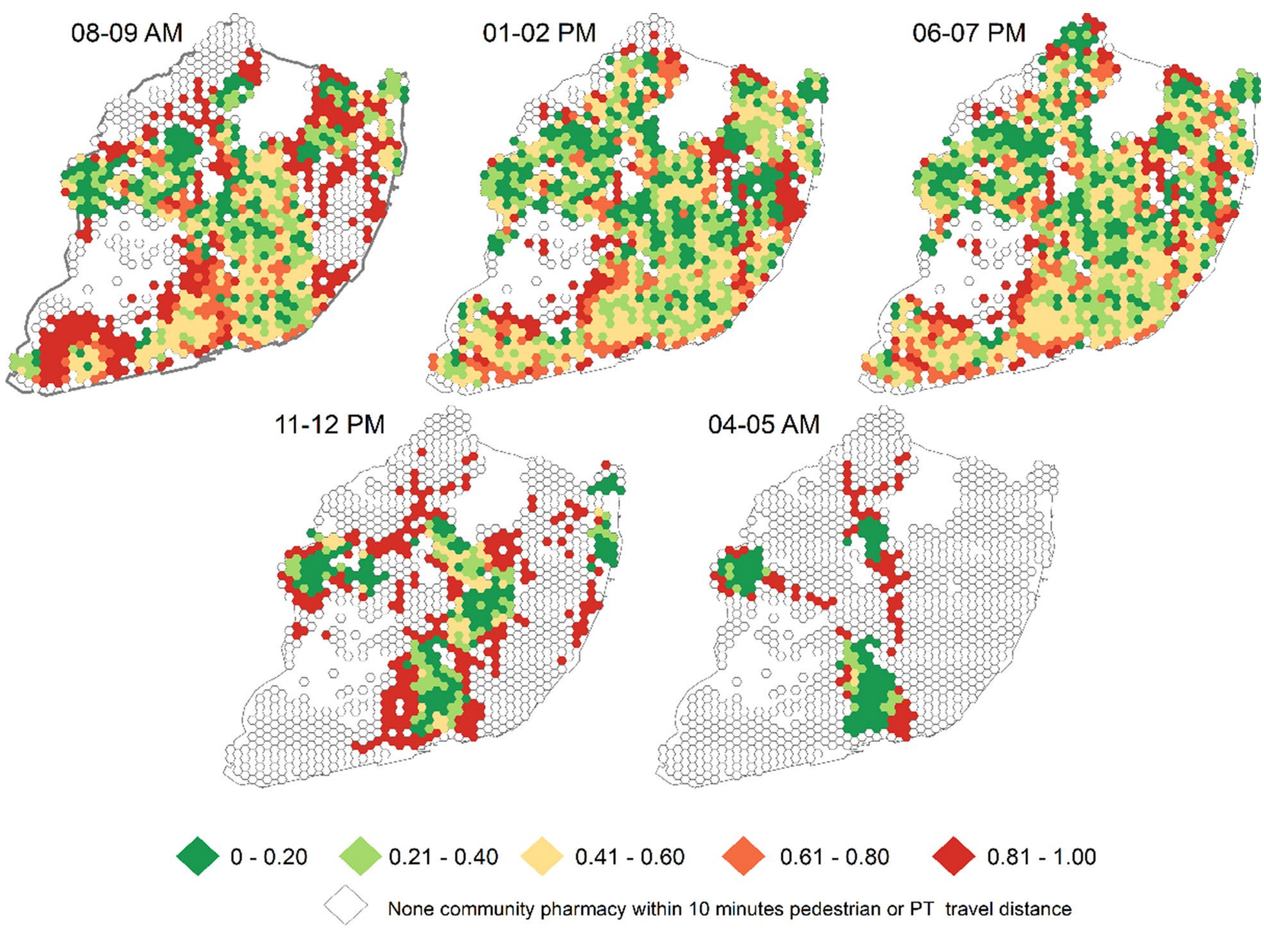

Fig. 5 Spatiotemporal disparity between travel modes

Table 3 Descriptive statistics of travel time to pharmacy services for city residents

	Residents—Descriptive statistics						
Transport mode	Timeframe	Min	Max	Sum	(%)	Mean	Std. Dev
By walking (< 10 min)	8–9 AM	1	4735	380,91	67	627	477
	1–2 PM	1	8904	515,71	91	578	539
	6–7 PM	1	8904	532,64	94	572	535
	11–12 PM	1	8904	146,13	25	632	687
	4–5 AM	1	8904	73,42	12	726	949
Public transport (< 10 min)	8–9 AM	1	4735	556,89	98	508	520
	1–2 PM	1	4735	522,22	92	537	458
	6–7 PM	1	4735	530,87	93	534	456
	11–12 PM	1	2166	250,88	44	571	436
	4–5 AM	1	2166	108,10	19	632	468

where accessibility is shaped by both spatial and temporal dynamics.

The findings of this study confirm significant discrepancies in pharmacy accessibility based on transport mode and time of day, highlighting areas with pronounced gaps in provision. These results align with previous research, such as Neutens et al. [36], which underscores the critical role of temporal and transport-based inequities in healthcare accessibility, and Padeiro [37], which identified similar challenges in pharmacy accessibility within Lisbon. By corroborating these findings, this study reinforces the importance of incorporating multimodal and temporal dimensions into healthcare accessibility research. This approach is essential for addressing existing inequities and promoting spatial equity in urban healthcare systems.

Spatiotemporal dynamics and findings

In Lisbon, spatiotemporal accessibility to community pharmacies exhibits significant variation throughout the day, with higher accessibility observed during daytime hours, particularly when traveling by public transport. Previous studies have assessed urban dynamics and healthcare accessibility using methods such as Euclidean distance, kernel density estimation, or the two-step floating catchment area (2SFCA) method [17, 22, 23, 37]. However, these approaches primarily capture geographical accessibility and often overlook temporal and multimodal dynamics.

Our spatiotemporal multimodal assessment ensures a uniform evaluation throughout the day, enhancing our understanding of spatial equity in accessing healthcare services. This underscores the importance of integrating spatiotemporal and multimodal factors in accessibility analysis to provide a more realistic assessment of healthcare access in urban areas [50]. Recent studies, such as Zhou et al. [54] and Cheng et al. [8], have similarly highlighted the need for comprehensive accessibility assessments in various urban contexts.

Our findings demonstrate significant variations in spatiotemporal accessibility, with peak accessibility occurring during the evening (6–7 PM) and morning (8–9 AM), when a majority of Lisbon's residents can access pharmacies within 10 min by walking or public transport. However, accessibility declines significantly during off-peak periods, particularly in the early morning (4–5 AM) and late-night hours (11–12 PM). Peripheral areas in the southwest and northwest of Lisbon face the most pronounced accessibility challenges, emphasizing the need for improved services during these times.

Studies have shown that access to reliable public transport is critical for equitable healthcare accessibility. For instance, Pereira et al. [39] demonstrated how public transport availability enhances healthcare access in urban areas of Brazil. Similarly, Bissonnette et al. [4] and Delmelle and Casas [11] highlighted the role of public transport in addressing healthcare inequities in Canada and Miami, respectively, particularly for vulnerable populations. These studies underscore that robust transport systems are essential for reducing spatial and social disparities in healthcare access.

In Lisbon, public transport significantly enhances pharmacy accessibility, particularly during peak hours. However, the limited availability of public transport during off-peak periods leads to substantial gaps in accessibility. Addressing these temporal variations is crucial to meeting urgent healthcare needs, particularly during late-night and early-morning hours. For instance, Gulliford and Morgan [18] emphasized the potential health implications of accessibility gaps in emergency care.

This study employed a 10-min travel time threshold to evaluate accessibility, a measure informed by previous research and the uniform distribution of community pharmacies across Lisbon. While effective for analyzing spatiotemporal patterns, a sensitivity analysis of alternative thresholds (e.g., 5, 15, or 20 min) was not conducted and remains a potential avenue for future research. Testing varying thresholds could reveal how travel time impacts accessibility patterns and whether specific thresholds better reflect user needs.

Additionally, our analysis of transport mode disparities revealed that public transport substantially increases pharmacy accessibility compared to walking. For example, during nighttime hours, public transport enables 90% of residents to access pharmacies within 10 min, compared to significantly lower accessibility by walking. These findings underscore that disparities are not solely geographic but are also shaped by factors such as transport availability [33].

Policy implications and recommendations

The detailed analysis of travel times for actual city residents highlights significant disparities in accessibility based on transport mode and time of day. During the evening period (6–7 PM), accessibility is highest, with 94% of residents able to reach pharmacies within 10 min by walking. Public transport further enhances accessibility, covering 98% of residents during the morning period (8–9 AM). Conversely, accessibility is lowest during the early morning (4–5 AM) and late-night (11–12 PM) periods for both transport modes.

These findings underscore the need for targeted strategies to address temporal gaps and ensure equitable access to healthcare services, including extending pharmacy operating hours and improving public transport services during off-peak times. Extending pharmacy operating hours could mitigate accessibility challenges during critical off-peak periods. Similarly, aligning public transport routes and schedules with pharmacy operating hours could bridge accessibility gaps and reduce the prevalence of underserved areas. Such interventions are particularly relevant for nighttime periods, where accessibility challenges are most acute.

The spatial analysis aligns with observations from other urban contexts, where central locations tend to have better healthcare accessibility compared to peripheral zones. To address these inequities, several targeted strategies can be implemented: (i) Infrastructure Improvements: Enhancing public transport frequency and coverage during off-peak hours can significantly improve accessibility to pharmacies, particularly for vulnerable populations. Policies that extend service hours and increase the number of routes in underserved areas can help address existing gaps [4],(ii) Strategic Facility Placement: Locating new healthcare facilities or pharmacies in underserved areas can improve accessibility. Urban planning initiatives that strategically place services closer to residents can reduce disparities in both spatial and temporal accessibility [14],(iii) Mobile and Community-Based Interventions: Mobile pharmacy units and community health centers can provide services in peripheral areas with consistently low accessibility. These interventions should be tailored to the specific needs of underserved populations, ensuring equity in healthcare delivery; (iv) Incentivizing Extended Operating Hours: Encouraging pharmacies to extend their operating hours, particularly during early morning and late-night periods, can ensure better accessibility for residents. Incentives, coupled with regulatory support, may be necessary to facilitate these changes.

Limitations and future research

While robust, our methodology has several limitations that warrant further investigation. First, it focuses solely on physical accessibility to community pharmacies, overlooking the growing role of information and communication technology (ICT)-based solutions, such as online pharmacies and medicine delivery services, which can bridge accessibility gaps for populations with mobility challenges [5]. Future research should explore the interplay between physical and digital accessibility to offer a more comprehensive perspective on healthcare access. Additionally, the use of centroids as proxies for residential areas may not fully capture the spatial distribution of demand [11, 30]. The exclusion of healthcare services in neighboring municipalities and private transport as a comparison mode further limits the scope of this analysis. Incorporating these elements in future studies could enhance the generalizability of findings.

While this study integrates population distribution data to approximate accessibility, it does not explicitly account for demand variations based on demographic factors such as age, gender, or employment status. These variables are crucial, as older populations may exhibit higher demand, and working populations often rely on evening or weekend accessibility [9]. Including these factors in future research would provide a more nuanced understanding of accessibility disparities and help inform targeted interventions. Lastly, the use of a 10-min travel time threshold, while effective for capturing spatiotemporal dynamics, does not account for varying user needs [17]. Future studies could explore sensitivity analyses with different thresholds or adopt FCA-based methodologies to better integrate supply–demand relationships. Addressing these limitations will contribute to a more thorough understanding and effective implementation of healthcare accessibility strategies [46].

Conclusion

The analysis of spatiotemporal accessibility disparities in Lisbon highlights significant challenges and opportunities for improving pharmacy accessibility. By combining descriptive statistics and spatial analysis with insights from the literature, this study underscores the importance of addressing both temporal and spatial factors to ensure equitable healthcare access. Targeted transport and healthcare policies have the potential to enhance accessibility and contribute to better health outcomes for all residents.

The findings demonstrate that public transport substantially increases pharmacy accessibility compared to walking, particularly during daytime hours. A significant portion of Lisbon's population can access pharmacies within 10 min, either by walking or using public transportation. However, disparities persist, especially in the southwest and northwest areas of the city, where accessibility is lowest during nighttime hours. These gaps are exacerbated by limited public transport availability and fewer operational pharmacies during off-peak times.

The proposed approach provides valuable insights into real-world accessibility to medications and pharmacy services, offering a more nuanced understanding of spatiotemporal dynamics in urban healthcare accessibility. This framework not only identifies areas where service provision is inadequate but also serves as a critical tool for informing public policies aimed at promoting spatial equity and improving population well-being.

Despite its contributions, this study acknowledges limitations and emphasizes the need for further research across diverse scales and urban contexts. Future studies should prioritize comparative analyses of different cities and regions to uncover best practices and shared challenges. Enhancing methodologies by incorporating more granular data and accounting for dynamic urban changes will further refine accessibility evaluations. Another limitation is the centroid-based method, as it assumes population is evenly distributed within buildings, which may not accurately reflect actual occupancy patterns. Future studies could integrate auxiliary datasets, such as floor area ratios or detailed land-use data, to refine population distribution estimates within urban grids. Additionally, expanding the focus to include private transportation, digital health solutions, and demographic-specific needs will offer a more comprehensive perspective.

Addressing spatiotemporal accessibility disparities to community pharmacies is essential for promoting equitable access to essential healthcare services. By leveraging these findings to inform policy and practice, urban planners and policymakers can work toward reducing healthcare inequities, ultimately improving public health outcomes and quality of life for all residents.

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Author contributions
CMV was responsible for the conception and design of the study, data analysis, and interpretation of results, as well as data curation, software, validation, visualization, and led the manuscript writing. LEA contributed to the data analysis, interpretation of results, validation, visualization, and assisted with manuscript revision. JR contributed to data analysis, interpretation of results, visualization, and manuscript revision. DSV was involved in the conception and design of the study, participated in data analysis and interpretation of results, and contributed to the manuscript revision.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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References
1. Alves F, Cruz S, Rother S, Strunk T. An application of the walkability index for elderly health—WIEH. The case of the UNESCO Historic Centre of Porto, Portugal. Sustainability. 2021. https://doi.org/10.3390/su13094869.
2. Billi JE, Pai CW, Spahlinger DA. The effect of distance to primary care physician on health care utilization and disease burden. Health Care Manage Rev. 2007;32(1):22–9. https://doi.org/10.1097/00004010-200701000-00004.
3. Birch CPD, Oom SP, Beecham JA. Rectangular and hexagonal grids used for observation, experiment, and simulation in ecology. Ecol Model. 2007;206(3–4):347–59. https://doi.org/10.1016/j.ecolmodel.2007.03.041.
4. Bissonnette L, Wilson K, Bell S, Shah TI. Neighbourhoods and potential access to health care: the role of spatial and aspatial factors. Health Place. 2012;18(4):841–53. https://doi.org/10.1016/j.healthplace.2012.03.007.

5. Boakye A, Olumide OB. The role of internet of things to support health services in rural communities. A case study of Ghana and Sierra Leone. Trans Corporat Rev. 2021;13(1):43–50. https://doi.org/10.1080/19186444.2020.1849937.
6. Capodici AE, Dorso G, Migliore M. A GIS-based methodology for evaluating the increase in multimodal transport between bicycle and rail transport systems. A case study in Palermo. IJGI. 2021. https://doi.org/10.3390/ijgi10050321.
7. Chen G, Wang CC, Jin P, Xia B, Xiao L, Chen S, Luo J. Evaluation of healthcare inequity for older adults: a spatio-temporal perspective. J Transp Health. 2020;19: 100911. https://doi.org/10.1016/j.jth.2020.100911.
8. Cheng M, Tao L, Lian Y, Huang W. Measuring spatial accessibility of urban medical facilities: a case study in Changning District of Shanghai in China. Int J Environ Res Public Health. 2021;18(18):9598. https://doi.org/10.3390/ijerph18189598.
9. Costa EM, et al. Geographies of primary healthcare access for older adults in the Lisbon Metropolitan Area, Portugal – a territory of differences. Saude Soc. 2020. https://doi.org/10.1590/S0104-12902020200108.
10. Delafontaine M, Neutens T, Schwanen T, Van de Weghe N. The impact of opening hours on the equity of individual space–time accessibility. Comput Environ Urban Syst. 2011;35(4):29–37. https://doi.org/10.1016/j.compenvurbsys.2011.02.005.
11. Delmelle E, Casas I. Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: the case of Cali, Colombia. Transp Policy. 2012;20:36–46. https://doi.org/10.1016/j.tranpol.2011.12.001.
12. Dony CC, Delmelle EM, Delmelle EC. Re-conceptualizing accessibility to parks in multi-modal cities: a Variable-width Floating Catchment Area (VFCA) method. Landsc Urban Plan. 2015;143:90–9. https://doi.org/10.1016/j.landurbplan.2015.06.011.
13. Farber S, Morang MZ, Widener MJ. Temporal variability in transit-based accessibility to supermarkets. Appl Geogr. 2014;53:149–59. https://doi.org/10.1016/j.apgeog.2014.06.012.
14. Fone DL, Christie S, Lester N. Comparison of perceived and modelled geographical access to accident and emergency departments: a cross-sectional analysis from the Caerphilly Health and Social Needs Study. Int J Health Geogr. 2006;5:1–10. https://doi.org/10.1186/1476-072X-5-16.
15. Frank LD, Giles-Corti B, Ewing R. The influence of the built environment on transport and health. J Transp Health. 2016;3(4):423–5. https://doi.org/10.1016/j.jth.2016.11.004.
16. Fu X, Qiang Y, Wang J, Zhao X, Hwang F-J, Chen C-H. Urban public transport accessibility to medical services from the perspective of residents' travel: a hybrid assessment based on the whole process. IEEE Access. 2021;9:8977–89. https://doi.org/10.1109/ACCESS.2021.3049814.
17. Guagliardo MF. Spatial accessibility of primary care: concepts, methods and challenges. Int J Health Geogr. 2004;3(1):1–13. https://doi.org/10.1186/1476-072X-3-3.
18. Gulliford M, Morgan M. (Eds.). Access to Health Care (1st ed.). Routledge. 2003. https://doi.org/10.4324/9780203867952
19. Ikram SZ, Hu Y, Wang F. Disparities in spatial accessibility of pharmacies in Baton Rouge, Louisiana. Geogr Rev. 2015;105(4):492–510. https://doi.org/10.1111/J.1931-0846.2015.12087.X.
20. INE. XV Recenseamento Geral da População. Instituto Nacional de Estatística. 2021.
21. Kim K, Horner MW. Assessing the effects of centroid assignment methods on measuring spatial accessibility. Trans GIS. 2024;28(7):2025–43. https://doi.org/10.1111/tgis.13228.
22. Lanford M, Higgs G, Fry R. Multi-modal two-step floating catchment area analysis of primary health care accessibility. Health Place. 2016;38:70–81. https://doi.org/10.1016/j.healthplace.2015.11.007.
23. Langford M, Price A, Higgs G. Combining temporal and multi-modal approaches to better measure accessibility to banking services. ISPRS Int J Geo Inf. 2022;11(6):350. https://doi.org/10.3390/ijgi11060350.
24. Lemonde C, Arsenio E, Henriques R. Integrative analysis of multimodal traffic data: addressing open challenges using big data analytics in the city of Lisbon. Eur Transp Res Rev. 2021;13:64. https://doi.org/10.1186/s12544-021-00520-3.
25. Li A, Chen J, Qian T, et al. Spatial accessibility to shopping malls in Nanjing, China: comparative analysis with multiple transportation modes. Chin Geogr Sci. 2020;30:710–24. https://doi.org/10.1007/s11769-020-1127-y.
26. Li M, Wang H, Wang J, Zhou H, Li D. Gated or ungated? A case study on walkability measurement for urban communities. Appl Spat Anal Policy. 2024;17(3):1017–41. https://doi.org/10.1007/s12061-024-09575-w.
27. Li X, Guo J, Gao C, Su Z, Bao D, Zhang Z. Network-based transportation system analysis: a case study in a mountain city. Chaos Solitons Fractals. 2018;107:256–65. https://doi.org/10.1016/j.chaos.2018.01.010.
28. Lin SJ. Access to community pharmacies by the elderly in Illinois: a geographic information systems analysis. J Med Syst. 2004;28(3):301–9. https://doi.org/10.1023/B:JOMS.0000032846.20676.94.
29. Lozano A, Storchi G. Shortest viable path algorithm in multimodal networks. Transport Res Part A Policy Pract. 2001;35(3):225–41. https://doi.org/10.1016/S0965-8564(99)00056-7.
30. Luo W, Wang F. Measures of spatial accessibility to healthcare in a GIS environment: synthesis and a case study in Chicago region. Environ Plann B Plann Des. 2003;30(6):865–84. https://doi.org/10.1068/b29120.
31. Luo J, Zhang W, Su J, Xiang F. Hexagonal convolutional neural networks for hexagonal grids. IEEE Access. 2019;7:142738–49. https://doi.org/10.1109/ACCESS.2019.2944766.
32. Mao L, Nekorchuk D. Measuring spatial accessibility to healthcare for populations with multiple transportation modes. Health Place. 2013;24:115–22. https://doi.org/10.1016/j.healthplace.2013.08.008.
33. McLafferty SL. GIS and health care. Annu Rev Public Health. 2003;24:25–42. https://doi.org/10.1146/annurev.publhealth.24.012902.141012.
34. Melton B, Lai Z. Review of community pharmacy services: what is being performed, and where are the opportunities for improvement? IPRP. 2017;6:79–89. https://doi.org/10.2147/iprp.s107612.
35. Merlin LA, Teoman D, Viola M, Vaughn H, Buehler R. Redrawing the planners' circle. J Am Plann Assoc. 2021;87(4):470–83. https://doi.org/10.1080/01944363.2021.1877181.
36. Neutens T, Delafontaine M, Scott DM, De Maeyer P. A GIS-based method to identify spatio-temporal gaps in public service delivery. Appl Geogr. 2010;32(2):453–64. https://doi.org/10.1016/j.apgeog.2011.05.006.
37. Padeiro M. Geographical accessibility to community pharmacies by the elderly in metropolitan Lisbon. Res Social Adm Pharm. 2018;14(7):653–62. https://doi.org/10.1016/j.sapharm.2017.07.014.
38. Pednekar P, Peterson A. Mapping pharmacy deserts and determining accessibility to community pharmacy services for elderly enrolled in a State Pharmaceutical Assistance Program. PLoS ONE. 2018. https://doi.org/10.1371/journal.pone.0198173.
39. Pereira RHM, Nadalin V, Monasterio L, Albuquerque PHM. Urban centrality: a simple index. Geogr Anal. 2013;45(1):77–89. https://doi.org/10.1111/gean.12002.
40. Pousinho S, Morgado M, Falcão A, Alves G. Pharmacist interventions in the management of type 2 diabetes mellitus: a systematic review of randomized controlled trials. JMCP. 2016;22(5):493–515. https://doi.org/10.18553/jmcp.2016.22.5.493.
41. Qato DM, Daviglus ML, Wilder J, Lee T, Qato D, Lambert B. 'Pharmacy deserts' are prevalent in chicago's predominantly minority communities. Raising Med Access Concerns Health Aff. 2014;33(11):1958–65. https://doi.org/10.1377/hlthaff.2013.1397.
42. Qian T, Chen J, Li A, Wang J, Shen D. Evaluating spatial accessibility to general hospitals with navigation and social media location data: a case study in Nanjing. IJERPH. 2020. https://doi.org/10.3390/ijerph17082752.
43. Santos T, Mendes RN, Julião RP. The potential of integrated transport modes: modelling the combined use of bicycles and train in Lisbon Portugal. CCT. 2023;2023(46):89–106.
44. Smith M, Bates DW, Bodenheimer T, Cleary PD. Why pharmacists belong in the medical home. Health Aff. 2010;29(5):906–13. https://doi.org/10.1377/hlthaff.2010.0209.
45. Stępniak M, Pritchard JP, Geurs KT, Goliszek S. The impact of temporal resolution on public transport accessibility measurement: review and case study in Poland. J Transp Geogr. 2019;75:8–24. https://doi.org/10.1016/j.jtrangeo.2019.01.007.
46. Talen E, Anselin L. Assessing spatial equity: an evaluation of measures of accessibility to public playgrounds. Environ Plan A Econ Space. 1998. https://doi.org/10.1068/a300595.
47. Tan ECK, Stewart K, Elliott RA, George J. Pharmacist consultations in general practice clinics: the Pharmacists in Practice Study (PIPS). Res Social Adm Pharm. 2014;10(4):623–32. https://doi.org/10.1016/j.sapharm.2013.08.005.

48. Vale DS, Ascensão F, Raposo N, Figueiredo AP. Comparing access for all: disability-induced accessibility disparity in Lisbon. J Geogr Syst. 2017;19(1):43–64. https://doi.org/10.1007/s10109-016-0240-z.
49. Vale D, Lopes AS. Accessibility inequality across Europe: a comparison of 15-minute pedestrian accessibility in cities with 100,000 or more inhabitants. NPJ Urban Sustain. 2023;3(1):1–13. https://doi.org/10.1038/s42949-023-00133-w.
50. Wan N, Zhan FB, Zou B, Chow E. A relative spatial access assessment approach for analyzing potential spatial access to colorectal cancer services in Texas. Appl Geogr. 2012;32(2):291–9. https://doi.org/10.1016/j.apgeog.2011.05.001.
51. Wang L, Ramroop S. Geographic disparities in accessing community pharmacies among vulnerable populations in the Greater Toronto Area. Can J Public Health. 2018;109(5–6):821–32. https://doi.org/10.17269/s41997-018-0110-1.
52. Yu J, Leung M, Ma G, Xia J. Older adults' access to and satisfaction with primary hospitals based on spatial and non-spatial analyses. Front Public Health. 2022. https://doi.org/10.3389/fpubh.2022.845648.
53. Zheng Y, gang, Zhang, H. sheng, Qi, K. tuo, & Ding, L. yu. Stripe segmentation of oceanic internal waves in SAR images based on SegNet. Geocarto Int. 2021;37(25):8567–78. https://doi.org/10.1080/10106049.2021.2002430.
54. Zhou X, Yu Z, Yuan L, Wang L, Wu C. Measuring accessibility of healthcare facilities for populations with multiple transportation modes considering residential transportation mode choice. IJGI. 2020;9(6):394. https://doi.org/10.3390/ijgi9060394.

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