Potential hospital care accessibility scores: association with
healthcare utilization and non-hospital care service accessibility

Fei Gao^{1,2}, Matthieu Jaffrelot^{1,4}, Séverine Deguen^{1,3}

Author Affiliation

¹ EHESP, F35000 Rennes, France

² Univ Rennes, EHESP, REPERES (Recher

³ INSERM, Sorbonne Université, Institut Pierre Louis d'Épidémiologie et de Santé Publique,
IPLESP, Department of social epidemiology, F75012 Paris, France ;

⁴ Univ Rennes, Ensai, F-35000 Rennes, France

Address for correspondence

Fei GAO

EHESP School of Public Health, Department of Quantitative Methods for Public Health,
Rennes, France

Avenue du Professeur Léon Bernard – 35043 Rennes - France

Tel: + 33 2 99 02 25 35

Fax: + 33 2 99 02 26 76

Email: fei.gao@ehesp.fr

Abstract

Background: Optimal healthcare access improves people's health status and decreases health inequalities. Many studies demonstrated spatial access importance in health outcomes. Recent studies assessed spatial healthcare access using the enhanced two-step floating catchment area (E2SFCA) method. The aim of this study was to build a hospital facility access indicator at a fine geographic scale and to determine whether there is a complementarity between non-hospital and hospital care accessibility by investigating the length of hospital stays (LOS).

Methods: This study focused on the ≥ 75 -year-old population of the Nord administrative region of France. Hospital spatial accessibility was computed with the E2SFCA method, and then the LOS score was calculated from the French national hospital activity and patient discharge database. Linear regression models were used to analyze the relationship between LOS and spatial accessibility to hospital-based care and to the three types of non-hospital care services (general practitioners, physiotherapists, and home-visiting nurses).

Results: Overall, there were 19.0 beds in Medical, Surgical and Obstetrics (MCO) facilities and 5.58 beds in Postoperative and Rehabilitation Care facilities (SSR) per 10,000 inhabitants, but with important geographic variations. Accessibility to hospital services was higher for people in large urban areas, despite the dense population and the higher demand. In 2014, the mean LOS scores were 0.26 for MCO and 0.85 for SSR, with a non-homogeneous geographical repartition. Linear regression analysis revealed a strong negative and significant association between hospital and non-hospital care accessibility.

Conclusions: This is the first study to measure spatial accessibility to hospital-based cares in France using the E2SFCA method, and the first to investigate the relationship between spatial accessibility to hospital-based care facilities and three types of non-hospital care services and healthcare utilization (LOS). Our findings should help to take decisions about deploying additional beds and to identify the best locations for non-hospital care services. Moreover, they should also help to improve access, and to ensure the best coordination and sustainability of inpatient and outpatient services, in order to better cover the population's healthcare needs. Other international studies using multiple consensual indicators of healthcare outcomes and accessibility and sophisticated modeling methods should be developed.

Keywords: Potential accessibility, hospital care, non-hospital care, length of stay, E2SFCA, administrative data uses

1. BACKGROUND

Access to healthcare is widely recognized as the foundation of any high performing healthcare system. Ensuring a high degree of healthcare access improves people's health status and decreases health inequalities. Guaranteeing equal accessibility to healthcare facilities for everyone is an essential goal for international political organizations and national governments [1-5].

Access to healthcare can be determined by two complementary dimensions: spatial and non-spatial dimensions [6]. Spatial access varies across space and time, and consequently it is affected by location relationships and travel impedance. On the other hand, non-spatial access mainly focuses on socioeconomic conditions and cultural background, such as ethnicity, income, social class, education, and language ability [7]. Many studies have demonstrated that spatial access plays an important role in health outcomes [8-13].

The assessment of spatial access to healthcare services should take into account the care provided by various facility types. Indeed, in many countries, the healthcare system is based on a combined architecture: non-hospital care based on general practitioners who can address patients to other healthcare professionals (e.g. nurses, physiotherapists, specialists doctors) and hospital-based care [14, 15]. Non-hospital care represents the most significant primary care contributor in many countries, including developing countries [16,17], because it ensures an effective and generally faster service that covers the large majority of personal healthcare needs [18], and acts as the principal point of continuing care for patients [19]. Nevertheless, hospitals remain one of the key actors. Care provided by hospitals represents

1 a major part of people's consumption of healthcare and medical goods, especially in Europe.
2 In 2017, nine of the ten countries with the highest hospital discharge rates worldwide were
3 European Union member states [20]. Therefore, coordination and organization between
4 hospital and non-hospital care are critical for a successful healthcare system. This is
5 particularly true during pandemic situations when hospitals may reach a point of "complete
6 saturation" due increased influx of patients, and non-hospital resources may anticipate and
7 limit the number of hospitalizations and the consumption of hospital-linked resources [21,
8 22]. Therefore, it is essential to assess accessibility to non-hospital care and hospital-based
9 care and also to examine whether there is a complementarity relationship between these
10 care types [23].

11
12 In parallel, the complementarity between accessibility to self-employed practitioners and to
13 hospital facilities should be investigated also by analyzing healthcare utilization, as done in
14 many studies [24, 25]. Medical administrative databases are appropriate to analyze
15 healthcare utilization [26]. Traditionally, healthcare utilization has often been expressed in
16 terms of health outcomes and healthcare service volume. For instance, one classical
17 indicator is the length of hospital stays that can be interpreted as an indicator of healthcare
18 supply and treatment efficiency [15, 27-29]. Thus, it can be recognized as an indicator of the
19 quantity and quality of the healthcare delivered by the healthcare system.

20
21 In this context, the aim of this study was to analyze the spatial accessibility to hospital-based
22 care following three main complementary steps: 1) to build a hospital facility access
23 indicator at a fine geographic scale; 2) to measure health service utilization using the length
24 of hospital stays; and 3) to determine whether there is a complementarity between non-

hospital and hospital care accessibility. This analysis focused on the ≥ 75 -year-old population of the Nord administrative region of France. Indeed, in many countries including France, elderly people represent a growing proportion of the total population with an increasing number of age-related diseases. The challenge is to respond to their demand by offering healthcare adapted to their specific needs. Additionally, different healthcare sources are involved in the elderly patients' management: hospital facilities, and non-hospital care (e.g. general practitioners, physiotherapists, and home-visiting nurses).

The hospital facility access indicator (step 1) was built using the enhanced two-step floating catchment area (E2SFCA) method, one of the most widely used gravity-based approaches. Based on this method, two different spatial indicators have been constructed in France: the localized potential accessibility score developed by the French Research Institute in Health Economic institute (IRDES) at the municipality level in 2011 [30], and at the census block level for the Greater Paris area in 2019 [31]. In 2016, the index of spatial accessibility (ISA) at the census block level was implemented by Gao and al. [32]. However, one common limitation of these studies was the focus on non-hospital care services only. So far, no French indicator based on the E2SFCA method measured access to hospital healthcare at a very fine geographic scale.

2. METHODS

2.1. Study setting and population

This study was carried out in the Nord administrative region that is located in the north of France, with a surface area of 5743 km² and a population density of 456 inhabitants per km². Multiple non-hospital care accessibility indicators are available for this department [30-32].

Moreover, it has been shown that edge effects lead to minor accessibility variations in this area [33]. The study focused on the ≥ 75 -year-old population of this area.

2.2. Data sources and statistical unit

Multiple data sources were combined for the present study:

- (1) The accessibility to three types of non-hospital, self-employed practitioners (general practitioners, physiotherapists, and home-visiting nurses) was described using the Localized Potential Accessibility (Accessibilité potentielle localisée: APL) database [34]; Based on E2SFCA method, APL indicators are available at national level but only computed for non-hospital practitioners.
- (2) The number of available beds in each hospital was extracted from the Annual Statistical Survey of Healthcare Facilities 2014 database (Statistique Annuelle des Établissements: SAE) [35]. Facilities were classified in two categories: Medical, Surgical and Obstetrics facilities (Médecine, Chirurgie, Obstétrique: MCO) and Postoperative and Rehabilitation Care facilities (Soins de Suite et de Réadaptation: SSR);
- (3) The postal address of each hospital was obtained from the National File on Health and Social Institutions (Fichier national des établissements sanitaires et sociaux: FINESS) [36], and then converted into latitude and longitude using the French National Address Base [37];
- (4) The Length Of Stay (LOS) was calculated from the French national discharge database that collects hospital activity and patient discharge data [38-41]. We used MCO and SSR inpatient care data for the year 2014;

(5) The number of ≥ 75 -year-old people in the Nord administrative region was obtained from the 2016 French national Census [42].

The statistical unit was the French Geographic Code unit (FGC), defined by the French national discharge database. The FGC is approximately equivalent to the municipality postal code. The Nord department is divided into 240 FGCs with a population ranging from 1000 to 227 000 residents per FGC.

2.3. Methodology

First, the E2SFCA method was implemented to compute the hospital spatial accessibility by combining geographical, supply, and demand factors. Second, the LOS indicator was estimated for each FGC unit. Third, linear regression models were used to analyze the relationship between LOS and spatial accessibility to hospital-based care and also to the three types of non-hospital care services (general practitioners, physiotherapists, and home-visiting nurses).

2.3.1. Assessing hospital care spatial accessibility using the E2SFCA method

The E2SFCA method [43] was implemented to assess spatial accessibility [5, 32, 44], which can be easily interpreted as medical care density. The method was implemented in two steps, as follows:

Step1: For each hospital center j with a MCO or SSR facility, the number of beds in the MCO or SSR facility S_j was counted and the population living in the FGC area k and located within

1 a threshold drive time d_{max} from the hospital center j (i.e. catchment area j) was estimated.

2 Then, the bed-to-population ratio R_j within the catchment area j was determined with

3 Equation 1:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_{max}\}} P_k * w(d_{kj})} \quad \text{Equation (1)}$$

4
5 where P_k is the patient population in the FGC area k the centroid of which falls within the
6 catchment area j (i.e. $d_{kj} < d_{max}$), S_j is the number of beds available in the hospital center j ,
7 and d_{kj} is the driving time between the FGC area k and the hospital center j , and $w()$ is a
8 weighted decay function that depends on the driving time d_{kj} .

9
10 Step 2: For each population location i , all MCO or SSR facility locations j that were within the
11 threshold driving time d_{max} from location i (i.e. catchment area i) were estimated, and all R_k
12 for the catchment area were summed to calculate the Index of Spatial Accessibility (A_i) at
13 location i (Equation 2):

$$A_i = \sum_{j \in \{d_{ij} \leq d_{max}\}} w(d_{ij}) R_j \quad \text{Equation (2)}$$

14 where R_j is the bed-to-population ratio of the hospital center j , and d_{ij} is the driving time
15 between the FGC area i and the hospital center j .

16
17 All driving times from i to j were obtained using Google Maps and then computed by SAS
18 version 9.3 [45]. The E2SFCA accessibility score was calculated with the MYSQL program. The
19 definition of the decay function $w()$ and time thresholds were previously explained [32].

20 Briefly, when the travel time to a MCO and to a SSR facility was longer than 41 and 69

minutes, respectively, that hospital was considered too distant to be accessible. These distance decay parameters were used as cut-off distances to define the catchment areas.

$$LOS_i = \sum_{g>75} \frac{dms_g}{P_g} \quad \text{Equation (3)}$$

2.3.2. Measuring health service utilization using the LOS indicator

The LOS was defined as the mean hospital stay length of elderly people (≥ 75 years of age) relative to the total ≥ 75 -year-old population in a given FCG (Equation 3). In this equation, g represents the three groups of ≥ 75 -year-old people (75-84, 85-94 and >95 years), and P_g the corresponding total population for that age group. The numerator represents the average length of stay of each age group, standardized to the total population for that age group (inpatients or not) in the denominator.

2.3.3. Linear Regression Model and composite accessibility indicator by principal component analysis

A multiple ordinary least squares regression model was applied to investigate the relationship between MCO and SSR LOS (Y : the dependent variable) and the hospital accessibility indicators (MCO and SSR ISA) and the APL for the three non-hospital practitioners (general practitioners, physiotherapists, and home-visiting nurses) as regressors (Equation 4). As our variables were log-normally distributed, they were normalized using the logarithmic Napierian function.

$$\ln(LOS^*) = \beta_0 + \beta_1 \cdot \ln(ISA^*) + \sum \beta_n \cdot \ln(APL_n) + \varepsilon; \text{ with } \varepsilon \approx iid(0; \sigma^2) \quad \text{Equation (4)}$$

Where * signifies that the LOS for MCO (with the corresponding ISA as independent variable) and for SSR (with the corresponding ISA as independent variable) were modeled separately, and n defines the number of different types of non-hospital healthcare professionals considered in the analysis ($n=3$: general practitioners, physiotherapists, and home-visiting nurses).

To describe the global accessibility to the three non-hospital services, a composite index was built using principal component analysis (Equation 5).

$$\ln(LOS^*) = \beta_0 + \beta_1 \cdot \ln(ISA^*) + \beta_2 \cdot \ln(Composite\ APL) + \varepsilon; \text{ with } \varepsilon \approx iid(0; \sigma^2) \quad \text{Equation (5)}$$

3. RESULTS

3.1 Descriptive analysis and spatial distribution of the ISA values for MCO and for SSR facilities

In total, there were 240 FGC units in the Nord administrative region. Table 1 summarizes the ISA values for MCO and SSR facilities. On average, there were 19.0 beds in MCO and 5.58 beds in SSR for 10 000 inhabitants. The values revealed important variations among FGCs with a standard deviation of 10.6 and 2.23 beds per 10 000 inhabitants in MCO and SSR,

1 respectively. Almost 25% of the population had access to fewer than 10 beds in MCO and 4
2 beds in SSR.

3
4 To compare the spatial distribution of the ISA values for MCO (a) and SSR (b) per 10 000
5 inhabitants (Figure 1) within the Nord administrative region, scores were categorized in five
6 classes using the Jenks Natural Breaks algorithm, from low to high accessibility. The Jenks
7 Natural Breaks algorithm assigns values to a given number of classes with the objective of
8 minimizing the variance within classes, while maximizing the between-class means. The
9 highest MCO ISA values ([24.04; 32.71] and [32.72; 39.28]) were observed in urban areas
10 located in the northern part of the studied territory, close to Dunkerque, and also in the
11 center, around Lille, Roubaix and Tourcoing. Conversely, the lowest values were observed
12 mostly in the southern part and around Hazebrouck. The highest ISA scores for SSR ([6.05;
13 7.14] and [7.14; 9]) were concentrated in the middle part of the region, whereas access was
14 lower in the north and south. These findings showed that accessibility to hospital services is
15 higher for people in large urban areas, despite the dense population and consequently the
16 higher demand.

17 18 3.2 Elderly population and LOS spatial distribution

19 The elderly population was not homogeneously distributed over the studied territory. The
20 percentage of ≥75-year-old inhabitants varied from 3.79% (in the north-west area around
21 Dunkerque, and in the center, particularly the cities of Roubaix, Lille and Villeneuve d'Ascq)
22 to 11.91% (around Bailleul and Hazebrouck and below the Valenciennes-Cambrai line)
23 (Figure 2).

1 Analysis of the LOS in MCO and SSR facilities for the ≥ 75 -year-old population in the Nord
2 administrative region (Table 2) showed that in 2014, the mean LOS were 0.26 and 0.85 for
3 MCO and SSR, respectively. The spatial variation was important, with standard deviations of
4 0.20 and 0.92 for MCO and SSR, respectively.

5
6 Analysis of the MCO and SSR LOS score distribution in the studied region highlighted a non-
7 homogeneous repartition with higher values close to the border with other French regions,
8 especially in the southern part (Figure 3 and Figure 4). From Dunkerque to Bailleul and also
9 around Tourcoing, Roubaix, Lille and Orchies, LOS scores were lower. This suggests the
10 existence of spatial dependencies in LOS distribution within the studied territory. This
11 hypothesis was confirmed with the Moran test (p-value = 0.000 for both MCO and SSR LOS
12 scores).

14 3.3 Determinants of MCO and SSR LOS

15 To investigate the determinants of MCO and SSR LOS scores separately, two independent
16 least square regression models were implemented at the FGC scale, including the covariates
17 presented in the Data sources section. The LOS variable was log transformed to normalize its
18 distribution.

19
20 The three APL variables were based on the activity level of these self-employed general
21 practitioners and on the healthcare utilization rates in function of the inhabitant age group
22 in order to estimate more precisely the healthcare supply and demand in a given territory. A
23 composite APL was integrated in the Linear Regression Model to better describe the overall
24 non-hospital care service accessibility. This analysis revealed a strong negative and
25 significant association between the composite APL and the MCO and SSR LOS (Table 3).

Furthermore, the MCO ISA showed that LOS were shorter for patients living in areas where people had easier access to a MCO facility.

4. DISCUSSION

4.1 Summary of the results

To our knowledge, the present study is the first one to investigate the relationship between spatial accessibility to hospital-based care facilities (ISA index) and to three types of non-hospital care services (APL index for general practitioners, physiotherapists, and home-visiting nurses) and healthcare utilization based on a national hospital database (LOS). One of its main strengths is the cross-referencing of different data sources that allowed us to address several major public health issues.

First, following a previously developed methodology [32, 43], we estimated a measure of spatial accessibility to hospital care, for MCO and SSR facilities separately at the French Geographic Code scale (FGC, approximately equivalent to the municipality scale). However, all previous French studies that used a similar methodology limited their accessibility measure to non-hospital care services [30-32]. The present study originality lies in extending the measure to hospital spatial accessibility, by taking into account the number of beds in MCO and SSR facilities, the car travel time, and the population distribution. The MCO and SSR ISA were initially developed at the census block scale, then summarized to the FGC scale to investigate the association with the LOS indicator, because FGC is the smallest spatial level for which hospital data are available. Even at this spatial scale, ISA distribution

1 highlighted the unequal accessibility to MCO and SSR facilities within the study area. Analysis
2 of ISA spatial distribution revealed that high-accessibility areas were mainly concentrated in
3 the center of the investigated area. This can be partially explained by the large number of
4 MCO and SSR facilities (25 of the 44 MCO and 24 of 30 the SSR centers) in these areas.
5 However, we observed exceptions. Around Valenciennes, where there are three MCO
6 hospitals with more than 400 beds in total, the ISA values were in the lower class.
7 Conversely, although no MCO facility was located in or close to Bailleul, the ISA value for this
8 area was quite high. This finding is coherent with the fact that the ISA index provides a
9 summary measure of two important and related components of accessibility: the volume of
10 services available relative to the population size, and the proximity of services available
11 relative to the population location. Therefore, although 400 MCO beds were located close to
12 Valenciennes, the population's size was too important to obtain a high accessibility score.
13
14 Then, we examined the association between the healthcare utilization indicator (LOS) and
15 two accessibility scores (ISA and APL). Our analysis revealed a significant and negative
16 association between LOS and spatial accessibility to the three non-hospital care services
17 (general practitioners, physiotherapists, and home-visiting nurses). In other words, a better
18 accessibility to these non-hospital services corresponded to shorter hospital stays. This
19 suggests that hospital-based care facilities and non-hospital care services interact in a
20 complementary way. One explication is that in areas with better accessibility to the three
21 non-hospital care services, hospitalizations are shorter because of the presence of effective
22 outpatient care: ambulatory care and neighborhood healthcare services. For instance, home-
23 visiting nurses and physiotherapists could be an alternative solution to SSR inpatient care.
24 These results further support the idea of complementary interactions between non-hospital

1 and hospital services. These first findings should be complemented by research to determine
2 the impact of primary care accessibility on LOS.

6 4.2 Comparison with the international literature

7 Previous studies have paid attention to healthcare spatial accessibility and the question of
8 whether healthcare activity could be rebalanced by expanding/strengthening the role of
9 primary care relative to the more costly hospital (secondary) care. However, much of the
10 recent research on geographic healthcare access has focused on assessing the potential
11 access to healthcare services, rather than on their utilization [46, 47]. Most studies that
12 focused on the use of primary care to reduce specialty/inpatient care were observational
13 studies in which the rates of preventable hospitalizations were correlated with the self-rated
14 access level [48] or distance [49, 50] to primary care services [51]. Few studies quantified
15 both hospital and non-hospital care spatial accessibility with the E2SFCA method, and
16 investigated their association with the length of hospital stay. The present study fills this gap
17 by integrating three factors: spatial accessibility (1) to hospital care facilities and (2) to three
18 types of non-hospital care (general practitioners, physiotherapists, and home-visiting
19 nurses), and (3) length of hospital stays. As few studies have considered all three with a
20 similar study design, comparison with the international literature was difficult. However, we
21 could find few studies that investigated one or two of these aspects. First, although this is
22 the first French study measuring hospital spatial accessibility using the E2SFCA method,
23 other countries, for instance China [52] and Japan [44], already developed hospital
24 accessibility scores following a similar approach. Second, other studies estimated the LOS to

1 assess how primary care could contribute to reduce the demand of secondary care. In
2 France, a study used the LOS for public-sector psychiatric facilities to investigate whether the
3 development of alternatives to full-time hospitalization (such as ambulatory care, part-time
4 hospitalization, and full-time outpatient care) may reduce the LOS [15]. They found a
5 significant negative association and concluded that their study was the first to provide
6 nation-wide evidence of the benefits of alternatives to full-time hospitalization in psychiatry.
7 Similarly, our study is the first to show that non-hospital care services may reduce the MCO
8 and SSR LOS. Our findings and those of this study in psychiatry suggest that in some cases,
9 non-hospital care services may constitute an alternative to hospitalization. Our results were
10 obtained by modeling the association between healthcare utilization and accessibility to two
11 types of healthcare services. These preliminary quantitative results should be supplemented
12 by data on other healthcare outcomes frequently associated with the quality of care, such as
13 unplanned readmission or mortality, as well as other aspects of accessibility (e.g. multiple
14 consensual indicators of spatial/non-spatial healthcare access). Additional studies using
15 sophisticated modeling methods should also be developed. The goal is to develop a
16 consolidated approach to facilitate the spatial organization of non-hospital medical services
17 in the territory with the aim of complementing hospital services and increasing healthcare
18 efficiency.

20 4.3 Limitations

21 As we used aggregated data at the FGC scale to assess associations between spatial
22 accessibility to hospital and to three types of non-hospital care services and healthcare
23 utilization, our findings may be subject to an ecological bias [32]. In addition, as previously
24 explained, while the ISA index was estimated at the census block scale, the two other

indicators (LOS and APL) were only available at the FGC scale, a cruder spatial scale. Thus, we could not take into account the spatial accessibility heterogeneity at the census block scale. For future research, we want to construct a LOS indicator at a finer scale using disaggregation techniques that take into account the population density.

In our analysis, we did not use statistical techniques that consider spatial autocorrelation. However, at the FGC scale, the Moran's indicator revealed the presence of spatial autocorrelation for both MCO and SSR LOS. To investigate more precisely the association of healthcare accessibility and utilization, the next step could be to consider the specificity of the study area by including its topological, geometric and geographic properties using spatial statistical models, such as the simultaneous autoregressive model, geographically weighted regression and Bayesian hierarchical model. Previous studies [53-57] demonstrated the robust properties of these models that can improve the methodology used to assess associations between healthcare spatial accessibility and utilization. For instance, Nicholas et al used Bayesian spatial models and location analysis methods to evaluate healthcare facility access [58].

5. CONCLUSION

This is the first study to measure spatial accessibility to MCO and SSR facilities in France using the E2SFCA method and to investigate the relationship between spatial accessibility to hospital-based care facilities and to non-hospital care services. It provides a basic understanding of the status of inpatient care within the studied area by showing the accessibility score variation across the territory and highlighting some areas with poor accessibility. This type of information is important to guide policy makers and local

managers. Moreover, our findings suggest that hospital-based and non-hospital care services (general practitioners, physiotherapists, and home-visiting nurses) interact in a complementary way. Based on this research, policy makers and local managers could identify areas where additional beds or healthcare professionals should be allocated in priority.

Additional studies in other areas characterized by their own specificity have to be developed in order to confirm our results. It is also crucial to design new research approaches to understand the underlying mechanisms and processes that explain the interaction between hospital-based and non-hospital care services with the ultimate objective of better organizing and allocating medical resources. This research should help to take decisions about deploying additional beds and identifying the best locations for non-hospital care services, and also to improve access, to ensure the best coordination and to contribute to the sustainability of inpatient care and outpatient services, in order to better cover the health needs of the population.

ABBREVIATIONS

APL: Localized Potential Accessibility
E2SFCA: Enhanced two-Step Floating Catchment Area
FINESS: National File on Health and Social Institutions
FGC: French Geographic Code unit
ISA: Spatial Accessibility Index
MCO: Medical, Surgical and Obstetrics

1 SAE: Annual Statistical Survey of Healthcare Facilities

2 SSR: Postoperative and Rehabilitation Care

3 LOS: Length Of Stay

4

5 DECLARATIONS

6 ETHICS APPROVAL AND CONSENT TO PARTICIPATE

7 Not applicable

8

9 CONSENT FOR PUBLICATION

10 Not applicable

11

12 AVAILABILITY OF DATA AND MATERIAL

13 All data generated or analyzed during this study are included in this published article. If

14 readers need supplementary information, they can contact me (fei.gao@ehesp.fr).

15

16 COMPETING INTERESTS

17 The authors declare that they have no competing interests.

18

19 FUNDING

20 Not applicable.

21

22 AUTHORS' CONTRIBUTIONS

1 FG designed the project, performed the statistical analysis and drafted the manuscript. SD
2 supervised the overall project, oversaw the statistical analysis, and helped to draft and
3 revised the manuscript. MJ performed the statistical analysis with FG and SD. All authors
4 interpreted the data and reviewed the manuscript for important intellectual content. All
5 authors have read and approved the final version of the manuscript.

6 7 ACKNOWLEDGEMENTS

8 This research is supported by EHESP Rennes, REPERES—EA 7449, IPLESP and ENSAI. We are
9 extremely grateful to JB Combes, M. PICHOT-UTRERA et A. TALEC for their commitment and
10 their role in the success of the study. Points of view or opinions in this article are those of
11 the authors and do not necessarily represent the official position or policies of the EHESP
12 Rennes, REPERES—EA 7449, IPLESP and ENSAI.

13 14 REFERENCES

15 [1] United Nations Transforming our world: The 2030 Agenda for Sustainable Development.
16 Available online: <https://sustainabledevelopment.un.org/post2015/transformingourworld/>
17 (accessed on 25 September 2015).

18 [2] Zhu L, Zhong S, Tu W, Zheng J, He S, Bao J, Huang C. Assessing Spatial Accessibility to
19 Medical Resources at the Community Level in Shenzhen, China. Int J Environ Res Public
20 Health. 2019 Jan 16;16(2). pii: E242. doi: 10.3390/ijerph16020242.

21 [3] Shah T, Bath B, Hayes A, Jones M, Bell S, Uswak G, Milosavljevic S. Comparative Analysis
22 of Geographic Accessibility of Dentists, Physiotherapists and Family Physicians in an Urban

1 Centre: A Case Study of Saskatoon, Canada. *J Can Dent Assoc.* 2019 Jul;85:j2. PMID:
2 32119638.

3 [4] Not enough there, too many here: understanding geographical imbalances in the
4 distribution of the health workforce. Dussault G, Franceschini MC. *Hum Resour Health.* 2006
5 May 27;4:12. doi: 10.1186/1478-4491-4-12.

6 [5] McGrail MR. Spatial accessibility of primary health care utilising the two-step floating
7 catchment area method: An assessment of recent improvements. *Int. J. Health Geogr.* 2012,
8 11, 50.

9 [6] Tang JH, Chiu YH, Chiang PH, Su MD, Chan, TC. A flow-based statistical model integrating
10 spatial and nonspatial dimensions to measure healthcare access. *Health Place.* 2017
11 Sep;47:126-138. doi: 10.1016/j.healthplace.2017.08.006. Epub 2017 Sep 4.

12 [7] Wang FH, Luo W. Assessing Spatial and Nonspatial Factors for Healthcare Access:
13 Towards an Integrated Approach to Defining Health Professional Shortage Areas. *Health &*
14 *Place* 2015, 11(2):131-46. doi: 10.1016/j.healthplace.2004.02.003.

15 [8] Héquette-Ruz R, Beuscart JB, Ficheur G, Chazard E, Guillaume E, Paccou J, Puisieux F,
16 Genin M. Hip fractures and characteristics of living area: a fine-scale spatial analysis in
17 France. *Osteoporos Int.* 2020 Mar 5. doi: 10.1007/s00198-020-05363-7.

18 [9] Graham S, Hallisey E, Wilt G, Flanagan B, Rodriguez JL, Peipins L. Sociodemographic
19 disparities in access to ovarian cancer treatment. *Ann Cancer Epidemiol.* 2019 Nov;3. doi:
20 10.21037/ace.2019.10.02. Epub 2019 Nov 27.

21 [10] Buchmueller TC, Jacobson M, Wold C. How far to the hospital? The effect of hospital
22 closures on access to care. *J. Health Econ.* 2006, 25, 740–761.

- 1 [11] Wang F, McLafferty S, Escamilla V, Luo L. Late-Stage Breast Cancer Diagnosis and Health
2 Care Access in Illinois. *Prof Geogr.* 2008 Feb;60(1):54-69. doi: 10.1080/00330120701724087.
- 3 [12] Alkire BC, Raykar NP, Shrimel MG, Weiser TG, Bickler SW, Rose JA, Nutt CT. Greenberg
4 SLM, Kotagal M, Riesel JN et al. Global access to surgical care: A modelling study. *Lancet Glob*
5 *Health.* 2015 Jun;3(6):e316-23. doi: 10.1016/S2214-109X(15)70115-4. Epub 2015 Apr 27.
- 6 [13] Clarke JR, Trooskin SZ, Doshi PJ, Greenwald L, Mode CJ. Time to laparotomy for intra-
7 abdominal bleeding from trauma does affect survival for delays up to 90 minutes. *J Trauma.*
8 2002 Mar;52(3):420-5. doi: 10.1097/00005373-200203000-00002.
- 9 [14] https://www.cleiss.fr/particuliers/venir/soins/ue/systeme-de-sante-en-france_en.html
- 10 [15] Gandré C, Gervais J, Thillard J, Macé JM, Roelandt JL, Chevreul K. The Development of
11 Psychiatric Services Providing an Alternative to Full-Time Hospitalization Is Associated with
12 Shorter Length of Stay in French Public Psychiatry. *Int J Environ Res Public Health.* 2017 Mar;
13 14(3): 325. Published online 2017 Mar 21. doi: 10.3390/ijerph14030325.
- 14 [16] Karpel MS. Using patient classification systems to identify ambulatory care costs. CBS
15 Business Network. Retrieved 25 July 2011.
- 16 [17] Berman P. Organization of ambulatory care provision: a critical determinant of health
17 system performance in developing countries. *Bulletin of the World Health Organization.*
18 2000. 78 (6): 791–802. PMC 2560790. PMID 10916916.
- 19 [18] Institute of Medicine (US) Committee on the Future of Primary Care, Donaldson MS,
20 Yordy KD, Lohr KN, Vanselow NA, eds. *Primary Care: America's Health in a New Era.*
21 Washington (DC): National Academies Press (US); 1996.

- 1 [19] World Health Organization. (2018). Continuity and coordination of care: a practice brief
2 to support implementation of the WHO Framework on integrated people-centred health
3 services. World Health Organization. <https://apps.who.int/iris/handle/10665/274628>.
- 4 [20] Hospital discharges and length of stay statistics. Eurostat:
5 <https://data.oecd.org/healthcare/hospital-discharge-rates.htm>. Accessed 14 April 2020.
- 6 [21] Committee on Guidance for Establishing Crisis Standards of Care for Use in Disaster
7 Situations; Institute of Medicine. Crisis Standards of Care: A Systems Framework for
8 Catastrophic Disaster Response. Washington (DC): National Academies Press (US); 2012 Mar
9 21. 8, Out-of-Hospital and Alternate Care Systems. Available from:
10 <https://www.ncbi.nlm.nih.gov/books/NBK201069/>
- 11 [22] Sills MR, Hall M, Simon HK, Fieldston ES, Walter N, Levin JE, Brogan TV, Hain PD,
12 Goodman DM, Fritch-Levens DD, Fagbuyi DB, Mundorff MB, Libby AM, Anderson HO, Padula
13 WV, Shah SS. Resource burden at children's hospitals experiencing surge volumes during the
14 spring 2009 H1N1 influenza pandemic. Academic Emergency Medicine. 2011;18(2):158–166.
- 15 [23] Les établissements de santé - édition 2017 | [https://drees.solidarites-](https://drees.solidarites-sante.gouv.fr/etudes-et-statistiques/publications/communiqués-de-presse/article/12-4-millions-de-patients-hospitalisés-en-2015)
16 [sante.gouv.fr/etudes-et-statistiques/publications/communiqués-de-presse/article/12-4-](https://drees.solidarites-sante.gouv.fr/etudes-et-statistiques/publications/communiqués-de-presse/article/12-4-millions-de-patients-hospitalisés-en-2015)
17 [millions-de-patients-hospitalisés-en-2015](https://drees.solidarites-sante.gouv.fr/etudes-et-statistiques/publications/communiqués-de-presse/article/12-4-millions-de-patients-hospitalisés-en-2015).
- 18 [24] Ang IYH, Tan CS, Nurjono M, Tan XQ, Koh GC, Vrijhoef HJM, Tan S, Ng SE, Toh SA.
19 Retrospective evaluation of healthcare utilisation and mortality of two post-discharge care
20 programmes in Singapore. BMJ Open. 2019; 9(5): e027220. Published online 2019 May
21 22. doi: 10.1136/bmjopen-2018-027220.

- [25] Poole PJ, Chase B, Frankel A, et al. Case management may reduce length of hospital stay in patients with recurrent admissions for chronic obstructive pulmonary disease. *Respirology*. 2001 Mar;6(1):37-42. doi: 10.1046/j.1440-1843.2001.00294.x.
- [26] Tuppin P, Rudant J, Constantinou P, Gastaldi-Ménager C, Rachas A, de Roquefeuil L, Maura G, Caillol H, Tajahmady A, Coste J, Gissot C, Weill A, Fagot-Campagna A. Value of a national administrative database to guide public decisions: From the système national d'information interrégimes de l'Assurance Maladie (SNIIRAM) to the système national des données de santé (SNDS) in France. *Rev Epidemiol Sante Publique*. 2017 Oct;65 Suppl 4:S149-S167. doi: 10.1016/j.respe.2017.05.004.
- [27] Horwood CR, Moffatt-Bruce SD, Rayo MF. Continuous Cardiac Monitoring Policy Implementation: Three-year Sustained Decrease of Hospital Resource Utilization. *Adv Health Care Manag*. 2019 Oct 24;18. doi: 10.1108/S1474-823120190000018007.
- [28] Sly KA, Lewin TJ, Frost BG, Tirupati S, Turrell M, Conrad AM. Care pathways, engagement and outcomes associated with a recovery-oriented intermediate stay mental health program. *Psychiatry Res*. 2020 Feb 20;286:112889. doi: 10.1016/j.psychres.2020.112889.
- [29] Shiyovich A, Gilutz H, Arbelle JE, Greenberg D, Plakht Y. Temporal trends in healthcare resource utilization and costs following acute myocardial infarction. *Isr J Health Policy Res*. 2020 Feb 12;9(1):6. doi: 10.1186/s13584-020-0364-y.
- [30] Barlet M, Coldefy M, Collin C, Lucas-Gabrielli V. L 'Accessibilité potentielle localisée (APL) : une nouvelle mesure de l'accessibilité aux médecins généralistes libéraux. *Institut de recherche et documentation en économie de la santé*. 2012;174.

- 1 [31] Lucas-Gabrielli V, Mangeney C. Comment améliorer les mesures d'accessibilité aux soins
2 pour mieux cibler les zones sous-denses ? Revue d'Epidémiologie et de Santé
3 Publique, Volume 67, Supplement 1, 2019. doi:10.1016/j.respe.2018.12.061.
- 4 [32] Gao F, Kihal W, Le Meur N, Souris M, Deguen S. Assessment of the spatial accessibility to
5 health professionals at French census block level. Int J Equity Health. 2016;15(1):125. doi:
6 10.1186/s12939-016-0411-z.
- 7 [33] Gao F, Kihal W, Le Meur N, Souris M, Deguen S. Does the edge effect impact on the
8 measure of spatial accessibility to healthcare providers? Int J Health Geogr. 2017; 16: 46.
9 Published online 2017 Dec 11. doi: 10.1186/s12942-017-0119-3
- 10 [34] Localized Potential Accessibility (APL) database:
11 http://www.data.drees.sante.gouv.fr/ReportFolders/reportFolders.aspx?IF_ActivePath=P,49
12 0,530. Accessed 12 march 2018.
- 13 [35] Annual Statistical Survey of Healthcare Facilities (SAE) database: [https://www.sae-](https://www.sae-diffusion.sante.gouv.fr/sae-diffusion/recherche.htm)
14 [diffusion.sante.gouv.fr/sae-diffusion/recherche.htm](https://www.sae-diffusion.sante.gouv.fr/sae-diffusion/recherche.htm). Accessed 1st April 2018.
- 15 [36] National File on Health and Social Institutions (FINESS) database:
16 <http://finess.sante.gouv.fr/fininter/jsp/recherche.jsp?mode=simple>. Accessed 1st April
17 2018.
- 18 [37] French National Address database <https://adresse.data.gouv.fr/>. Accessed 12 march
19 2018.
- 20 [38] Exposto F, Petrică N, Davies E, Beaudet A. Identification of a pulmonary arterial
21 hypertension (PAH) patient cohort and study of its burden of illness in Programme de

1 Médicalisation des Systèmes d'information (PMSI). *Int J Cardiol.* 2020 Feb 13. pii: S0167-
2 5273(19)34942-3. doi: 10.1016/j.ijcard.2020.02.034.

3 [39] Charles-Nelson A, Lazzati A, Katsahian S. *Obes Surg.* Analysis of Trajectories of Care After
4 Bariatric Surgery Using Data Mining Method and Health Administrative Information Systems.
5 2020 Feb 6. doi: 10.1007/s11695-020-04430-6.

6 [40] Lamarsal le L, Hunt B, Schauf M, Szwarcensz tein K, Valentine WJ. Evaluating the clinical
7 and economic burden of healthcare-associated infections during hospitalization for surgery
8 in France. *Epidemiol Infect.* 2013 Dec;141(12):2473-82. doi: 10.1017/S0950268813000253.
9 Epub 2013 Feb 28.

10 [41] Fourquet F, Demont F, Lecuyer AI, Rogers MA, Bloc DH. French medical hospital
11 information system and cross infection surveillance: theory and feasibility. *Médecine Mal*
12 *Infect.* 2003; 33(2):110– 3. [https:// doi.org/10.10 16/s0399-077x \(02\)00005 -7](https://doi.org/10.1016/s0399-077x(02)00005-7).

13 [42] Institut national de la statistique et des études économiques : <http://www.insee.fr/fr/>.
14 Accessed 2 may 2018.

15 [43] Luo W, Qi Y. An enhanced two-step floating catchment area (E2SFCA) method for
16 measuring spatial accessibility to primary care physicians. *Health Place.* 2009
17 Dec;15(4):1100-7. doi: 10.1016/j.healthplace.2009.06.002.

18 [44] Nakamura T, Nakamura A, Mukuda K, Harada M, Kotani K. Potential accessibility scores
19 for hospital care in a province of Japan: GIS-based ecological study of the two-step floating
20 catchment area method and the number of neighborhood hospitals. *BMC Health Serv Res.*
21 2017 Jun 26;17(1):438. doi: 10.1186/s12913-017-2367-0.

1 [45] Zdeb M. Driving Distances and Times Using SAS® and Google Maps. SAS Global Forum
2 2010.

3 [46] Higgs G. The role of GIS for health utilization studies: literature review. Health Services
4 Outcomes Res Methodology. 2009;9:84–99. doi: 10.1007/s10742-009-0046-2.

5 [47] Delamater PL, Shortridge AM, Kilcoyne RC. Using floating catchment area (FCA) metrics
6 to predict health care utilization patterns. BMC Health Serv Res. 2019;19(1):144. Published
7 2019 Mar 4. doi:10.1186/s12913-019-3969-5

8 [48] Bindman AB, Grumbach K, Osmond D, Komaromy M, Vranizan K, Lurie N, Billings J,
9 Stewart A. Preventable Hospitalizations and Access to Health Care. Journal of the American
10 Medical Association. 1995;274(4):305–11.

11 [49] Goodman DC, Fisher E, Stukel TA, Chang C. The Distance to Community Medical Care
12 and the Likelihood of Hospitalization: Is Closer Always Better? American Journal of Public
13 Health. 1997;87(7):1144–50.

14 [50] Ricketts TC, Randolph R, Howard HA, Pathman D, Carey T. Hospitalization Rates as
15 Indicators of Access to Primary Care. Health & Place. 2001;7:27–38.

16 [51] Fortney JC, Steffick DE, Burgess JF Jr, Maciejewski ML, Petersen LA. Are primary care
17 services a substitute or complement for specialty and inpatient services?. Health Serv Res.
18 2005;40(5 Pt 1):1422–1442. doi:10.1111/j.1475-6773.2005.00424.x

19 [52] Wang X, Pan J. Assessing the disparity in spatial access to hospital care in ethnic
20 minority region in Sichuan Province, China. BMC Health Serv Res. 2016 Aug 17;16(1):399.
21 doi: 10.1186/s12913-016-1643-8.

[53] Ye H, Lee S, Kim H. Effects of Neighborhood Characteristics on Length of Inpatient Stay: Findings from the U.S. National Data. *Soc Work Res.* 2016 Jun;40(2):117-126. Epub 2016 Mar 28.

[54] Batten AJ, Augustine MR, Nelson KM, Kaboli PJ. Development of a novel metric of timely care access to primary care services. *Health Serv Res.* 2020 Apr;55(2):301-309. doi: 10.1111/1475-6773.13255. Epub 2020 Jan 14.

[55] Yuan Y, Cave M, Xu H, Zhang C. Exploration of spatially varying relationships between Pb and Al in urban soils of London at the regional scale using geographically weighted regression (GWR). *J Hazard Mater.* 2020 Feb 22;393:122377. doi: 10.1016/j.jhazmat.2020.122377.

[56] Chan J, Polo A, Zubizarreta E, Bourque JM, Hanna TP, Gaudet M, Dennis K, Brundage M, Slotman B, Abdel-Wahab M. Access to radiotherapy and its association with cancer outcomes in a high-income country: Addressing the inequity in Canada. *Radiother Oncol.* 2019 Dec;141:48-55. doi: 10.1016/j.radonc.2019.09.009.

[57] Burkner P. brms: An R package for Bayesian Multilevel Models using Stan. *J Stat Softw.* 2017;80(1):1-28.

[58] Nicholas J. Tierney, Antonietta Mira, H. Jost Reinhold, Giuseppe Arbia, Samuel Clifford, Angelo Auricchio, Tiziano Moccetti, Stefano Peluso, Kerrie L. Mengersen. Evaluating health facility access using Bayesian spatial models and location analysis methods. *PLoS One.* 2019; 14(8): e0218310. Published online 2019 Aug 7. doi: 10.1371/journal.pone.0218310.

LIST OF TABLES

Table 1: Descriptive analysis of the Index of Spatial Accessibility (ISA) for MCO and SSR.

Nord administrative region (expressed for 10 000 inhabitants).

	N	Min	Mean (Sd)	Max	25 th	Median	75 th
MCO	240	0.44	19.0 (10.69)	39.28	10.28	14.32	29.41
SSR	240	0.03	5.58 (2.19)	9.00	4.25	6.33	7.25

Sd, standard deviation

Table 2. LOS of ≥75-year-old people in MCO and SSR facilities – Nord administrative region.

	N	Min	Mean (Sd*)	Max	25 th	Median	75 th
MCO	240	0.01	0.26 (0.20)	1.68	0.10	0.20	0.37
SSR	240	0.03	0.85 (0.92)	10.98	0.33	0.65	1.08

* Standard deviation

Table 3: Summary of the two regressions models: the MCO and SSR LOS scores at FGC scale.

	MCO LOS score	SSR LOS score
COMPOSITE APL	-1.141***	-1.379***
MCO ISA	-.283**	NA
SSR ISA	NA	.045
Observations	240	239
R²	0.134	0.082
VIF	<1.17	<1.13

** p<0.01; *** p<0.001; R²: determination coefficient; VIF: Variance Inflation Factor; NA: Not applicable

FIGURE LEGENDS

Fig. 1 Spatial distribution of the Index of Spatial Accessibility at the FCG level.

(a) Index of Spatial Accessibility for Medical, Surgical and Obstetrics (MCO) and (b) Post-operative and Rehabilitation Care (SSR) centers. For each map, the French neighboring administrative regions are colored in green, whereas the Nord administrative region is represented using a graduated color approach, to highlight the different ISA scores.

Fig. 2 Distribution of the ≥ 75 -year-old population at the FGC level in Nord administrative region in 2016.

Fig. 3 MCO LOS spatial distribution for ≥ 75 -year-old people at the FGC level.

LOS for Medical, Surgical and Obstetrics (MCO) centers

Fig. 4 SSR LOS spatial distribution for ≥ 75 -year-old people at the FGC level.

LOS for Post-operative and Rehabilitation Care (SSR) centers