

# **Exploring the temporal variations in accessibility to health services for older adults: A case study in Greater London**

## **Abstract**

*Introduction:* Increasing attention has been paid to accessibility and equity during the last two decades. Yet, despite the proliferation of studies investigating accessibility and equity from the perspective of the younger generation, only modest progress has been made in embedding a temporal perspective and targeting health services for older adults. Currently, the number of people over 60s in London is growing rapidly and is projected to increase to approximately two million by 2035.

*Aims:* This research aims to examine walking accessibility to General Practitioners (GPs) for older people in Greater London, with a particular focus from a temporal perspective.

*Methods:* Three different datasets were used for this study, namely: GP services data and data on GP Opening Times data from NHS Choices; the London Lower Super Output Area (LSOA) atlas; and the road network derived from OpenStreetMap (OSM). This study uses on the cumulative method to calculate accessibility to GPs – and applies the vertical equity index to measure temporal equity.

*Results:* Our results show that opening times have a significant impact on accessibility to health services for older people in London. Overall accessibility peaked at midday when 15.88% of areas have a low degree of accessibility. Additionally, our study classifies local authorities into five groups based on their performance on accessibility and vertical equity measurements. We found several districts with inadequate and unequal accessibility that can be identified as vulnerable areas.

*Conclusions:* Gaining insights into the temporal variations in accessibility to GPs represents a key step towards providing optimal services. Our findings can be used to provide an evidence-based reference for transport planners and policymakers to promote age-friendly development and planning.

## **Keywords**

Accessibility; Health services; Older population's mobility; Spatio-temporal analysis; Equity; Greater London

## **Highlights**

- We examine walking accessibility to General Practices for older people.
- Opening times have a significant impact on accessibility to health services.
- There are five classified groups regarding accessibility and vertical equity measurements.
- Several districts with inadequate and unequal accessibility have been identified.
- Our findings contribute and promote age-friendly development and planning.

## 1 **1. Introduction**

2 An important dimension of modern healthcare systems is equal accessibility to healthcare  
3 services (Mayaud et al., 2019). The extent to which there is equity in terms of access to healthcare  
4 services, such as General Practices (GPs), is regarded as a useful evaluation standard of policy  
5 performance and social wellbeing. In addition, equity of access to healthcare services is widely  
6 acknowledged as an indicator of social exclusion, because health facilities, as an important aspect of  
7 community facilities and services, can offer social interaction within the built environment (Ewing and  
8 Cervero, 2001). Therefore, much of the existing literature has focused on physical accessibility to  
9 healthcare, from the perspectives of accessibility measures (Crawford et al., 2009; Kelly et al., 2016),  
10 an assortment of health-related indicators (Tussing, 1983), the association between distance and health  
11 outcomes (Field and Briggs, 2001; Thomson et al., 2014), and the level of GP provision (Sexton and  
12 Bedford, 2016; Eibich and Ziebarth, 2014). The aforementioned studies have all claimed that better  
13 physical accessibility is beneficial to individuals' health.

14 Demographic ageing has become one of the most notable social phenomena of the modern  
15 world. According to a report by the UN (2019), there were 703 million persons aged 65 and over in the  
16 world in 2019. Over the next three decades, the older population is projected to more than double,  
17 globally, and to reach 1.5 billion in 2050. In London, the number of residents over 60 is projected to  
18 increase to approximately two million by 2035 (GLA, 2017). Older people have more frequent and  
19 intensive demands for healthcare services. Due to physical constraints and factors relating to their living  
20 environment, older people experience a higher risk of social exclusion, which may lead to inequalities  
21 in access to healthcare services. Thus, improving the accessibility and equality of healthcare services  
22 for older people has become an important policy goal. The WHO (2002) emphasises that healthcare  
23 should be within physical reach of all older adults, even in the case of those living in rural areas. The  
24 COVID-19 pandemic has also made improving health accessibility more important for older adults.

25 In addition, because of a number of access barriers (e.g. lack of information, personal mobility,  
26 and access to transport) (Allin et al., 2011; Hudson and Nolan, 2015), walking accounts for a greater  
27 absolute proportion of the travel modes used by the older population (Feng, 2017), especially when it  
28 comes to accessing GPs. Moreover, the existing studies have indicated that walking is the daily travel  
29 mode favoured by the largest proportion of older people, particularly in large cities (Cheng et al., 2019;  
30 Huang and Wu, 2015). In terms of sociality, as a means of travel, walking is considered to play a major  
31 role in maintaining the social participation of the older adults (Cheng et al., 2019; Feng, 2017).  
32 Therefore, understanding more about walking accessibility for the older population group can enable  
33 interventions to be tailored in a way that can improve their quality of life. Although some older people  
34 may choose to use other means of transport, or be limited by the natural environment in some way, they  
35 are in the minority. Consequently, it is important to investigate walking accessibility to GPs by older  
36 people in order to inform the planning of GPs both in terms of time and space.

37 Existing studies on accessibility to healthcare services by older people have mainly focused on  
38 the spatial dimension and the measurement of physical accessibility, as well as their effects on aspects  
39 such as hospital attendance (Turnbull et al., 2008; Layte et al., 2009; Borrescio-Higa, 2015).  
40 Consequently, they have the mainly two limitations: first, although the spatial distance dimension has  
41 been widely discussed, few studies have considered accessibility to GPs by older people from a  
42 temporal perspective. The temporal component is significant in terms of accessibility for the older  
43 population, because it is closely associated with the availability of opportunities, services levels of  
44 transport modes, and the time availability of individuals (Stepniak et al., 2019). A lack of knowledge  
45 about temporal variations in accessibility to GPs could cause biases in understanding the current  
46 situation regarding GP provision, and thus hamper attempts to improve the welfare of older people.  
47 More data has become available during the last decade, and some studies have attempted to introduce  
48 a temporal perspective to examine differing levels of accessibility to various types of opportunities (or  
49 services), such as jobs (Boisjoly and El-Geneidy, 2016; Hu and Downs, 2019), grocery shops and  
50 supermarkets (Widener et al., 2017; Farber et al., 2014), but few have discussed accessibility to health  
51 services or focused exclusively on the older population. Second, the existing literature on healthcare  
52 facilities (Allin et al., 2011; Mohan et al., 2019; Hoeck et al., 2013) has rarely discussed the vertical  
53 equity of accessibility to GPs or compared the degree of access to GPs for different age groups.  
54 Although the ultimate goal of equal access for equal need is regarded as unfeasible (Lovett et al., 2002),  
55 gaining a comprehensive understanding of the disparities in accessibility would be a fundamental step  
56 towards achieving more equal and age-friendly communities, and therefore facilitate a higher quality  
57 living environment.

58 In order to overcome the limitations of the existing studies, our study, therefore, aims to explore  
59 temporal walking accessibility to GPs for older people, using London as a case study. To achieve this  
60 goal, this study addresses two questions: 1) What is the temporal variations of GP accessibility in  
61 London? 2) Are there significant disparities in GP accessibility between different local authorities,  
62 specifically taking the needs of older age groups into account? Using three official datasets, we calculate  
63 older people's accessibility to GPs by the cumulative method, and the vertical equity by applying the  
64 Spearman's rank correlation coefficient between the vulnerability index and accessibility levels. In  
65 particular, we examine the temporal fluctuations in both accessibility and the vertical equity indicators  
66 and use these two indicators to classify local authorities into groups to facilitate more inclusive and  
67 tailored practices. This study is not only intended to offer an effective planning channel for the  
68 distribution and opening hours of GPs, but also to provide the first-hand evidence that can be used to  
69 promote an age-friendly society and overall social wellbeing. Furthermore, the study contributes to the  
70 existing literature by elaborating on the criticality of the temporal dimension in understanding  
71 accessibility and equity.

72 The remainder of this paper is organised as follows. Section 2 reviews the accessibility studies  
73 with a focus on the temporal perspective and health services. The study area, data and methods used to

74 measure walking accessibility to GPs are introduced in Section 3. Section 4 elaborates on the temporal  
75 variations in accessibility to GP services for all, and then specifically for the older population in London  
76 at a Lower Layer Super Output area (LSOA) level, as well as examining accessibility and vertical equity  
77 at local authority level. The paper concludes with a discussion of significant findings and some  
78 suggestions for future research.

79

## 80 **2. Literature review**

### 81 **2.1 Temporal accessibility**

82 Accessibility has long been a topic of discussion within the field of transport. Hansen (1959)  
83 first brought the concept of accessibility to wider attention and defined accessibility as the potential of  
84 various opportunities for interaction, i.e., the ease with which interactions can take place (El-Geneidy  
85 et al., 2016; Pereira, 2019). Numerous debates about the definition of accessibility followed (Geurs et  
86 al., 2012; Handy and Niemeier, 1997; Le Vine et al., 2013; Morris et al., 1979). Gradually, different  
87 interpretations of accessibility were translated into practical approaches and tangible measurements.  
88 The most widely used of these are cumulative opportunity measures (also known as isochrones  
89 measures), the shortest travel time measure, the gravity measure, the utility measure and the space-time  
90 prism model. A detailed review can be found in Neutens' (2015) work.

91 Although there are many definitions and measurements of accessibility within the research,  
92 accessibility can generally be understood as a collection of four components. Geurs and Van Wee (2004)  
93 identified the following four components of accessibility: land-use (the distribution of origins and  
94 destinations and their characteristics), transport, individual, and temporal. They defined accessibility as  
95 the extent to which the interaction between land use and various types of transport helps different  
96 individuals to participate in social activities during different periods of time. In other words,  
97 accessibility is a function that is dependent on people, transport and land use (social activities) and  
98 varies across time. Therefore, there is a family of accessibility measurements that can refer to different  
99 combinations of these components, such as the native-born black population and immigrant women's  
100 accessibility to jobs (Parks, 2004); children's walking accessibility to urban parks (Reyes et al., 2014);  
101 accessibility to jobs and education by public transport (Hernandez, 2018); and public transport  
102 accessibility to health facilities by vulnerable populations (those aged 65 and over, single-parents and/or  
103 low-income households) (Gilliland et al., 2019). Most current research on accessibility analysis has  
104 provided greater nuance by subdividing each component into different scenarios, e.g., classifying  
105 individuals by various socio-demographic features, categorising transport into different modes of travel  
106 (driving, public transport, walking and cycling); and subdividing land use into various key services,  
107 such as jobs and education. Järv et al. (2019) provided a detailed summary showing how various  
108 combinations of these components have been used in empirical studies of accessibility.

109 However, empirical studies on the fourth component – time – have only become popular in  
110 recent years. Space-time based accessibility (Miller, 1991; Kwan, 1998) can capture heterogeneous

111 social constraints on a person's daily activities and movements in space and time based on the time  
112 geographic framework (Hägerstrand, 1970; Neutens et al., 2007; Lee and Miller, 2018). For instance,  
113 O'Sullivan et al. (2000) first integrated opportunity-based accessibility and a space-time measure to  
114 explore transit-based space-time accessibility in Glasgow. It was found that the travel range shown by  
115 isochrones maps varied considerably depending on the departure time of the chosen transportation mode.  
116 Similarly, Weber (2003) studied the extent to which the temporal aspect influenced individuals'  
117 accessibility to major employment centres in Portland, Oregon, using space-time measures. He argued  
118 that the space-time measure was a more realistic one to use for gaining insight into accessibility. It is  
119 only in recent years that accessibility has been studied more from a temporal perspective, as the  
120 temporal data from various sources have become more widely available (Stępniaak et al., 2019).  
121 'Temporal' can be understood, here, as having a threefold meaning: first, the availability of  
122 opportunities; second, the availability and service levels of transport modes; and third, the time  
123 availability of individuals, i.e., whether people are capable of participating in specific activities, such  
124 as work and shopping, during certain time periods. The emerging research can be broadly classified  
125 into two types: temporal variability in accessibility (Boisjoly and El-Generidy, 2016; Hu and Downs,  
126 2019; Moya-Gómez and García-Palomares, 2017; Pritchard et al., 2019); and the impact of temporal  
127 resolution on accessibility (Fransen et al., 2015; Stępniaak et al., 2019). The distinction between temporal  
128 variability and temporal resolution is that: the former used multiple departure times to reflect  
129 fluctuations in travel times and availability of services and their impacts on accessibility; the latter used  
130 various time intervals (e.g., 1-minute, 10-minute and 1-hour resolutions) to reflect the variations in  
131 accessibility. The temporal resolution perspective is particularly important in studying public transport  
132 accessibility, as public transport services often vary significantly over different time scales. Stępniaak  
133 and colleagues (2019) provided a justification for this in their empirical research, stating that the  
134 reduction in temporal resolution is associated with a reduction in the accuracy of measuring public  
135 transport accessibility. Regarding variability in accessibility, an interesting piece of research by Järv et  
136 al. (2018) examined accessibility to food over a 24-hour period in Tallinn, Estonia. By comparing static  
137 accessibility and dynamic accessibility, they found that, when the former is used, accessibility tends to  
138 be over-estimated and confirmed the importance of incorporating a temporal perspective when studying  
139 accessibility. With regard to temporal resolution in accessibility, there was found to be a trade-off  
140 between the length of time taken to perform the calculation (higher data requirement) and the granularity  
141 of accessibility. Stępniaak et al. (2019) applied a hybrid strategy using 5, 10, 15, 30 and 60-minutes  
142 resolutions and found that using a 15-minute temporal resolution provides a good balance between  
143 precision and computational time. It should be noted that the complexity of temporal accessibility varies  
144 on a case-by-case basis. For example, walking accessibility has a weak relationship with the temporal  
145 limitations of transport services, as the attributes of pavements do not change dramatically over time.  
146 However, in the case of public transport accessibility, the capacities of transport services do change  
147 significantly over time. Changes in service performance will directly affect travel costs, such as travel

148 time and fares, and indirectly affect accessibility. Similarly, selecting which time interval is most  
149 appropriate to use depends on the context and is strongly limited by time availability.

150

## 151 **2.2 Health service accessibility and equity**

152 Accessibility to GP services has been found to encourage the efficient use of health services because of  
153 physician-induced demand (Mohan et al., 2019). Depending on whether the measurement of  
154 accessibility takes the demand side into account, current research on accessibility can be divided into  
155 two types: the measurement of accessibility through utilisation of data purely from the supply side; and  
156 the measurement of accessibility by assessing the ratio of residential demand to the supply of healthcare  
157 within predefined areas or varying boundary areas. The former is typically based on the measurement  
158 of cumulative opportunity, which is simple to compute and requires less data; the latter takes into  
159 account the spatial variations within the boundary of a catchment area and the demand-supply  
160 interaction across the boundaries, thereby providing more accurate accessibility results but also  
161 requiring more data (Luo and Whippo, 2012). An example of this approach is the two-step floating  
162 catchment areas method (Luo and Wang, 2003) which has been used in several studies to measure  
163 accessibility to health services (McGrail, 2012; McGrail and Humphreys, 2014; Tao et al., 2020). The  
164 two-step floating catchment areas (2SFCA) approach comprises the following two steps: the first step  
165 identifies all areas that are within the distance of a specified travel cost from the available health services  
166 and then calculates the physician-to-population ratio by dividing the capacity of a facility by the number  
167 of residents who use it. The second step aggregates all the physician-to-population ratios which are  
168 within reach of the population's travel cost. Following Luo and Wang's (2003) method, there have  
169 been several advancements in the 2SFCA, such as introducing distance decay functions (Dai, 2010)  
170 within the catchment areas; and applying varying sizes of catchment areas (Chen and Jia, 2019).

171 Increasing accessibility to health services needs to be integrated into health policies,  
172 particularly in the case of the older population, because they are more frequent and heavy users of health  
173 facilities than other population groups (Hudson and Nolan, 2015). For instance, Kelly et al. (2016)  
174 found that there is an inverse relationship between a patient's physical location (usually residential) and  
175 their use of healthcare services and/or health outcomes (Kelly et al., 2016). However, although the  
176 importance of adequate accessibility to GPs has been acknowledged by the NHS (Iacobucci, 2014), and  
177 the topic of health service accessibility has received growing attention in both the fields of transport  
178 and public health, studies on accessibility to GPs by older adults are still relatively scarce. The current  
179 research on accessibility for older people mainly pertains to green space (Guo et al., 2019; Nicholls,  
180 2001) and specific transport services (Lin et al., 2014). For example, Cheng et al. (2019) investigated  
181 walking accessibility to recreational amenities for people over 60 in Nanjing, in China. They found that  
182 older adults have lower level of accessibility than the younger generation. Only a few studies have  
183 examined accessibility to GPs for older adults and/or vulnerable groups. For instance, Bauer et al. (2018)

184 studied the spatial accessibility of primary care in England and found that there are substantial  
185 differences in accessibility across the country, i.e., approximately 25.8% people lived in areas with a  
186 significantly low level of accessibility. Their other counterintuitive finding was that socially deprived  
187 areas did not have lower levels of accessibility to GPs than other areas.

188 The question raised here is why are we particularly interested in exploring accessibility for  
189 older groups? The notion of vertical equity is key (Cao, 2019; Litman, 2007), which advocates treating  
190 people differently by providing particular discounts and special services for disadvantaged cohorts  
191 (Low et al., 2020), such as low income and/or older people. The rationale for doing so is mainly to  
192 compensate for overall societal inequalities from a holistic perspective (Cao and Hickman, 2020;  
193 Delbosc and Currie, 2011; Ricciardi et al., 2015). By contrast, horizontal equity treats all individuals  
194 the same without favouring any specific individuals or groups. Viewed from the perspective of either  
195 vertical equity or horizontal equity, social exclusion is not due to a lack of social opportunities, but to a  
196 lack of access to those opportunities (Cao and Hickman, 2019; Hine and Grieco, 2003; Hine and  
197 Mitchell, 2016; Jones and Lucas, 2012; Preston and Rajé, 2007). This explains why accessibility is  
198 widely used as a metric for calculating the level of transport equity at the local or regional level. Recent  
199 studies (Cao et al., 2019; Cheng et al., 2020; Guzman and Oviedo, 2018; Lucas et al., 2016) have used  
200 the Gini coefficient or index (Gini, 1936) as measurements of transport equity from an egalitarian  
201 perspective of social justice. However, as Nazari et al. (2018) argued, the Gini coefficient is unable to  
202 capture how changes in equity are related to deprivation. To overcome this, they proposed an alternative  
203 criterion – vertical equity – that could be used to assess the association between changes in the  
204 vulnerability index and accessibility levels. Using a vertical equity indicator, Deboosere and El-Geneidy  
205 (2018) found that vulnerable individuals seem to experience higher levels of accessibility compared to  
206 other groups in most cities in Canada. To the best of our knowledge, no previous studies have applied  
207 the notion of vertical equity to investigating accessibility to GPs for older adults from a temporal  
208 perspective.

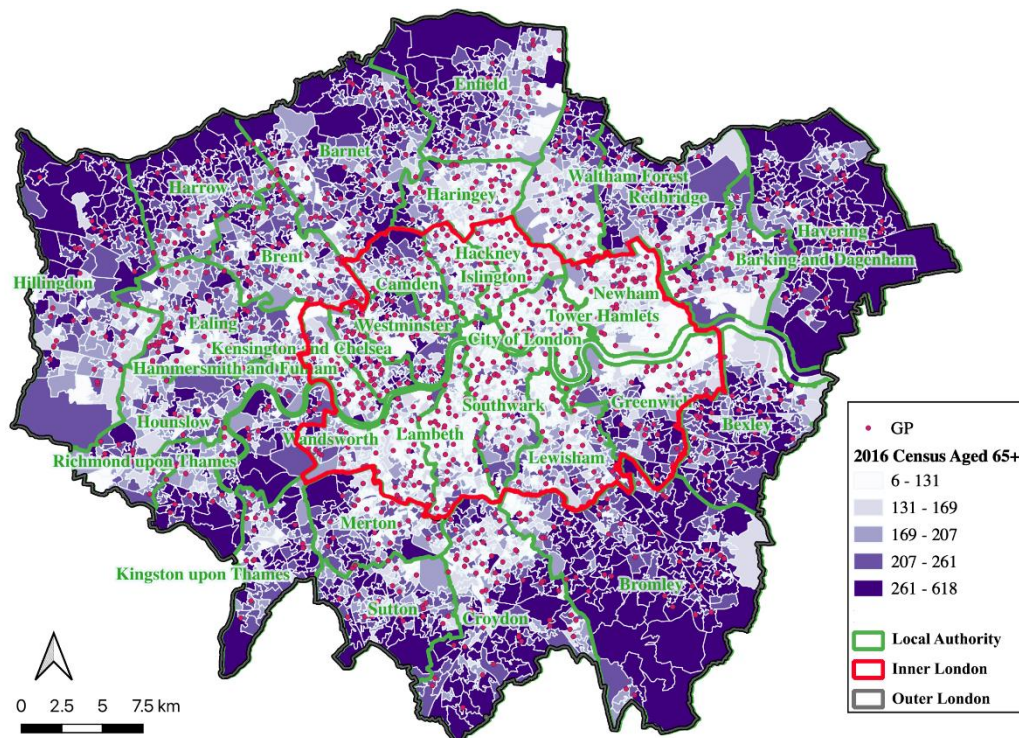
209

### 210 **3. Methods**

#### 211 **3.1 Study area and data**

212 Our case study is based on London. Like most major international cities, London has  
213 traditionally tended to revolve around the younger demographic; however, currently nearly 1.1 million  
214 of its residents are over 65 and this figure is estimated to increase at an unprecedented rate of 86% -  
215 much higher than that of the younger generation - in the next 30 years (GLA, 2018a). With regards to  
216 spatial distribution, the older population are more likely to live in Outer London (see Fig. 1). According  
217 to statistics produced by Trust for London in 2019, a small proportion of those living in Inner London  
218 are over 65 (9.5%), while the figure is 13.9% for Outer London. London is composed of 33 local  
219 authority districts (32 boroughs and the City of London) and 4,835 Lower Layer Super Output Areas

220 (LSOAs). This study measures accessibility at the LSOA level and compares degrees of vertical equity  
 221 at the local district level.  
 222



223 **Fig. 1. Study area and the distribution of older adults at LSOA level.**

224

225 Three datasets were used for this study. The first dataset consists of General Practice services  
 226 data and General Practice Opening Times data from NHS Choices (downloadable from  
 227 <https://data.gov.uk/search?filters%5Bpublisher%5D=NHS+Choices>). Acting as gatekeepers for access  
 228 to secondary care services (Hudson, 2015), GPs normally treat all common illnesses and refer patients  
 229 to hospital and other health services for urgent and specialist care. This data consists of geographical  
 230 information about a list of active GP branches and their opening times.

231 The London LSOA atlas, which contains demographic data at LSOA level, was retrieved from  
 232 the Office for National Statistics. An LSOA is a basic geographical unit for which census estimates are  
 233 provided in England and Wales. An LSOA typically contains 1,000-3,000 residents or 400-1,200  
 234 households. London is composed of 4,835 LSOAs, and the average population for each LSOA is  
 235 approximately 1,700. This study treats ‘older adults’ as those aged 65 and above (Allin et al., 2011).

236 The third dataset on the road network was derived from OpenStreetMap (OSM). This contains  
 237 data about eight types of roads, such as motorways, trunk roads and residential roads. The road network  
 238 data on different types of roads was prepared for further road network-based buffer generation. In  
 239 addition, this study also uses geographical London boundary data, and boundary data for 33 local  
 240 authorities.



### 241 3.2 Accessibility measurement

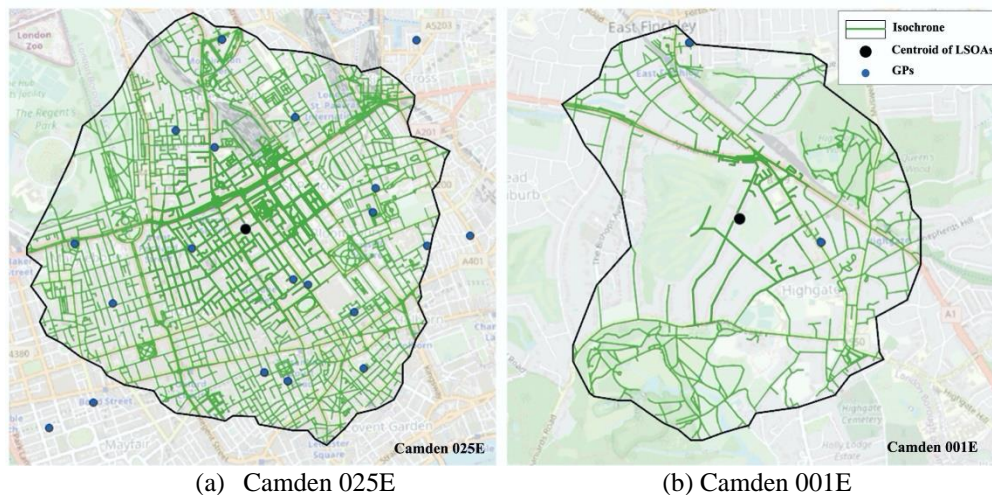
242 Despite the benefits of the 2SFCA, this study uses a cumulative method to calculate  
243 accessibility to GPs, taking 1,200 metres (Xiao et al., 2016) as the walking threshold. The main reason  
244 is that there are significant variations between the levels of health services provided by GPs in Greater  
245 London. In other words, using the number of GPs instead of the specific number of physicians or other  
246 indicators that more accurately reflect the capacity of the health services may lead potential biases in  
247 estimating accessibility in this case. Specifically, we calculated accessibility for every hour on a typical  
248 working day (Tuesday). The cumulative accessibility was calculated as follows:

$$249 \quad A_i = \sum_{j=1}^n O_j f(C_{ij}) \quad (1)$$

$$f(C_{ij}) = \begin{cases} 1 & \text{if } C_{ij} \leq d_{ij} \\ 0 & \text{if } C_{ij} > d_{ij} \end{cases} \quad (2)$$

250 Where  $A_i$  is the accessibility in the census tracts (LSOAs) from zone  $i$  to all GPs.  $O_j$  is the number of  
251 GPs available in zone  $j$ , and  $f(C_{ij})$  is an identifier *Equation*. If the travel cost (distance) from  $i$  to  $j$  is  
252 lower than the specified threshold  $d_{ij}$ , then  $f(C_{ij})$  is equal to 1, i.e., the GPs reachable within the  
253 thresholds are counted. If the travel cost (distance) from  $i$  to  $j$  is greater than  $d_{ij}$ , then  $f(C_{ij})$  is equal to  
254 0, i.e., the GPs reachable beyond the thresholds are not counted (El-Geneidy et al., 2016).

255 To capture the walking zones more accurately, we followed Vale's (2018) approach to generate  
256 road network-based traffic analysis zones (TAZs). Pedestrian networks were calculated using  
257 OpenStreetMap data for LSOA centroids. Compared to using the buffer areas, the road network-based  
258 TAZs are capable of more accurately defining the areas that can be reached within the specific walking  
259 distance thresholds, especially in areas where there are significant differences in road densities, as  
260 previous studies (Frank et al., 2017; Oliver et al., 2007) have found that land use characteristics are  
261 more likely to show statistically significant associations with road network-based buffers than circular  
262 buffers. Figure 2 shows an example of how accessibility to GPs was measured. The green lines indicate  
263 the 1,200m isochrones for two LSOAs (Camden 025E and Camden 001E). From this, it can be seen  
264 that Camden 001E has a lower level of accessibility than Camden 025E. This is not only because of the  
265 distribution of GPs (represented by blue points), but also due to the relatively low road density. Because  
266 of the unavailability of travel behaviour survey data on the older population in London, we applied a  
267 uniform distance in order to generate the buffers. However, it should be noted that this approach may  
268 result in more inaccuracies than the adaptive threshold approach (Cheng et al., 2019), based on the  
269 context-specific data.  
270



271 **Fig. 2. Example showing how accessibility to GPs is measured.**

272

### 273 3.3 The vertical equity measurement

274 In order to guide practical inclusive accessibility planning for each local authority district, or  
 275 borough, in London, we calculated a vertical equity indicator to discern accessibility to GPs for  
 276 older and young cohorts (those aged 65 and over, and those under 65). In contrast to horizontal equity  
 277 measurements, such as the Gini coefficient (Cao et al., 2019; Delbosc and Currie, 2011; Guzman et al.,  
 278 2017; Mayaud et al., 2019; Ricciardi et al., 2015), the vertical equity measure is able to directly reflect  
 279 the relationship between changes in accessibility and deprivation. In line with the approach adopted by  
 280 Cheng et al. (2019) and Adli and Donovan (2018), a vertical equity indicator was calculated based on  
 281 the Spearman's rank correlation coefficient between the rankings of accessibility to GPs and the  
 282 vulnerability index. In this case, the vulnerability index was estimated using the percentage of older  
 283 adults (i.e., those aged 65 and above) at LSOA level. The vertical equity indicator (VE, defined in Eq.  
 284 3) measures those boroughs with the highest need for GPs, as well as those with the highest level of  
 285 accessibility (Deboosere and El-Genedy, 2018). In other words, older adults living in boroughs with a  
 286 low level of vertical equity are likely to have limited access to GPs, and thus need to be prioritised for  
 287 interventions. The vertical equity index was then calculated for every four hours from 8:00 to 20:00 on  
 288 a typical weekday to reveal if there were any significant variations:

$$289 \quad VE^B = \frac{Cov(R_{Acc}, R_{Age})}{\sigma_{R_{Acc}}\sigma_{R_{Age}}} \quad (3)$$

290 Where  $VE^B$  indicates the vertical equity indicator at borough level, and  $Cov$  indicates the covariance  
 291 between the ranked accessibility  $R_{Acc}$  and the ranked vulnerability index-based on the percentage of  
 292 older people  $R_{Age}$ . The rankings are shown in decreasing order, i.e., the LSOA with  $R_{Age}$  of 1 has the  
 293 highest percentage of older adults within its boroughs, while the LSOA with  $R_{Acc}$  of 1 has the highest  
 294 degree of accessibility within its boroughs.  $\sigma_{R_{Acc}}$  and  $\sigma_{R_{Age}}$  are standard deviations. The vertical equity

295 indicator measures whether the borough with the highest percentage of older people also has the highest  
296 level of walking accessibility to GPs. If the vertical equity is equals to 1, it indicates that the borough  
297 with the highest ranking level of accessibility is also the highest ranking in terms of the percentage of  
298 the older adults (v) in that borough, compared to other boroughs (i.e. there is an appropriate match  
299 between them); whereas if the vertical equity is equals to -1, it means that the borough with the highest  
300 ranking level of accessibility ranks lowest with regard to the percentage of older adults (i.e. there is not  
301 an appropriate match between them). In the latter case, more interventions are needed to reduce  
302 inequalities within the borough.

303 Because the vertical equity index is a comparative indicator that can only reveal the relative  
304 equity between each administrative unit, this study also examined the degree of accessibility and  
305 vertical equity. It would not make sense to simply discuss equity in isolation, as higher equity does not  
306 necessarily mean that there is greater accessibility to GP services or more opportunities for participation.  
307 A min-max normalisation with a 0–1 range was then applied to calculate vertical equity and accessibility  
308 at the borough level. In order to inform practical planning more effectively, we classified 33 local  
309 districts by conducting K-means clustering (Likas et al., 2003) analysis, based on their normalised  
310 vertical equity and accessibility values. In the K-means clustering analysis, the elbow method was  
311 applied to select the optimal K number (Bholowalia and Kumar, 2014). This method allows us to use  
312 within-group homogeneity to evaluate the variability. In addition, there may be a concern about the  
313 vertical equity regarding why accessibility to general practitioners differs between different age cohorts  
314 at any particular point in time. The evidence suggests that older adults' understanding of and ability to  
315 use hospital reservation technology in the information age puts them at a disadvantage. Additionally,  
316 although some GPs may have clinics or GP sessions that are exclusively for older adults, they are the  
317 exception rather than the rule, and they are not sufficient to meet the needs of older adults for GP  
318 services. Thus, to a large extent, our measurement of vertical equity provides a more accurate reflections  
319 of reality and can thus serve our research aim.

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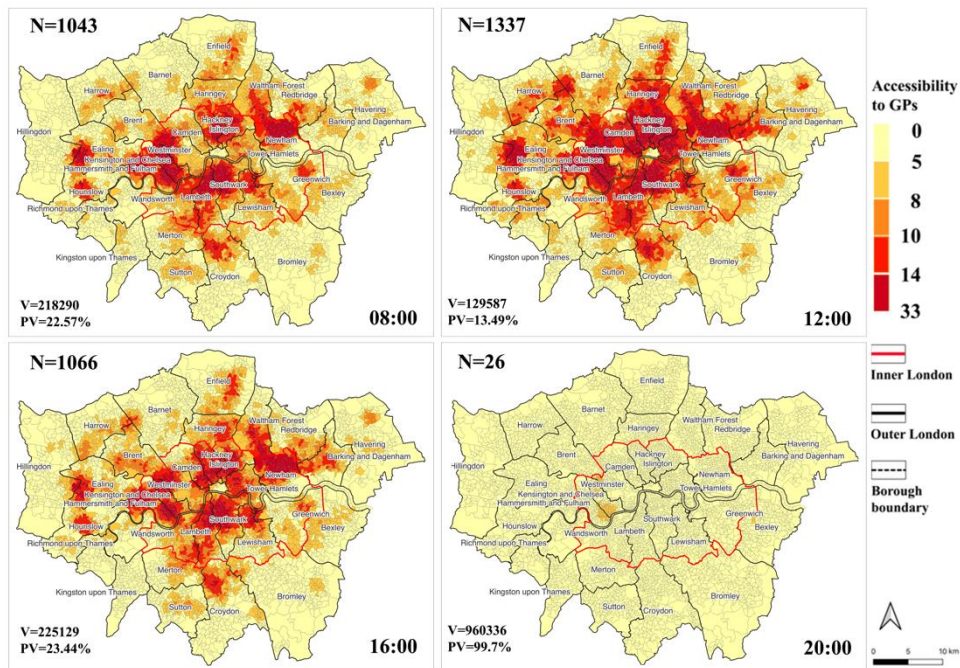
## 321 **4. Results**

### 322 **4.1 Temporal walking accessibility to GPs**

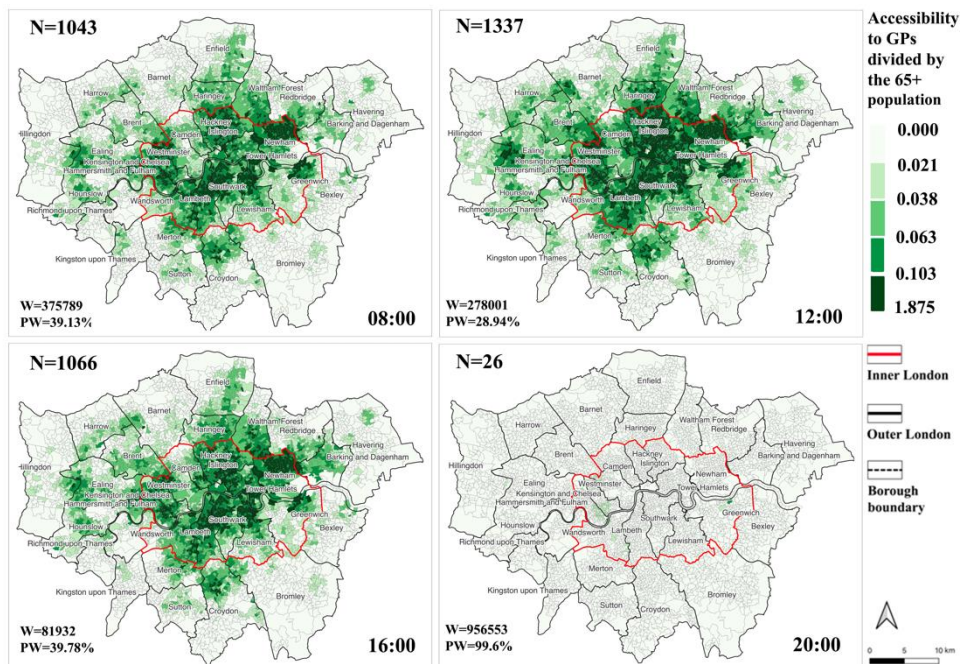
323 Before discussing accessibility to GPs for older adults in more depth, we first examine the  
324 general picture regarding temporal variations in accessibility to GPs in London on a typical weekday.  
325 As shown in Figure 3a, there are large fluctuations in accessibility from 8:00 to 20:00. Accessibility is  
326 greatest at 12:00 when nearly 15.88% of areas have a low degree of accessibility (below 5). Early in  
327 the morning (8 am) and later in the afternoon (4 pm), the figures are 26.08% and 26.10%, respectively.  
328 Correspondingly, 13.49% of the older cohort have low accessibility to GPs at 12:00, while a higher  
329 proportion – 22.57% and 23.44% - have low accessibility at 8:00 and 16:00, respectively. At 8 pm,  
330 1.63% of local areas offer very limited access to GPs, as only 26 GPs are open and all of those are  
331 located in the western part of Inner London. These findings confirm the necessity of taking the temporal

332 perspective into account in order to better understand accessibility. The static measure of accessibility  
333 analysis may overestimate accessibility, as it assumes that all GPs are open, when, in fact, this is not  
334 the case for London, as our findings show that, even at midday when accessibility is at its highest, not  
335 all GPs are open to patients. Furthermore, this research examines the weighted accessibility to GPs, the  
336 ratio of accessibility and the number of over 65s in each area. As shown in Fig. 3b, the general varying  
337 pattern of weighted accessibility is consistent with the accessibility in Fig. 3a. The weighted  
338 accessibility is greatest at 12:00 when nearly 19.50% of areas have a low degree of weighted  
339 accessibility (below 0.021). In the early morning (8 am) and late afternoon (4 pm), the figures are 39.13%  
340 and 39.78%, respectively. Correspondingly, 28.94% of the older cohort have low weighted accessibility  
341 to GPs at midday, while a higher proportion – 39.13% and 39.78% - have low weighted accessibility at  
342 8:00 and 16:00, respectively. By comparing accessibility and weighted accessibility, it can be found  
343 that more people in the older age group have limited accessibility to their GPs. For example, at 12:00  
344 p.m., 28.94% of the older population group has lower weighted accessibility, which is almost twice as  
345 high as accessibility when the number of older adults is not weighted.  
346





(a)



(b)

347

348 **Fig. 3. a) Spatial variations in accessibility to GPs during four different time periods on a typical weekday.**

349 **b) Spatial variations in weighted accessibility to GPs during four different time periods on a typical**

350 **weekday (N indicates the number of GPs that are open; V and PV indicate the number and the percentage of**

351 **people in the older age group with a low level of accessibility (<5) to GPs; W and PW indicate the number and**

352 **the percentage of people in the older population group with low weighted accessibility to GPs (<0.021); The**

353 **quantile classification of (weighted) accessibility at 12p.m. is used for four time periods. More information about**

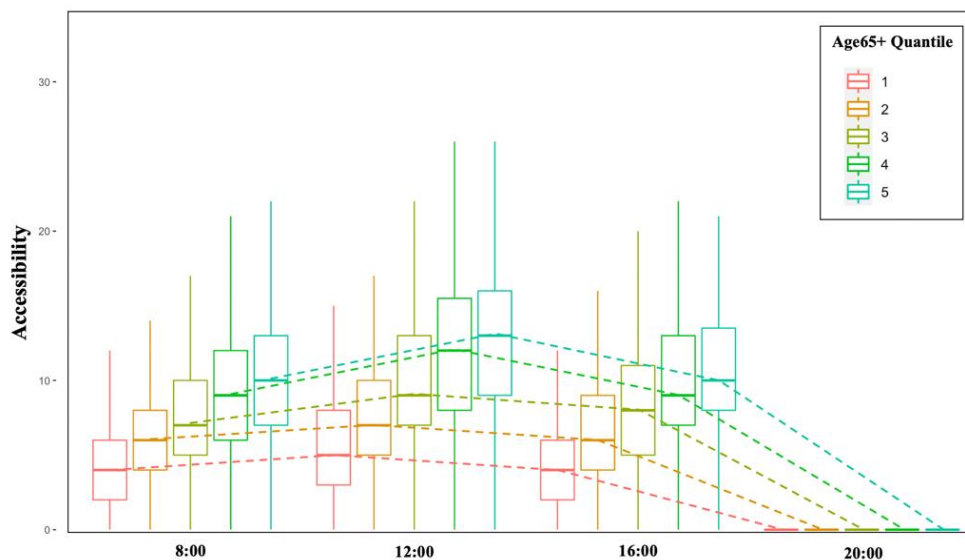
354 **variations in accessibility from 7:00 am to 9:30 pm can be found at [GitHub](#)).**

355

356

357

358 With regards to spatial distribution, the areas with higher levels of accessibility are mainly  
 359 concentrated in Inner London, although there are a few areas in Outer London that also have high  
 360 accessibility levels, such as several LSOAs in Ealing, Hounslow and Croydon (labelled in Fig. 3a).  
 361 Focusing now on accessibility to GPs for older adults in London, the boxplot in Figure 4 shows the  
 362 variations in accessibility during four different time periods on a typical weekday, classified by  
 363 quantiles, based on the percentage of older residents living in each of the LSOAs. The results show an  
 364 evident disparity between accessibility for the older population and other population groups. In other  
 365 words, older people in London are more likely to experience relatively low levels of accessibility, which  
 366 may lead to social exclusion. More specifically, by comparing the first quantile and the fifth quantile,  
 367 it can be seen that accessibility in areas with the lowest ratio of older people is roughly 2.1 times higher  
 368 than for areas with the highest ratio of older residents. This finding can probably be explained by the  
 369 fact that the majority of older people live in Outer London where the distribution density of GPs is  
 370 lower.  
 371

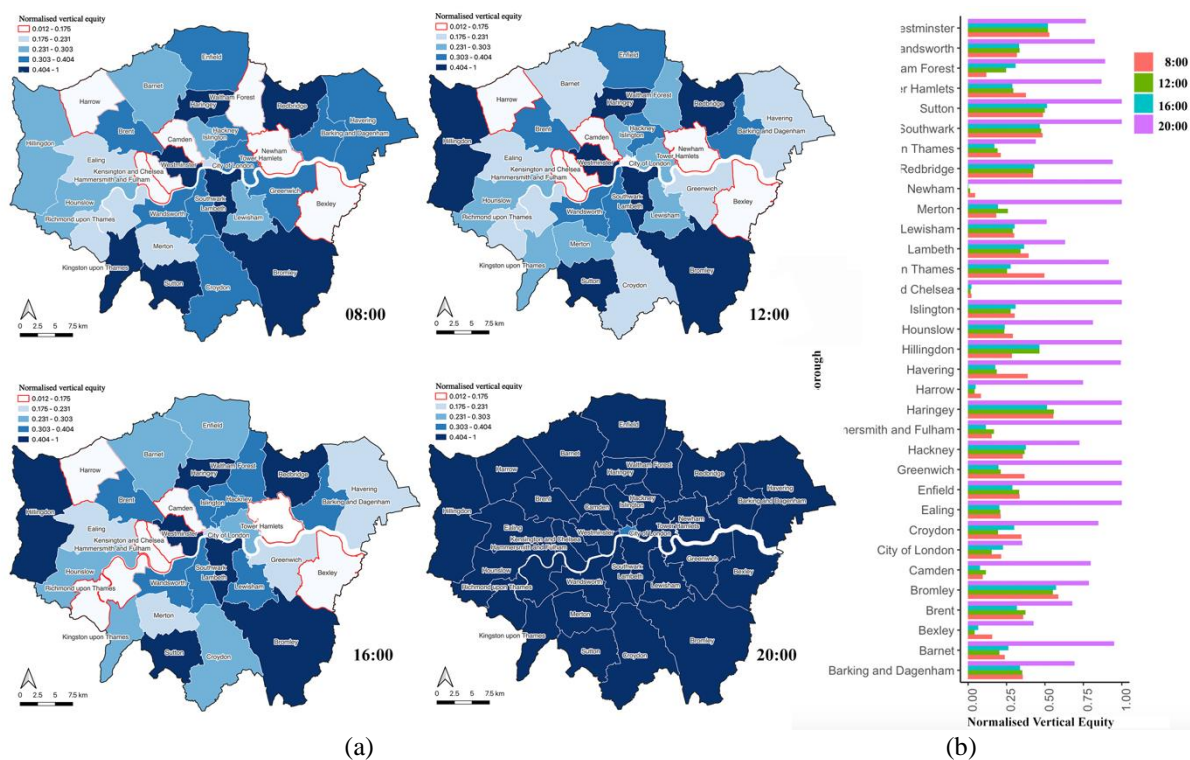


372 **Fig. 4. Variations in walking accessibility to GPs by individuals over 65 during four different time periods**  
 373 **on a typical weekday.**  
 374

#### 375 **4.2 Temporal equity and accessibility**

376 Following the above discussion of varying accessibility levels, we now further examine the  
 377 temporal variations in vertical equity at local authority district (borough) level and compare how vertical  
 378 equity changes in relation to accessibility to GPs. Similar to the results for accessibility, vertical equity  
 379 exhibits changes over time and some districts show substantial changes between 8:00 and 18:00 (see  
 380 Fig. 5). For example, the degrees of vertical equity for Waltham Forest at 8:00, 12:00 and 18:00 are  
 381 approximately 0.12, 0.25 and 0.31, respectively. Furthermore, it can be seen that the patterns of  
 382 variation differ between areas. For instance, some districts, such as Merton, reach their highest level of

383 vertical equity at midday. However, in the case of Tower Hamlets, the highest equity level is reached  
 384 at 8:00 am and it then gradually decreases until 6 pm. The variations in vertical equity are inconsistent  
 385 with the findings of Järv et al. (2018) who showed that equity levels for grocery stores in Tallinn  
 386 remained stable during the day time. Interestingly, but not surprisingly, vertical equity reaches its  
 387 highest level at 8 pm, after most GPs have closed, and accessibility levels for most boroughs are low.  
 388 Therefore, we argue that the heterogeneity in equity over different time periods also confirms that the  
 389 static equity measure may sometimes overestimate or underestimate vertical equity.

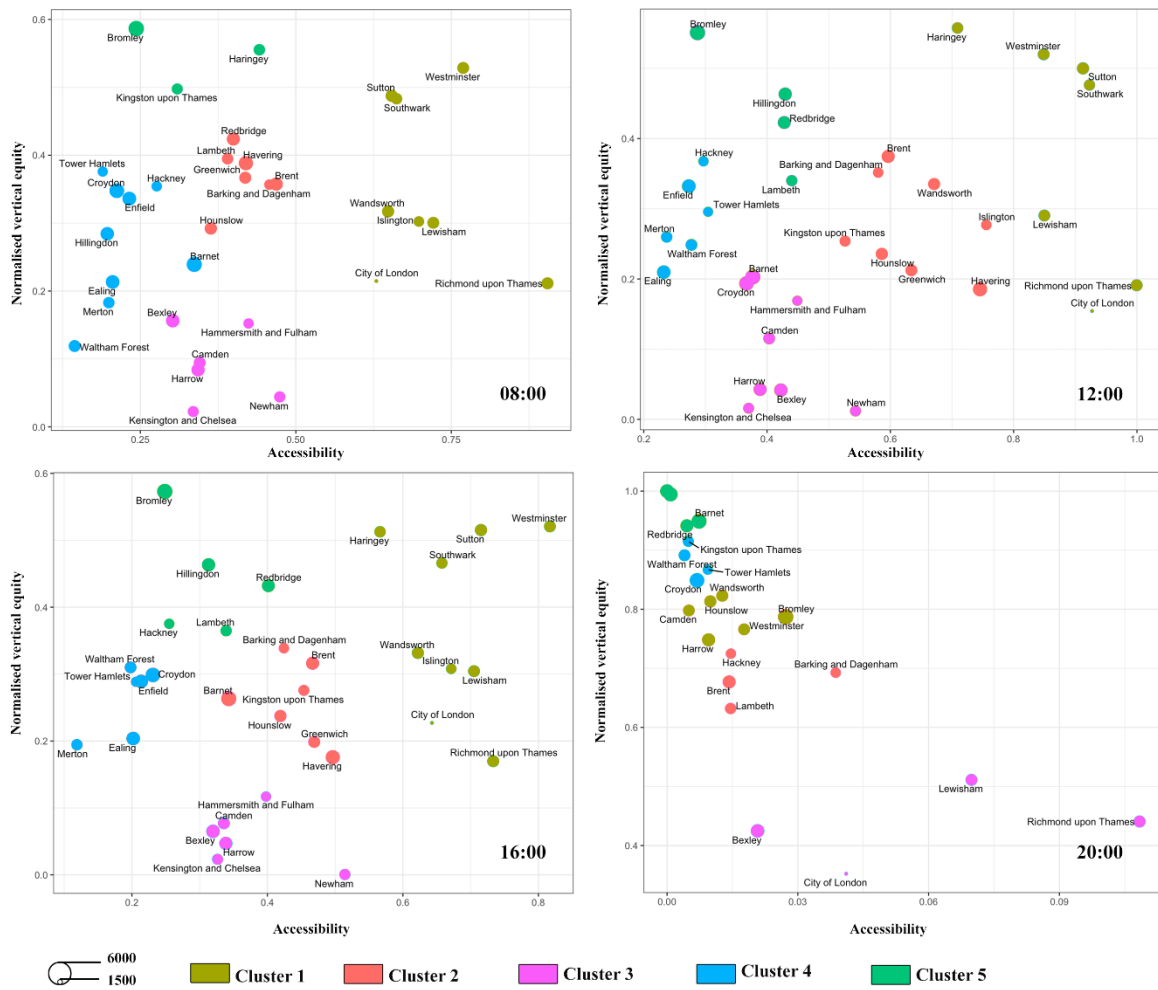


390 **Fig. 5. (a) Vertical equity at London borough level during four different time periods on a typical**  
 391 **weekday (The quantile classification of vertical equity at 12p.m. is used for the four time periods); (b) Vertical**  
 392 **equity index.**

393  
 394 As Deboosere and El-Geneidy (2018) argued, the optimal case is the borough located at point  
 395 (1,1), which represents an area with adequate and equitable health services. This point indicates that  
 396 older adults would find it relatively easy to access GPs, and that accessibility is evenly distributed  
 397 between older adults and other population groups. In contrast, the least desirable case is that of the  
 398 boroughs located close to point (0, 0), where health services are inadequate and inequitable. These  
 399 boroughs have significant disparities in accessibility between various age groups and a low overall  
 400 degree of accessibility to health services. To better capture each local district's performance and provide  
 401 more tailored guidance for future planning, K-means cluster analysis was applied between normalised  
 402 vertical equity and accessibility. Five clusters were obtained (Fig. 6). For the purpose of discussion, we  
 403 focus specifically on the clustering results obtained at 8:00, 12:00, and 16:00, given that 20:00 is an

404 exceptional case because most GPs have closed by then. Of the five clusters, districts in Cluster 1 such  
405 as Westminster, Sutton and Southwark, perform well both in terms of accessibility and vertical equity.  
406 Cluster 2 (e.g., Hounslow and Greenwich) is characterised by a relatively high degree of vertical equity  
407 and accessibility. Compared to Cluster 1 and Cluster 2, the other three clusters require more attention  
408 and policy interventions from local authorities. Cluster 3 (e.g., Kensington and Chelsea, Bexley) has a  
409 medium level of accessibility, but there are significant spatial disparities between the older population  
410 and other population groups. Therefore, local authorities need to introduce some more inclusive policies  
411 in these areas, such as extending the opening hours of GPs where there is a high concentration of older  
412 people. Cluster 4 and Cluster 5 are characterised by relatively high levels of vertical equity and low  
413 levels of accessibility. Bromley represents an extreme case where older adults have very limited  
414 opportunities to gain access to GPs. There is no statistically significant evidence that shows disparities  
415 in accessibility between older population groups and others. In this case, vertical equity seems to be  
416 insignificant, as the overall degree of accessibility is relatively low. Therefore, the relevant local  
417 authorities should make it a priority to improve overall accessibility to GPs in these two boroughs. The  
418 vertical equity and accessibility indicators can be used as a reference for comparing various scenarios  
419 and optimising the local distribution of GPs in these districts to create an environment with better  
420 accessibility for older adults.





421 **Fig. 6. Temporal variations in vertical equity and accessibility to GPs at local authority district level**  
 422 (circle size indicates the proportion of older people living in each local authority district).  
 423

424 **5. Discussion and Conclusions**

425 Since 2013, the NHS has placed much emphasis on the importance of adequate access to GPs  
 426 (Iacobucci, 2013), particularly for vulnerable groups, such as older people. However, current literature  
 427 has paid little attention to accessibility to health services, either in terms of accessibility among the  
 428 older population or from a temporal perspective. This study used the cumulative accessibility approach  
 429 to investigate walking accessibility to GPs for older adults in London, with a particular focus on the  
 430 added value of incorporating a temporal dimension into our understanding of accessibility.

431 This study has four key findings. First, the empirical results revealed large variations in  
 432 accessibility on a typical weekday in London. Overall accessibility peaked at midday when  
 433 roughly 15.88% of areas have a low degree of accessibility. Second, we found that there were  
 434 discrepancies in accessibility between older people and others. Accessibility in areas with the lowest  
 435 proportion of older adults is approximately 2.1 times higher than in areas with the highest proportion  
 436 of older residents. Third, the vertical equity measure not only revealed a high level of heterogeneity in  
 437 terms of spatial distribution of accessibility, but also exhibited varying trends over time. Fourth, using

438 K-means clustering on the vertical equity and accessibility indicators, this study classified the local  
439 authority districts into five groups and suggested corresponding policy guidance, especially for those  
440 districts that were characterised by a low level of accessibility and significant spatial disparities in  
441 accessibility.

442 The significance and novelty of this study is threefold. First, gaining insights into the spatio-  
443 temporal variations in accessibility to GPs represents a key step towards providing optimal services, in  
444 terms of spatial distribution and opening hours. This study is the first attempt to examine the temporal  
445 variations in accessibility to GPs for older people in London. The first-hand evidence it provides could  
446 serve as a robust reference for the Mayor of London and local authorities in their plans to achieve  
447 London's health equality plans (GLA, 2018b). More specifically, in addition to spatial distribution  
448 planning, there should be a greater focus on temporal planning, such as the opening hours and start  
449 times of GP surgeries, both of which will help planners and policymakers to achieve a more equal and  
450 healthier city. Second, in line with the existing studies (e.g., Geurs and van Wee, 2004; Boisjoly and  
451 El-Geneidy, 2016; Lee and Miller, 2018), our study corroborates that the measurement of accessibility  
452 can be sensitive to temporal constraints on opportunities. Therefore, it is necessary to incorporate a  
453 temporal perspective into analysing accessibility and vertical equity. The static measures of  
454 accessibility that have traditionally been used may overestimate the accessibility, as well as either  
455 overestimating or underestimating the degree of vertical equity; thus, merely using the static  
456 measurement may lead to possible biases in the findings. Third, in order to inform practical planning  
457 more effectively, we carried out a clustering analysis to classify local authorities based on their  
458 accessibility and equity levels. Although there is no 'one size fits all' policy, this classification based  
459 on vertical equity and accessibility nonetheless offers useful guidance for comparing different types of  
460 interventions and optimising the local distribution of GPs. The assessment of vertical equity will also  
461 help local authorities to identify those neighbourhoods which are unfriendly towards the health needs  
462 of the older population cohort and thus in greater need of GPs, as well as to develop tailored policy  
463 packages to promote healthier and ageing-friendly communities.

464 In particular, more attention needs to be paid to the districts identified as having lower levels  
465 of accessibility and significant disparities. This study also provides an example of how a temporal  
466 method can be used to examine the accessibility and vertical equity for the older age group. The  
467 analytical approach could also be used in other types of accessibility research examining various  
468 vulnerable groups, as well as studies set in other UK or even international cities.

469 We recognise that our analysis has some limitations, as well as areas for further development.  
470 First, this study uses the number of GPs as a measure; however, this may not adequately reflect all  
471 practical health services available or the capacities of services. Therefore, future studies could use  
472 additional measures or proxies, such as the number of NHS staffs or the areas covered by GPs.  
473 Furthermore, if the data was available, future research could also include more different types of health  
474 facilities, such as clinics and hospitals. Second, it would be more reasonable to integrate the distance

475 decay functions (e.g., Exponential function) into the accessibility estimation to capture how  
476 accessibility to GPs changes relative to the walking distance, as the walkers are sensitive to the travel  
477 distance (Vale and Pereira, 2016). Furthermore, this study only examined temporal variations on a  
478 weekday using a limited temporal resolution. Therefore, a finer grained approach, using temporal  
479 variations with smaller temporal resolutions (Stępniaak et al., 2020) could be further explored - for  
480 instance, variations in accessibility for every half an hour. Third, our research is premised on the  
481 assumption that the older adults residing in various areas have the same demand for health services, but,  
482 in fact, the utilisation of health services can vary greatly among the older population. It would therefore  
483 also be of great interest to consider the dynamic demand for health services among older people  
484 (Neutens, 2015) in a future study. Finally, a normative walking distance threshold of 1,200 metres was  
485 chosen in this study; however, age heterogeneity within the 65-plus population could play a crucial role,  
486 which could be taken into consideration in order to decide on an appropriate walking distance threshold  
487 in different contexts in future studies.  
488

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