Ref. Ares(2022)8902580 - 21/12/2022

OASES

Promoting evidence-based reforms on medical deserts

D4.3
Output results analysis

21/12/2022

Co-funded by
the Health Programme
of the European Union

OASES Promoting evidence-based reforms on medical deserts

D4.3-Output results analysis.

Project title	prOmoting evidence-bASed rEformS on medical deserts
Acronym	OASES
Number	101018341
Call identifier	**HP-PJ-2020-2**
Topic	PJ-01-2020-2 Support to reforms in health workforce field - Initiatives on medical deserts (Heading 1.2.1.1 of the AWP 2020)
Starting date	01/03/2021
Duration in months	36
Website	http://www.oasesproject.eu/
Work package	4
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Peer reviewers	
Version	1.0
Due date	31.12.2022
Submission date	21.12.2022
Dissemination level of this deliverable	Public

Co-funded by the Health Programme of the European Union

Keywords

Medical desert, health workforce, floating catchment area method, spatial accessibility.

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Table of contents

List of tables

OASES Promoting evidence-based reforms on medical deserts

List of maps

List of figures

Introduction

The WHO AAAQ framework, first developed for the concept of "effective coverage", then adopted for the health workforce (Campbell and al. 2013), is a reference for the OASES project. It considers accessibility to care along different dimensions: accessibility, availability, acceptability, and quality (Deliverable 5.1).

In the OASES project, the focus is on healthcare workforce availability and accessibility. Availability of the healthcare workforce covers the adequate amount of health workers and their competence about the population´s needs. Accessibility means that healthcare workforce is equally distributed geographically, demographically and in different social and healthcare sectors (WHO 2016, WHO 2021). Quality and acceptability are dimensions that become present only when the interaction between patients and health professionals occurs (Deliverable 5.1), while the dimensions of availability and accessibility of health professionals and services are the ones that need to be targeted by policy reforms to identify areas of medical desert.

The identification of such areas is a major issue and a challenge because 'the greatest obstacle to the application of the concept of accessibility lies in the difficulty of translating it in the form of operational indicators' (Handy and Niemaer, 1997). This is exacerbated by the fact that the accessibility itself is complex to address due to its multidimensional nature (spatial, temporal, financial and cultural) (Penchansky R. and Thomas 1981). However, the measurement of the spatial dimension of accessibility is essential (Guagliardo 2004; Bissonnette and al. 2012) and provides information for the public authorities and regional planners about areas with poor accessibility (Apparicio and al. 2008).

The objective of this report corresponds to the Deliverable 4.3 (based on the previous steps: Milestone 17 and Milestone 18) of the OASES project. It aims at performing a sensitivity analysis in a given area to evaluate the impact of the different indicators. Those indicators have been chosen based on the scenario defined by each country according to the organization of health system and data available (Deliverable 4.2).

The sensitivity analysis aims to assess the consistency of the results obtained. Different methods were used. The first method is a descriptive analysis of the indicators to compare the statistical distribution of their value and their spatial distribution. This analysis is concluded by an analysis of variance (ANOVA) to check that the indicators are statistically different. Then a comparison of these indicators in pairs and a focus on a municipality particular case are carried out to understand the impact of the changes of indicators on the results.

1 Choice of indicators according to the scenarios produced by countries involved

A methodological guide to measure medical deserts was sent to the seven European countries that will carry out the measurement to share knowledge about them. It was based on the two geographical approaches that exist to analyze medical desert to current knowledge, consisting in: (1) developing an accurate index of accessibility and (2) defining spatial taxonomy including other dimensions than healthcare accessibility (Deliverable 4.1).

In a second time, a feasibility study was carried out to help each country define its own indicators. Each participating team was invited to assess the availability and accessibility of different datasets in their own country and to provide datasets examples (Deliverable 4.2).

From the collected detailed information on datasets availability, we noticed that the interest of countries is mainly focused on the first type of approach. More precisely, measures of accessibility of health services which were selected are (1) population-to-provider ratios (PPR) (2) distance to the closest service and to a lesser extent (3) x-floating catchment area (xSFCA) indicators combining availability and proximity (table 1).

Table 1: Selection of accessibility indicators according to countries.

Population-to-provider ratio	Distance to the closest service	XSFCA indicators
Finland, France, Hungary, Italy, Moldova, Romania	Finland, France, Italy	France

Different measures can be used by a country if more than one type of health care supply falls within the definition of the medical desert definition.

1.1 Population-to-provider ratio

This type of indicators is very commonly used. They have the advantage of being easy to calculate and intuitive for professionals and decision-makers and of mobilizing readily available data. Health care supply ratios (densities) are traditionally used in international comparisons of healthcare systems to highlight differences in staffing between countries (European Observatory on Health Systems and Policies 2020; OECD 2016) or within countries to measure disparities in staffing at different scales. Similarly, they are very often used to set standard rates of equipment in terms of capacity or professionals in the context of planning or regulation exercises carried out by national or local authorities. They have also been used to delimit the territories where health professionals should be encouraged to settle. Depending on the type of health care provision considered, the scale of analysis used can be more or less fine - interregional, regional or intermediate for hospital facilities, smaller for primary care.

In addition to the traditional densities (relating the supply of care to the population for a given geographical unit), distributed density will be tested to define a relevant density calculation for small geographical unit (supply is counted in the municipality and neighboring municipalities and then related to the population of the municipality and neighboring municipalities).

1.2 Distance

Distance is also a commonly used measure of proximity to care (Fortney, Rost and al. 2000, Rosero-Bixby 2004). In particular, it is recognized as a good measure of spatial accessibility in rural areas, because the choice in terms of care supply is limited and the closest supply is the one that has the highest probability of being used. On the other hand, consulting a care supply that is not the closest to the place of residence is also frequently observed when the quantity of care supplies available in the patient's environment allows it to be chosen (Goodman and al. 2003, Hyndman and al. 2003). An alternative solution is not to consider the immediate proximity but the average distance to the services, i.e. the distance between a place and several locations within a defined perimeter, which makes it possible to relativize the finding established with the immediate proximity. The distance of access to the nearest service is nonetheless a relevant indicator for highlighting the thresholds beyond which access to a specialty, a hospital discipline or a heavy facility becomes difficult. This distance thus makes it possible to locate populations that live far from care. It is a good indicator of the performance of resource allocation in a given territory, because controlling and reducing distance is a permanent concern in the planning of health care provision in particular for certain services such as primary care or certain hospital services (maternity, orthopedics, etc.). The development of geographic information systems (GIS) has made it possible to improve the measurement of distances, from Euclidean distances (as the crow flies) to travel time distances according to the mode of transportation used (on foot, by car, by bicycle, or by public transit). The most commonly used one is the distance by car because of the availability of data. It is measured in time rather than kilometers since it takes into account several parameters such as topography, network configuration and network operation.

1.3 XSFCA indicators

The indicator of xSFCA method is a fairly recent one; it was proposed in 2003 by Luo and Wang (2003) based on the work of Radke and Mu (Radke 2000). This type of measurement makes it possible to overcome several limitations related to the population-to-provider ratio and distance. For population-to-provider ratio, the fundamental limitations are that it refers only to the availability of health care in a given area and implicitly assumes that the service or professional located just across the boundary of the area will not be accessible. It thus ignores population movements across administrative boundaries, even though these are frequent, especially when density is measured for small areas. Distance, on the other hand, ignores geographic boundaries but does not take into account the quantity of supply in a given location.

The principle of the xSFCA is to take into account the supply of care and demand in the geographical unit under consideration, but also that of the surrounding geographical units. Thus, applied at the municipal level for GPs for example, this indicator considers that the inhabitants of a municipality have access to the supply in their municipality but also to all GPs located in the surrounding municipalities up to a certain distance. At the same time, each GP potentially responds to the demand of all the inhabitants of the municipalities located up to a certain distance from the practice.

2 Framework for analysis

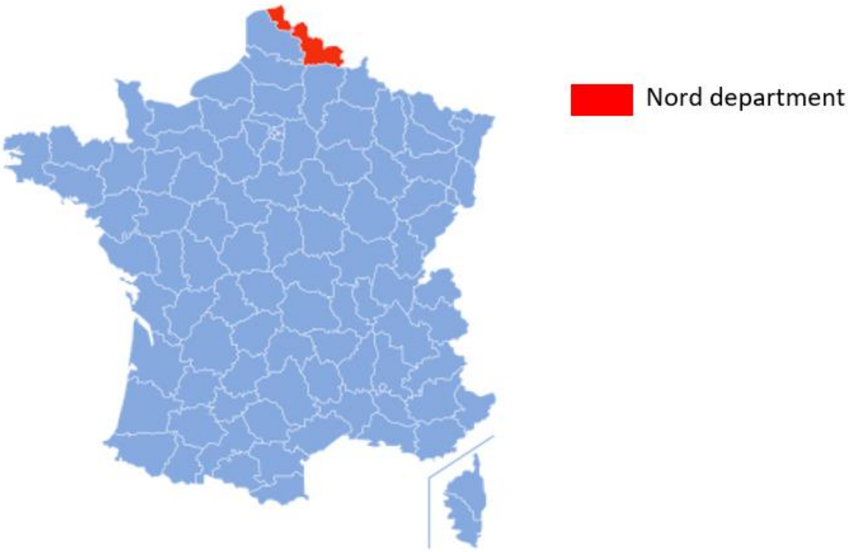
2.1 Principles for the sensitivity analysis

Based on the indicators selected by the countries to build their scenarios, four indicators were chosen for the sensitivity analysis including two population to provider ratio (density, distributed density) and two x-floating catchment area indicators (2SFCA and 3SFCA) (see Annex 1 for more information on their calculation). Distance indicator was not selected because the metric is not comparable contrary to previous indicators which are expressed as population-to-provider ratio.

The four indicators focus on general practitioners (GPs) and were calculated with unchanged parameters on the supply and demand dimensions. Indeed, this analysis of sensitivity focuses on a purely methodological aspect and does not consider the way to define supply and demand and their interaction, because it depends to a large extent on the organization of health systems, which differ from country to country. It should be noted however, that adjusted health care demand on population characteristics like age (Ngui and Apparicio, 2011) and social status (Lucas-Gabrielli and Mangeney 2019) or adjusted health care supply using level of activity of health professionals rather than headcount (Barlet and al. 2012) could have a major impact on the accessibility indicator.

2.2 Study setting and statistical unit

This study was carried out in the Nord department (NUTS3) that is located in the north of France (Map 1). This department was chosen because it can represent a wide variety of space types. On the one hand, the Nord has some major cities like Lille, Roubaix or Tourcoing and a rather high density for France with 456 inhabitants per km². It is also the most populated department in the country with 2 608 346 inhabitants in 2019. And on the other hand, there are many rural areas, and it concentrates a significant proportion of the region's agricultural activity. Moreover, this area was selected because multiple non-hospital care accessibility indicators are available for this department (Barlet M. and al. 2012; Gao 2016; Lucas-Gabrielli and Mangeney 2019).



Map 1: French administrative regions and Nord

The municipality level (local administrative unit for France) was selected for all the indicators except density because it is the smallest administrative subdivision in France and it serves as a basic unit for many statistics (population data and medico-administrative databases, INSEE, XSFCA indicator for France). There are in total 648 municipalities in Nord administrative department.

Density is measured at a higher level of the EPCI[1] that lies between the municipalities (LAU) and the department (NUTS3)[2]. Calculating a density at the municipality level did not make sense because traditional density refers only to the availability of health care in a given area and implicitly assumes that the service or professional located just across the boundary of the area will not be accessible. This is a big disadvantage at the municipality level as it is common for patients to cross municipalities boundaries to access a GP.

One methodological limitation mentioned in most research considering accessibility concerns the fact that studies have often failed to include behavior outside the study area. This is known as the edge effect. Edge effect occurs "*when the study area is defined by a border which does not prevent travel across the border*" and people are free to travel beyond that border to receive healthcare goods and services. Previous research of our team has shown that edge effects lead to minor accessibility variations in this area - for more information please refer to Gao et al. 2017.

[1] EPCIs are groups of municipalities whose purpose is to carry out joint development projects.

2.3 Data source

To measure the demand, we used the population per municipality in 2018 from the census produced by the French National Institute of Statistics and Economics Studies, whereas to qualify the supply, the number of GPs in practice on 31/12/2020 (including with a particular mode of exercise) was collected from the national register of health professionals (FNPS). We made the choice to focus on headcount instead of FTEs (Full-time equivalent) since this is the choice made by most countries.

The distances necessary for the calculations are distances by car and were provided by a distance matrix backed by a GIS developed by IRDES, which takes into account congestion related to population density and the impact of altitude. We took the average distances during off-peak and peak hours by car and the distances have been calculated between the town halls of each municipality.

3 Descriptive statistics

3.1 Statistic dispersion and spatial distribution of the four indicators

The statistic dispersion and spatial distribution of the four indicators highlight some of their features.

First, for the simple density, we noticed that the standard deviation[2] is the lowest (Table 2, Figure 1) and the distribution of values is very condensed around only a limited number of modalities with fewer extreme values than the others (Figures 2 and 3). This distribution is reflected in space, since we can see through the map that blocks of homogeneous municipalities corresponding to the EPCI emerge with neighboring municipalities that are similar (Map 2). This means that density masks local disparities in staffing and does not allow the diversity of situations to be represented on a fine scale. These phenomena can be explained by the geographical scale of this indicator (see 1.1), which is the EPCI, unlike the three other indicators. Since it implicitly assumes that patients are not able to overcome geographical boundaries to consult health professionals in a neighboring municipality, simple density should not be calculated on a too fine scale. Moreover, previous works have already shown that the density results were strongly influenced by the administrative limits (Donohoe and al, 2016). This leads to abrupt breaks between the administrative boundaries of the EPCIs, with well-endowed and less well-endowed EPCIs side by side. For example, the EPCI of Hazebrouck, has a higher accessibility to neighbors and the EPCI of Coudekerque-Branche has a poorer accessibility.

Concerning distributed density, the standard deviation is the highest of the four indicators (Table 2, Figure 1) and the extreme values are well represented (Figures 2 and 3). At the spatial level, there are greater disparities with some heterogeneity between neighboring municipalities in some places. For example, around Denain we can see a great diversity of accessibility values with side-to-side municipalities with low, middle and high accessibility levels (Map 2). These results show that the calculation of the indicator at the municipality level allows a better understanding of the diversity of situations at a fine scale while remaining coherent at the same time, since the offer of the surrounding municipalities is also considered.

[2] "The standard deviation is used to measure the dispersion, or spread, of a set of values around their mean." (INSEE). So, in our case the lower the standard deviation, the more homogeneous the municipalities are.

The 2SFCA distribution shows similarities with the distributed density distribution. Its standard deviation is quite high, meaning that there is an important dispersion of values (Table 2, Figure 1). The map also highlights strong contrasts - for example at the south of Valenciennes - and shows local disparities (Map 2). However, it can be noted that the average of the indicator is lower than the others (Table 2). This could be explained by its calculation method. Indeed, in the calculation of the 2SFCA indicator, the inhabitants are supposed to attend potentially all the surrounding supplies in the same way. The algorithm maximizes the patient volume. Thus, the demand is overestimated so that the supply-demand ratio obtained is lower.

The 3SFCA indicator has a narrow distribution (Figures 2 and 3) with a lower standard deviation (Table 2, Figure 1). This is reflected spatially by a smoothing of the values visible on the map (Map 2). There are gradients in accessibility to GPs, ranging from the highest accessibility in the center of the department around Lille to the lowest towards the margins with some other centers such as Cambrai and Dunkerque. There is therefore a greater homogeneity within blocks of neighboring municipalities. It can also be noted that this indicator has the highest minimum value. These phenomena can, once more, be explained by the method of calculation of the indicator. Although developed at the municipality level and considering neighboring municipalities as 2SFCA method, the distribution is smoother since this indicator takes competition into account. The patient base is calculated with the selection probability according to the competing supply, which allows a more realistic distribution of demand between the different offers.

Table 2: Descriptive statistics of four indicators: density, distributed density, 2SFCA and 3SFCA.

	Density*	Distributed density*	2SFCA*	3SFCA*
mean	84.36	80.90	78.37	82.94
std	17.68	26.34	25.68	21.56
min	43.90	0.00	22.91	42.21
25%	67.29	63.08	59.80	67.85
50%	82.66	79.46	75.24	78.29
75%	93.89	96.38	95.43	94.72
max	117.93	195.14	196.58	167.14

* GPs per 100 000 inhabitants

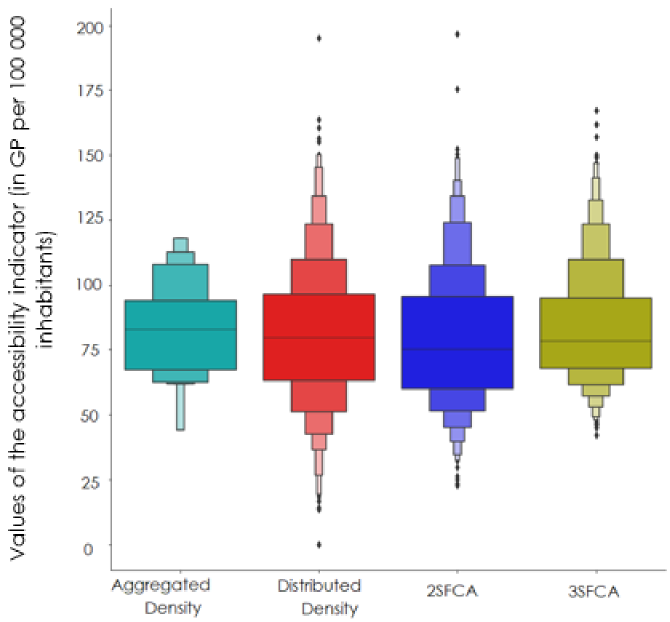


Figure 1: Boxen distribution of four types of indicators: density, distributed density, 2SFCA and 3SFCA.

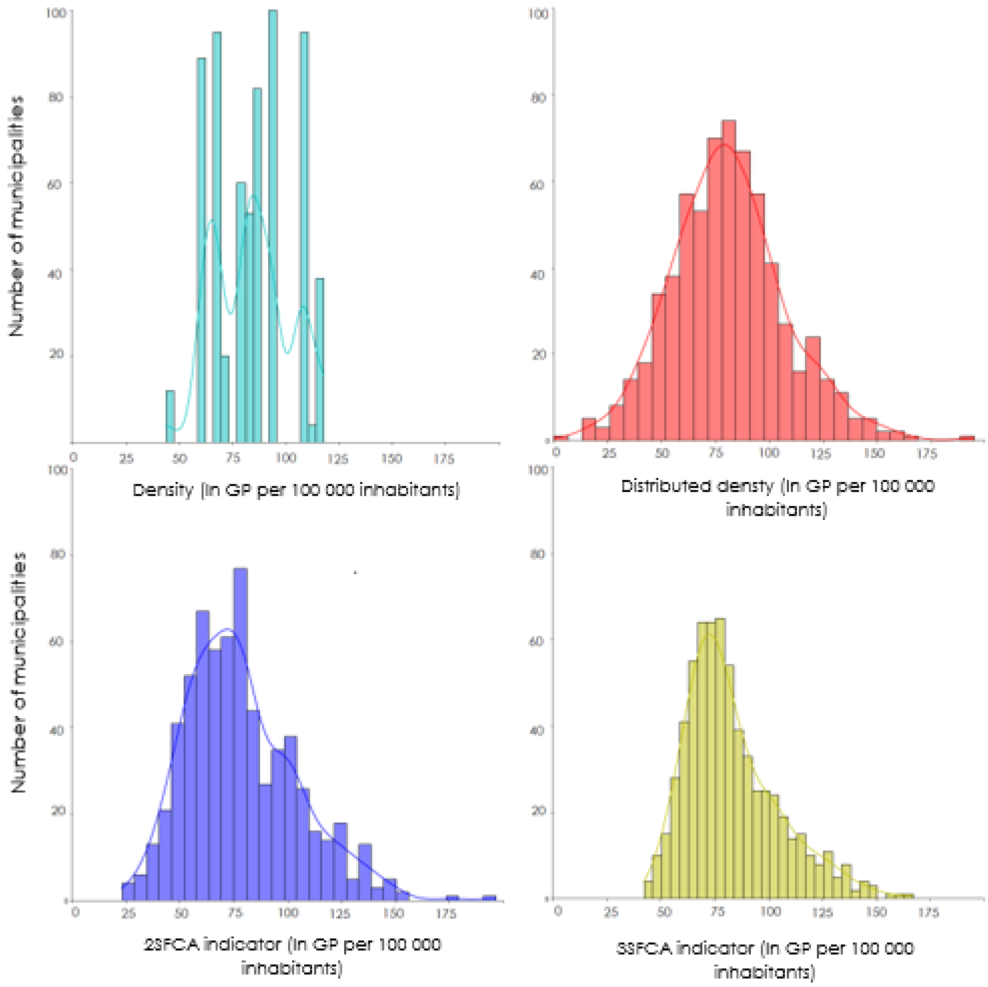


Figure 2: Distribution of the four indicators: density, distributed density, 2SFCA and 3SFCA

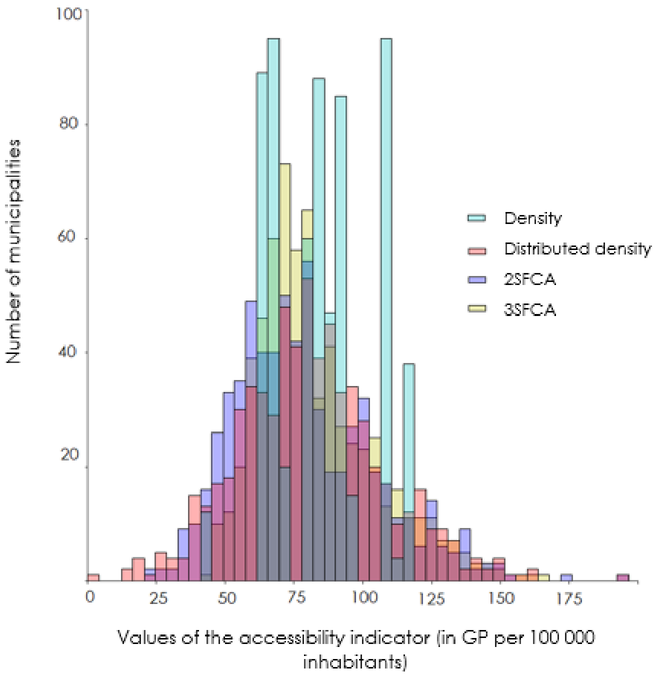
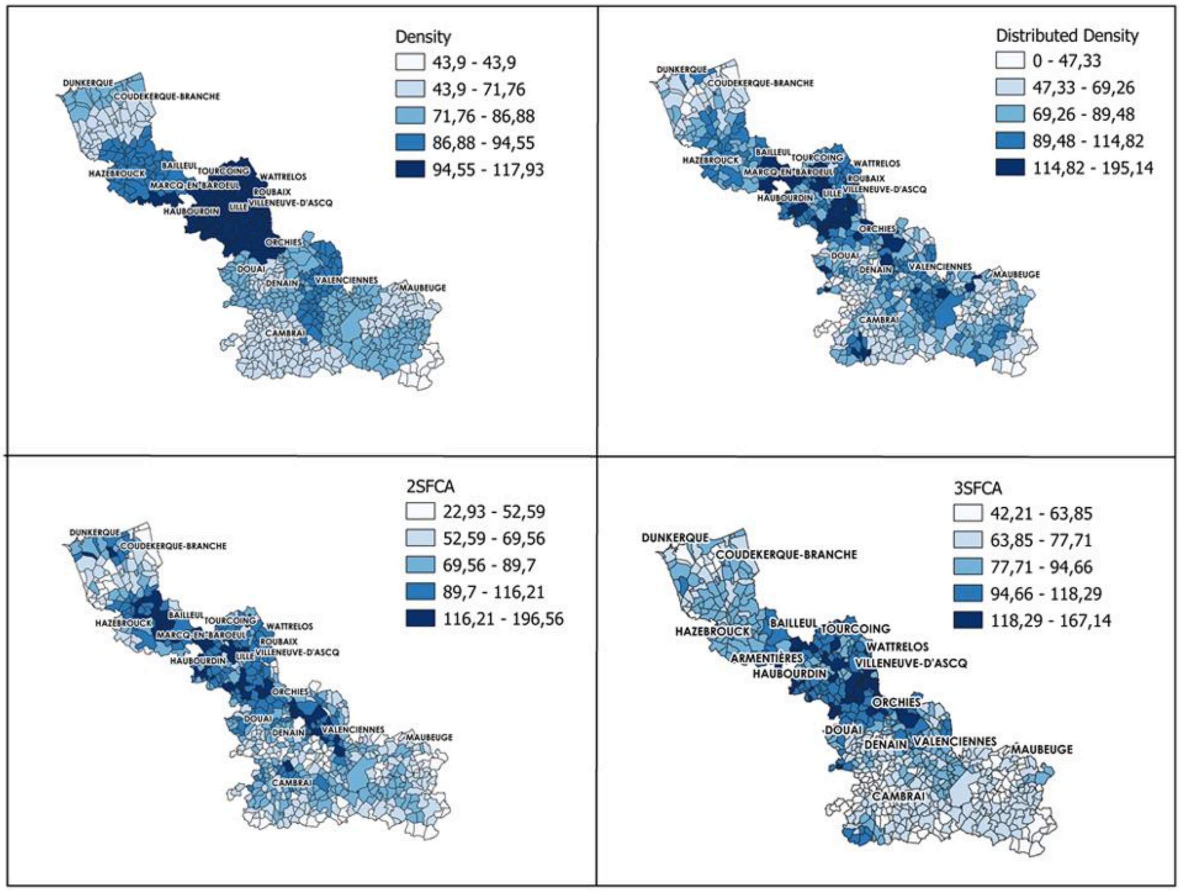


Figure 3: Comparison of distribution of four types of indicators



Map 2: Spatial distribution of density, distributed density, 2SFCA and 3SFCA.

3.2 Analysis of variance: four indicators statistically different

Looking at the statistical and spatial distribution of the four indicators separately, differences can be noticed. In this section, we will try to confirm these findings by verifying whether these indicators are significantly different from a statistical point of view. The goal is to see if there is an impact when using one indicator rather than another. For this purpose, an analysis of variance has been carried out.

Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among means. Repeated measures ANOVA is the equivalent of the one-way ANOVA, but for related, not independent groups, and is the extension of the dependent t-test. A repeated measures ANOVA is also referred to as a within-subjects ANOVA or ANOVA for correlated samples. All these names imply the nature of the repeated measures ANOVA: that of a test to detect any overall differences between related means.

Since in our case we study the different types of indicators for each municipality of Nord administrative region, our subjects are always the same geographical unities. Thus, each type of indicator is considered as a repeated measure.

Table 3: Results of RM ANOVA

Source	ddof1	ddof2	F	p-unc	p-GG-corr	ng2	eps	sphericity	W-spher	p-spher
Within	3	1941	961.483502	0.0	0.0	0.340979	0.84695	False	0.695284	1.064330e-48

F: F-value
p-unc: Uncorrected p-value
p-GG-corr: Greenhouse-Geisser corrected p-value
W-spher: Sphericity test statistics
p-spher: p-value of the sphericity test
sphericity: sphericity of the data (boolean)

Table 3 shows that both uncorrected p-value and Greenhouse-Geisser corrected p-value have a near-zero value. We can thus reject the null hypothesis (H0) which states that the means of each group are equal. The alternative hypothesis (HA) suggests that at least two means are significantly different. Then we did the same analysis two by two and obtained the same results, suggesting us to reject the H0 and keep the HA which stated that the means of each type of indicator were all different.

4 Pairwise comparison

In this section, as we have seen that the indicators were statistically different, indicators will be compared two by two to explain more specifically the variations induced by choosing one or another. Three pairs of indicators will be analyzed: density/distributed density, distributed density/2SFCA indicator and 2SFCA indicator/3SFCA indicator. We did not choose to analyze all pairs two by two, which represented six pairs, but to analyze the most similar pairs from a methodological point of view. Thus, density and distributed density are compared because both are simple versions of population-to-provider ratio. The indicators 2SFCA and 3SFCA belong to the same family of floating catchment area indicators (XSFCA). In the same ways, 2SFCA and distributed density share the same principle of extending density beyond the administrative boundaries of the municipality. The goal is to show how a slight change of the method can influence the results. It was also interesting to underline that even for the methodologically most similar indicators, with only a little more data (density /distributed density introducing distance) or an additional implementation step (e.g. distributed density/2SFCA indicator, 2SFCA indicator/3SFCA indicator), we could refine our accessibility measures.

To investigate the relationship between each pair of indicators, maps were created to highlight their differences. We cut each type of indicator's value into four classes depending on their quantile values. Then we calculated the level of the variation between each couple of methods for each municipality by looking at how many quartiles ranks the same geographical unit has increased or decreased by changing from one indicator to another. For instance, Lille's density value is in the first quantile, such as its distributed density value. Thus, its variation level between these two types of methods is 0. Then, the 2SFCA value of the same municipality is in the third quantile class, whereas its 3SFCA value is in the second quantile class. Its variation level between 2SFCA and 3SFCA methods is -1. The distribution of classes of the 648 municipalities is summarized at Table 4.

Table 4: Distribution of variation level by indicators quantiles values

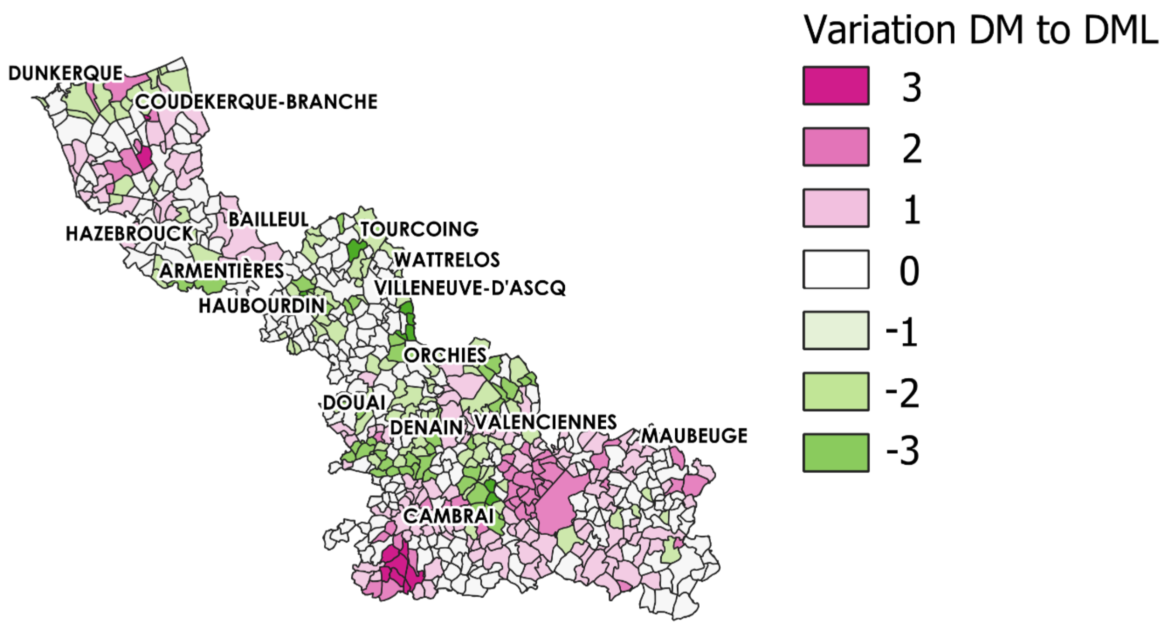
Level of variations	Density to DD*	DD to 2SFCA	2SFCA to 3SFCA
-3	10	13	12
-2	44	53	55
-1	98	128	141
0	292	252	237
1	150	142	133
2	47	49	56
3	7	11	14

* DD: Distributed Density

4.1 Comparison between density and distributed density

Using distributed density rather than classical density allows a finer scale. Indeed, a density at the municipality level does not make sense because it implicitly assumes that patients are not able to overcome geographical boundaries to consult health professionals in a neighboring municipality. Thus, the population is supposed not to access GPs if they do not have any in the municipality. That is the reason why this indicator should be calculated at a more aggregated level, here the EPCI. Since distributed density considers neighboring municipalities located less than 10 minutes away in the definition of its supply and demand, it goes beyond the administrative limits and allows us to measure the indicator at the level of municipalities.

Because of this change of scale, we note that the diagnosis is refined with the scatter plot (Figure 4). While there were very few possible modalities with the classical density (X-axis), the diversity of accessibility is better taken into account with the distributed density (Y-axis). In the same way, the map of the differences between the two indicators highlights some variations within the most heterogeneous EPCIs (Map 3). Thus, in the zone in the South of Cambrai there are municipalities in edge of the department which see their level of accessibility strongly decreasing by passing to distributed density. This is because they were in the EPCI of Cambrai, which was rather well endowed, so they benefit from a good general level of accessibility. However, by calculating the indicator at the municipality level, we reveal the disparities within this EPCI and highlight the marginal areas with a poorer accessibility far from Cambrai. We can see the same changes at the south of Valenciennes. On the contrary, it also increases the accessibility of municipalities on the edge of some EPCI boundaries. For example, the corridor at the North-East of Cambrai can take advantage of the supply of Cambrai now that there are no more administrative limits.



Map 3: Levels of variation from density to distributed density

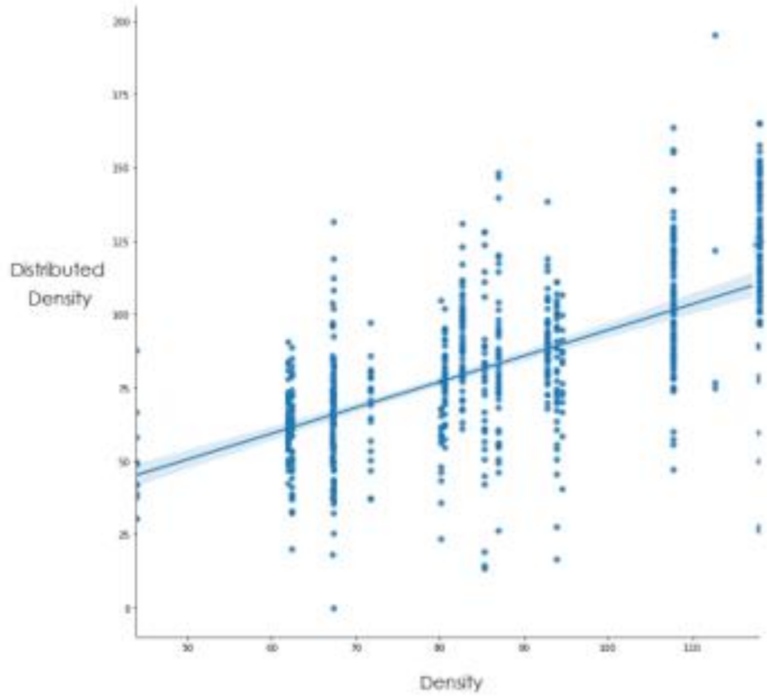
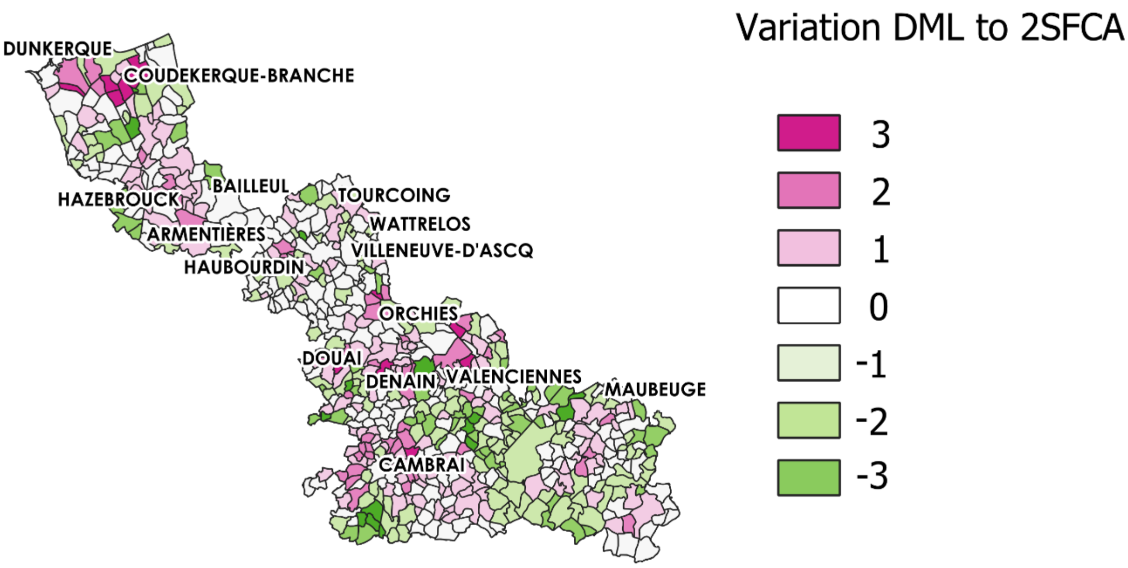


Figure 4: Level of accessibility of municipalities measured with density (abscissa) and distributed density (ordinate)

4.2 Comparison between distributed density and 2SFCA

The change from distributed density to the 2SFCA indicator has induced the most significant change among the three pairs analyzed. Indeed, the correlation coefficient of the two indicators is the lowest, with a value of 0.47. However, their distributions appear to be linked as shown in the graphic (Figure 5). This difference could be explained by the change between density on a fixed catchment area (classic density and distributed density) and indicators for which density is calculated on a floating catchment area. This means that attraction zones are calculated for both supply and demand in the case of a 2SFCA method as opposed to the density method which defines a single attraction zone around each municipality. As a result, the 2SFCA model locates supply and demand much more accurately. This algorithm is based on gravity model, which takes into account spatial interactions between each municipality. On the contrary, distributed density only builds a buffer zone around each municipality according to a distance but does not analyze the relationships between municipalities within this buffer. Furthermore, for the distributed density, the population of a municipality has the same potential access to all the supply located within the whole catchment area, whereas for the 2SFCA method a decay function has been introduced according to the distance within the floating catchment area.

All these differences are translated spatially. It can be seen through the map (Map 4) that when switching to the 2SFCA indicator, the South of Dunkerque gains in accessibility as well as areas near by Cambrai and the North of Valenciennes. On the contrary, it is the margins further away from the major centers that are losing accessibility. For example, the fringe between the catchment areas of Maubeuge and Valenciennes is losing accessibility, as is the extreme south of Cambrai on the edge of the department. This loss of accessibility to the margins can reflect the introduction of the decay function, which no longer makes the supply of urban centers accessible in the same way in the margins of the cities. Indeed, previous work has already shown that with the introduction of the declining function the abundant supply of city centers is no longer accessible by the suburbs which lose accessibility (Donohoe and al, 2016).



Map 4: Levels of variation from distributed density to 2SFCA indicator

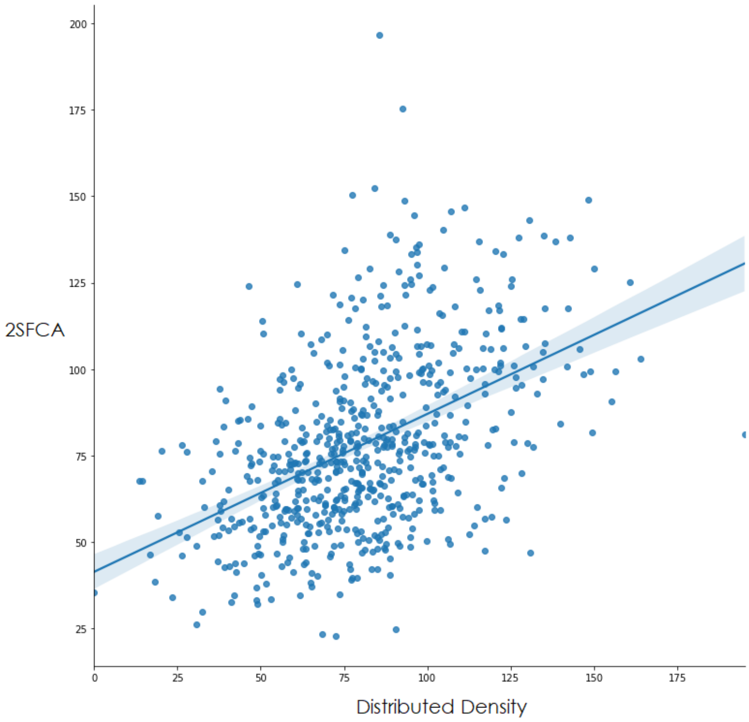


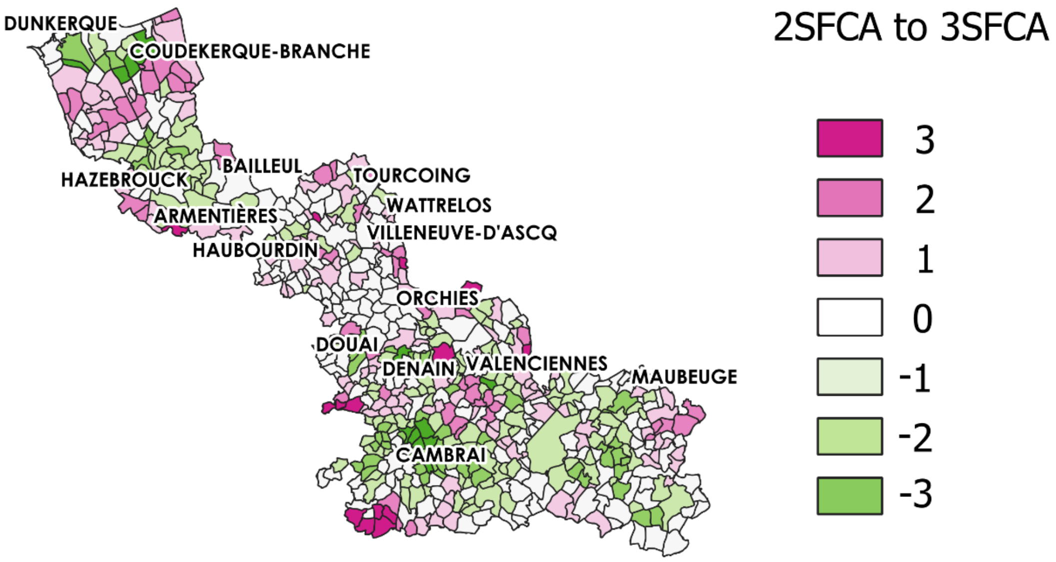
Figure 5: Level of accessibility of municipalities measured with distributed density (abscissa) and 2SFCA indicator (ordinate)

4.3 Comparison between 2SFCA and 3SFCA

The 2SFCA indicator and the 3SFCA indicator both belong to the family of the floating catchment area indicators and are both based on gravity models. That is why they have similarities. The two indicators are correlated with each other with a correlation coefficient of 0.49 and the graphic seems to show that they have a linear relationship.

Nevertheless, the observation of the graph and the map also underlines differences. The graph (Figure 6) and the comparison of the means and medians (Table 2) show that the density of GPs tends to be higher with the 3SFCA indicator than with the 2SFCA indicator. Moreover, the map of the two indicators (Map 2) and the map of the variation (Map 5) highlight that the 3SFCA homogenizes the results of the 2SFCA. The switch to the 3SFCA indicator rebalances the situations between neighboring municipalities. The zone north of Cambrai thus gains in accessibility to GPs while the southern zone has a reduced accessibility level. The same applies to the area around Dunkerque, with the core area gaining accessibility and the southern area losing it. It can also be seen that accessibility to the south of Maubeuge is increasing and that accessibility to the central area around Lille is decreasing slightly.

This smoothing effect can be explained by the major differences between 2SFCA indicators and 3SFCA indicators: the consideration of competition which allows to limit the overestimation of demand. The probability of using the supply no longer depends only on the distance but also on the quantity of the supply available in the vicinity. Therefore, if 2SFCA indicator can be considered as measuring a maximum demand, 3SFCA indicator comes closer to the real demand by allocating patients between the different supplies instead of allocating them several times. All this leads to a smoothing of accessibility, with the patient base being better distributed between all the supplies.



Map 5: Levels of variation from 2SFCA indicator to 3SFCA indicator

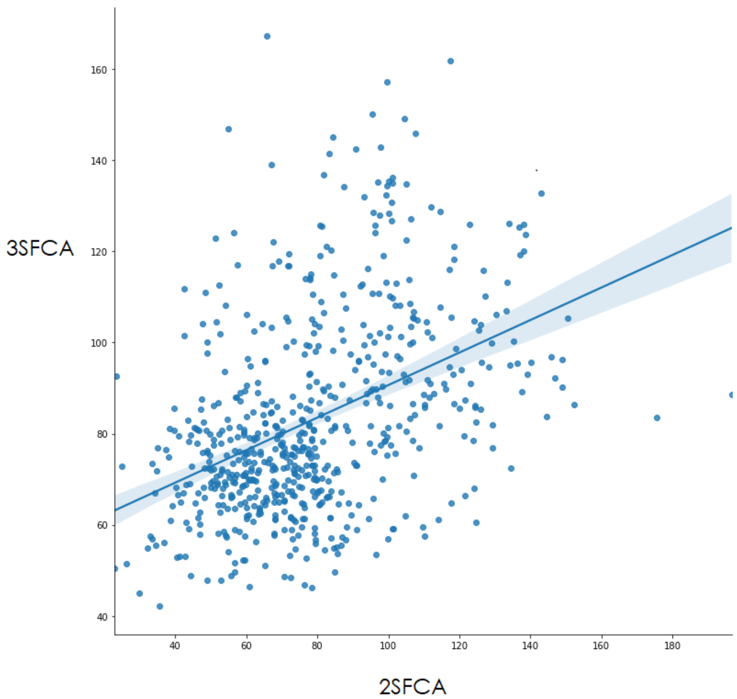


Figure 6: Level of accessibility of municipalities measured with 2SFCA indicator (abscissa) and 3SFCA indicator (ordinate)

5 Case study

To illustrate the differences between indicators values obtained by distributed density, 2SFCA and 3SFCA method, we chose the municipality 59356 that has the most significant value variation. The following table (Table 5) shows us that its values of density, distributed density and 3SFCA indicator are significantly higher than that of the 2SFCA indicator. In the following section, we will discuss in detail why the same geographical unit could have such a variation of accessibility value, depending on different methods.

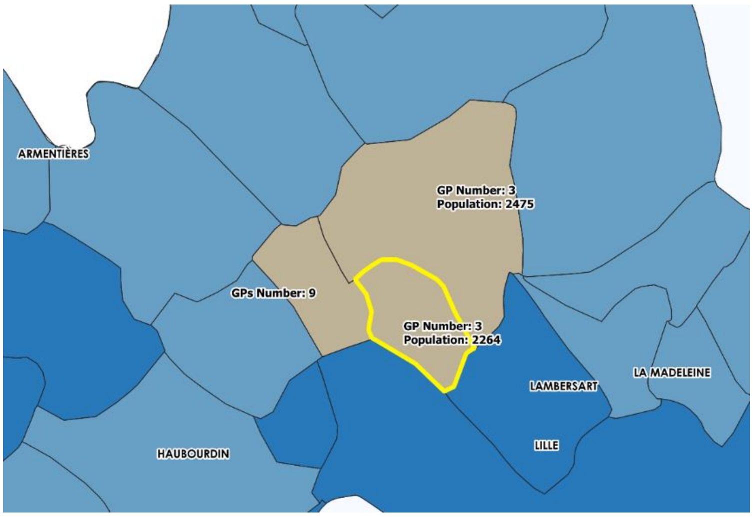
Table 5: Variation of indicators quantiles levels for municipality 59356

	Density*	Distributed density*	2SFCA*	3SFCA*
59356	107.73	114.05	54.79	146

* Per 100 000 inhabitants

5.1 Distributed density

We first defined a driving time threshold of 10 minutes. As shown in the map (Map 6), there are only two other municipalities located within the threshold of 10 minutes from the centroid of 59356 (highlighted in yellow). Thus, the catchment of 59356 includes only these three geographical unities. We simply sum up all GPs available within the catchment (9 + 3 + 3) and divide it by the total population (2475 + 2264 + 8413), to obtain a ratio of 114.05 GPs per 100 000 inhabitants.



Map 6: Distributed density calculation of municipality 59356

5.2 2ESFCA

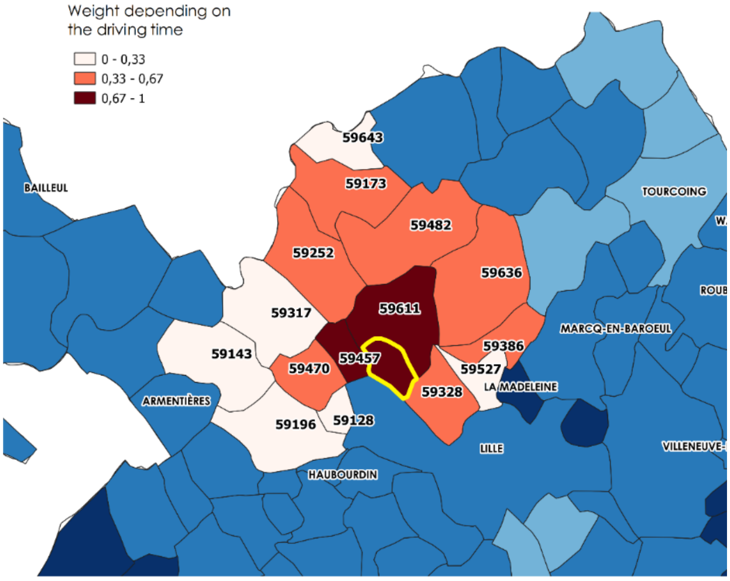
The E2SFCA method is based on gravity model supposing that not all population within the catchment has the same level of accessibility, by including a weighted decay function (Luo and Qi, 2009). This method was implemented in two steps:

First, we defined a catchment within a driving time threshold of 20 min from the centroid of the municipality 59356 (highlighted in yellow). As shown by Map 7, all municipalities whose centroid falls within the catchment area are colored in graduated red tone. Only the E2SFCA method supposes that not all population within the catchment has the same level of accessibility, by including a weighted decay function. Thus, all zones that fall into the threshold of 10 minutes are in dark red. All unities located between 10 and 15 minutes are in orange and between 15 and 20 minutes are in light pink. We assigned a weight of 1,0.67 and 0.33 respectively to these zones, using the reference distance weight defined in the previous works[3]. Then, we should determine a supply ratio for each municipality within the catchment with health service supply (GPs in our case). Let us take the example of the municipality 59128 (highlighted in green at Map 8) that falls into the catchment of 59356. As previously done, we should first determine a catchment area with decay weight for municipality 59128, and then find out all population in this catchment. The Map 8 shows us the population of each municipality as well as the GPs number available within the catchment of 59128. This means that all populations labeled might have access to these two GPs, but with different levels of accessibility. This is why we should multiply population by its distance weight (0.33, 0.67 or 1) and sum up the results to get a global estimation of population (weighted population) who has access to these two GPs. Then, we can calculate a physician-to-population ratio for 59128: number of GPs in relation to the total population. In our case, we obtain a ratio of 9e-06. However, we could not conclude that every inhabitant in the catchment of 59128 has a share of 9e-06 of GP coming from 59128. The decay weight should be included too. This point will be discussed in the next paragraph.

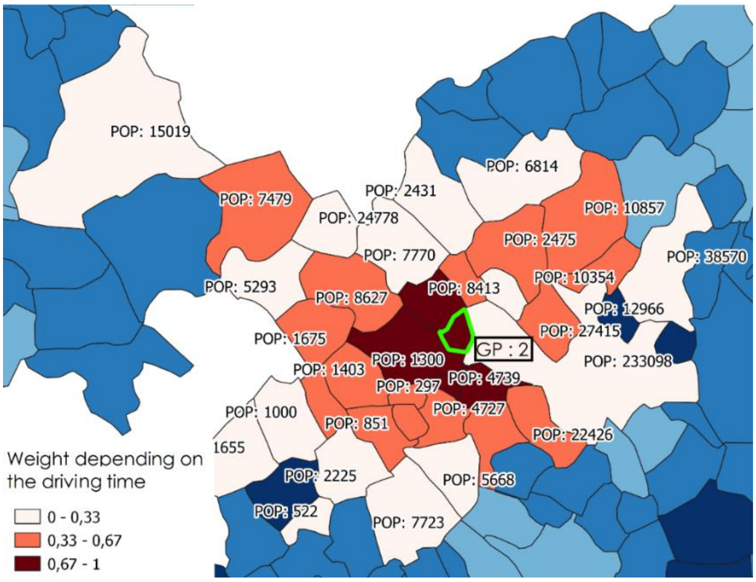
Once we determine the ratio of each municipality in the catchment of 59356 (as shown in Map 8), we should sum up all of them to get a global accessibility score by taking into account the distance weight (Map 9). The physician-to-population ratio of 59128 is 9e-06, but we cannot conclude that each inhabitant from 59356 has a share of 9e-06 GP. Not all population from 59356 is taken into account in the denominator of ratio calculation, only the weighted population depending on the distance. In this case, the weighted population is 2264 * 0.33 since the driving time from 59128 and 59356 is between 15 and 20 minutes. Consequently, the ratio should be multiplied by the distance weight. We conclude that every inhabitant from 59356 has a share of 9e-06 * 0.33 of GP coming from 59128. After summing up all ratios multiplied by their distance weight, we obtained a 2SFCA value of 54.79 GPs per 100 000 inhabitants.

In our case, the 2SFCA indicator has a much lower value, because 1) the demand population beyond 10 minutes driving time is significant (weighted population is 48278, compared to population taken into account in the distributed density which is 13152). Therefore, its physician-to-population ratio is reduced; and 2) ratios of this zone are also low since in their own catchment, there are few GPs shared by a significant volume of population (weighted population from 63120 to 268027).

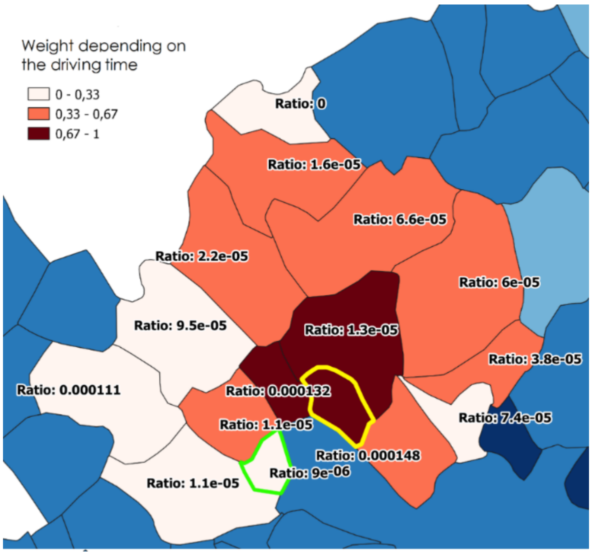
[3] Depending on previous works of La direction de la Recherche, des Études, de l'Évaluation et des Statistiques (DRESS) and Institut de recherche et de documentation en économie de la santé (IRDES), the distance weights used in order to measure the accessibility to GPs were defined as follow: 1) when car travel time is inferior or equal to 10 minutes, the weight is set to 1; 2) when car travel time is superior to 10 minutes and inferior or equal to 15 minutes, the weight is 0.67; 3) when the car travel time is superior to 15 minutes and inferior or equal to 20 minutes, the weight is equal to 0.33 and 4) finally the threshold is defined as 20 minutes, meaning that if the car travel time is superior to 20 minutes, the accessibility is considered as 0.



Map 7: Identification of catchment with decay weight for municipality 59356



Map 8: Calculation of ratio for two GPs in municipality 59128 (in green) within the catchment of 59356



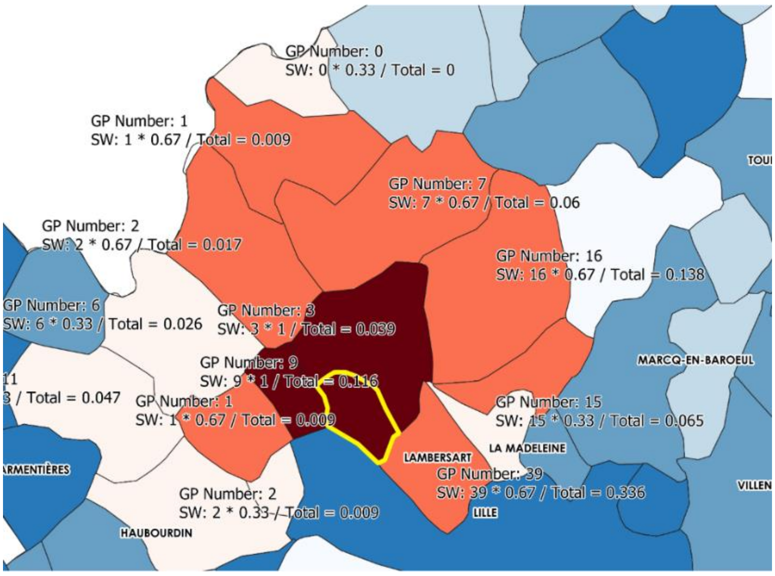
Map 9: Calculation of 2ESFCA indicator by summing all ratios multiplied by weight of each municipality within the catchment of 59356 (in yellow)

5.3 3SFCA

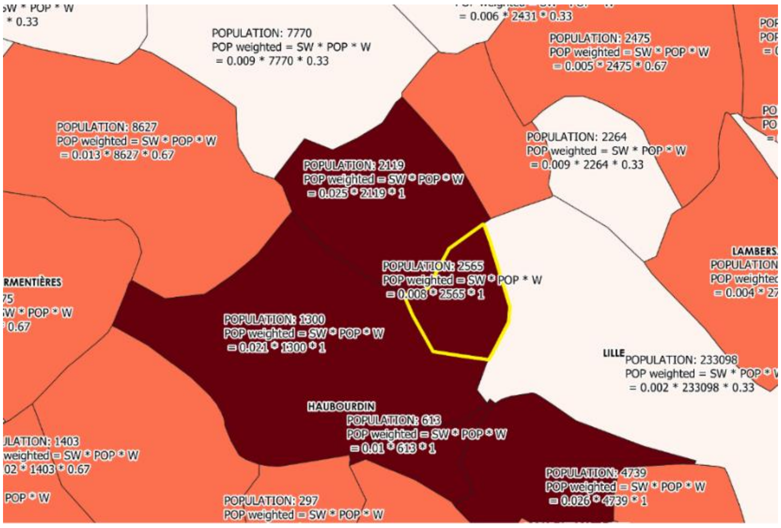
3SFCA was developed by minimizing demand overestimation problem of gravity-based spatial access models as 2SFCA mentioned above. It assumes that a population's healthcare demand for a medical site is influenced by the availability of other nearby medical sites (Wan 2012; Luo 2014). This method was implemented in three steps. We illustrate it here with the same municipality 59356.

First, we determined for population located within 59356 (highlighted in yellow) a catchment, as we did in the first step of 2SFCA. In our case, as shown by the map 10, this catchment is constituted by 16 municipalities, with a weight coefficient varied from 0.33 to 1. We should find out the available GPs number within each municipality and calculate a "selection weight" equivalent to GPs number in the current municipality, divided by the total GP number multiplied by distance weight. In other words, the selection weight is equivalent to Sj weighting by the coefficient relating to the distance W(i,j) in relation to the weight of all alternative supply available in the patient catchment area of the municipality. The idea is: if there is more offer in zone A than zone B, with the same distance, the patient will more probably go to zone A. As we can see in the map 10, the municipality Lambersart has 39 GPs, so that its selection weight is the most significant (0.336), meaning that the population from 59356 is more likely to see GPs in Lambersart than any other municipalities within its catchment.

In the step 2, we repeat the same calculation as in step 1 of the 2SFCA algorithm: for each of the 16 municipalities within the catchment of 59356, we determined their own catchment one by one. Once again, we take the example of municipality 59128 whose catchment includes 37 municipalities. First, we should determine the population volume who might have access to the two GPs in municipality 59128. The weighted population volume is obtained by multiplying population volume with selection weight then distance weight (Wan 2012; Luo 2014). For instance, the population of Lille (59350) city is 233 098. We multiply it by its selection weight 0.002 previously calculated, and then by distance weight 0.33 (the driving time from 59128 to 59000 is between 15 and 20 minutes). We obtained a weighted population of 1538, meaning that theoretically 1538 inhabitants from Lille have access to the two GPs in 59128. In 2SFCA mentioned above, this population volume was 76922 (233 098 multiplied by 0.33). This is one of the reasons of the significant difference between 2SFCA and 3SFCA. Once we determined the weighted population of municipality 59128 (Map 11), we can get the ratio as mentioned in the first step of 2SFCA, by dividing the GPs number within 59128 (2) by the total weighted population (1440). At the end, we obtained a ratio of 0.0014.

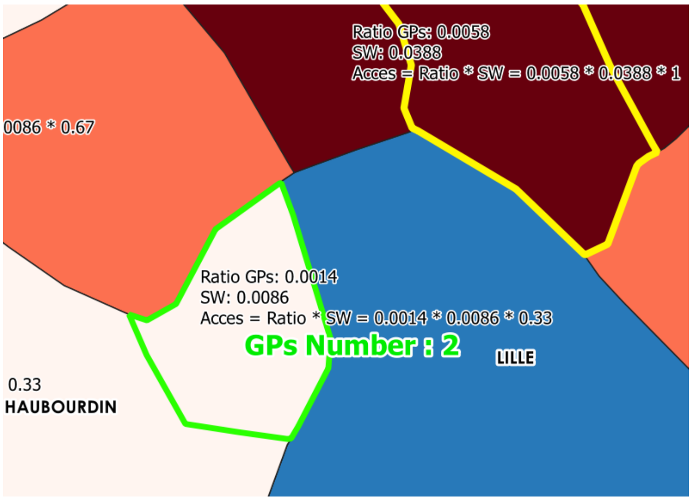


Map 10: Identification of catchment with decay weight for municipality 59356 and calculation of selection weight for each municipality within the catchment

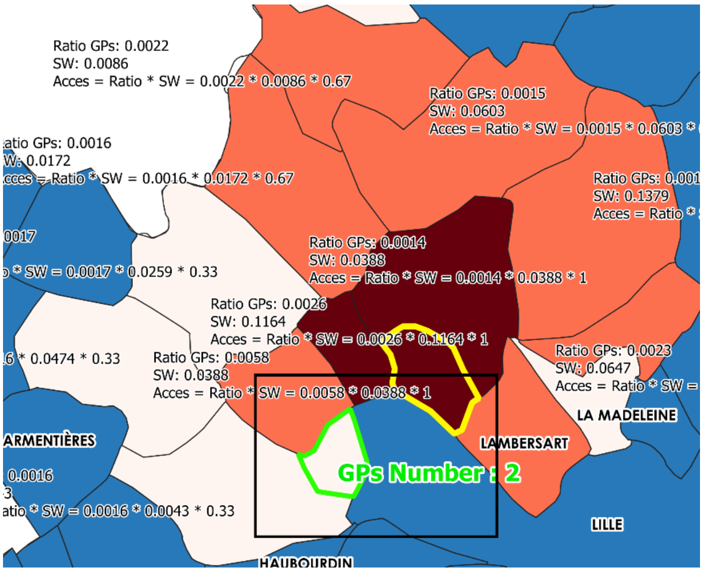


Map 11: Calculation of weighted population and ratio for two GPS in municipality 59128 (in yellow)

The third step is similar to the second step of 2SFCA algorithm. Once we obtained the ratio for each of the 16 municipalities within the catchment of 59356, all of the sixteen ratios should be summed up. The physician-to-population ratio of 59128 is 0.0014, but not all population from 59356 is taken into account in the denominator of ratio calculation, only the weighted population depending on the distance and selection weight (Wan 2012; Luo 2014). In this case, the weighted population is 1440 * 0.33 * 0.0086, since the driving time from 59128 and 59356 is between 15 and 20 minutes, and the selection weight of 59356 to 59128 is 0.0086. Consequently, the ratio should be multiplied by the distance weight and selection weight. We conclude that every inhabitant from 59356 has a share of 0.0014 * 0.33 * 0.0086 of GP coming from 59128 (Map 12). After summing up all ratio multiplied by the 2 weights, we obtained a 3SFCA value of 146.80 GPs per 100 000 inhabitant (Map 13). The reason why the 3SFCA indicator is in the highest class compared to 2SFCA is that the most populated municipalities are located in the catchment of 15-20 minutes. Therefore, the weighted population of 3SFCA taking into account the selection weight is significantly reduced, which helps getting a better the ratio as well as the accessibility indicator value.



Map 12: Calculation of contribution of two GPs in 59128 (in green) for 3ESFCA indicator of 59356 (in yellow)



Map 13: Calculation of 3ESFCA indicator by summing all ratios multiplied by selection weight and distance weight for each municipality within the catchment of 59356 (in yellow)

Conclusion

In this section, we proposed an analysis of sensitivity of the different indicators chosen by participating Member States (see Deliverable 4.2), based on a case study in a given area: the Nord department in France. The aim was to show the impact of the choice of indicators on the results and to explain it. This analysis of sensitivity focused on a purely methodological aspect and did not consider the way to define supply and demand and their interaction, because it depends largely on the organization of health systems, which differs from country to country.

This methodological analysis highlights that the measure of accessibility to care is very sensitive to the choice of indicators. The four indicators had different spatial and statistics distributions. Then, the ANOVA revealed that they were significantly different from a statistical point of view. This variability is explained by several improvements that switching from one indicator to another brings. The change from density to distributed density makes it possible to go beyond the administrative limits of the study scale and thus to go down to finer geographical levels. The change of scale results in a wider dispersion of values and makes it possible to capture spatial heterogeneities more precisely. The transition from distributed density to XSFCA methods allows us to move to gravity models in which the inter-connection between each of the grid cells (here the municipalities) is considered. The result is more accurate as supply and demand are better located and a decay function of distance is introduced which reveals nuances between city centers and suburbs. Finally, the change from the 2SFCA indicator to the 3SFCA indicator means that demand is no longer overestimated by taking into account the probability of use. This leads to a smoother result because the population is better distributed between the different supplies. Furthermore, even if it was not the goal here, numerous publications have shown that the choice of parameters within each indicator can also influence the results. For example, one study showed that, for the xSFCA method, how the decay function was parameterized, and the size of the catchment area had a strong influence on the results (Donohoe and al, 2016).

Beyond the choice and settings of indicators, special attention must be paid to measures of supply and demand to obtain a more accurate accessibility indicator. Some studies have already improved their methods of measurement by adjusting health care supply using, for example, level of activity of health professionals (Barlet and al. 2012) rather than headcount when care is provided on a fee-for-service basis or by adjusting health care demand on age (Ngui and Apparicio, 2011), or even social situation (Lucas-Gabrielli and Mangeney 2019). Indeed, for a better understanding of the territorial health service organization, usually we should combine accessibility indicator with other elements, such as demographical, social-economic and health supply context. This could make analysis results quite difficult to interpret. Taking into account these elements in the construction of accessibility indicators, as done by different authors mentioned above, may help to avoid this problematic.

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Annexes

Annex 1: Calculation methods for the construction of indicators.

- *Density*

Density is defined by the number of GP's Sj divided by the number of individuals Pj served in a geographical unity, resulting from the ratio of health capacity to population within an area (generally referring to an administrative area). However, density ignores potential interactions across borders as well as the unequal spatial distribution of healthcare professionals within a given spatial unit. For these reasons, densities are usually calculated at higher geographical levels so they can represent patient mobility (people may move out of their locality to access a doctor). Density is the only indicator of this analysis calculated at the ECPI scale that lies between the municipalities (LAU) and the department (NUTS3)[4].

$$D_j = \frac{S_j}{P_j} \qquad \text{Equation (1)}$$

- *Distributed density*

Distributed density makes it possible to achieve a density that goes beyond administrative boundaries by taking into account supply and demand in neighboring municipalities. The distributed density method was implemented as follows: for each municipality j, identify all neighboring municipalities k within a distance dmax[5], then the number of all GPs and the population living in municipalities k is estimated.

$$DM_j = \frac{S_j + \sum_{k \in \{d_{kj} \leq d_{max}\}} S_k}{P_j + \sum_{k \in \{d_{kj} \leq d_{max}\}} P_k} \qquad \text{Equation (2)}$$

where Pj is the patient population in the municipality j, Pk is the patient population in the municipality k the centroid of which falls within the catchment area j (i.e. dkj < dmax), Sj ,Sk are the number of GPs available in the municipality center j and k respectively, dkj is the driving time between the municipality k and the municipality j.

[4] In order to compare the results on a constant scale, the values of the EPCIs were then reallocated to the municipalities that make them up.

[5] For this analysis the dmax is equal to 10 minutes because this is the distance for which accessibility to a GP is considered perfect in France according to the Located Potential Area (Vergier, Chaput et Lefèvre, 2017).

- *2SFCA indicator*

The 2SFCA method is based on the construction of 'floating catchment areas' instead of predefined zones (Luo and Wang 2003). A floating catchment area is associated to each municipality and is defined as a zone limited by an isochronous curve centered on the seat of the municipality being studied (town hall). We thus consider that the inhabitants in a given municipality have access to all GPs located at a shorter distance from their place of residence than the reference distance (patients' catchment area). At the same time, each GP potentially satisfies the demand of all the inhabitants in municipalities located at a shorter distance than this reference distance (physicians' catchment area). The 2SFCA indicator is thus constructed in two phases and integrates this potential 'competition' effect between municipalities as the GP services supply can be shared between different municipalities.

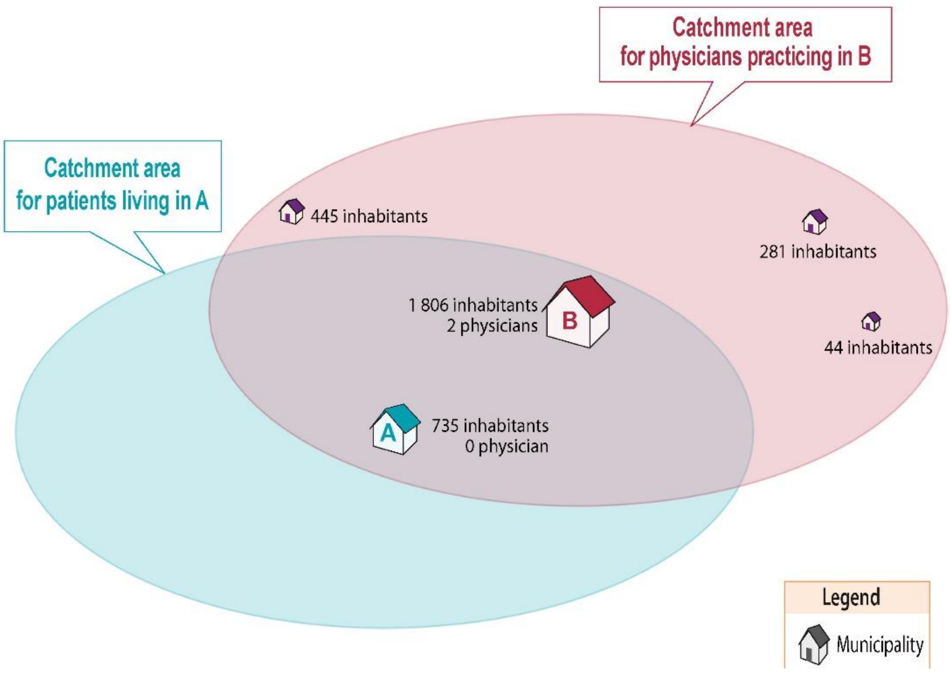

Figure 7: Example of a patient catchment area and a physician catchment area

It is implemented as follows:

Step1: for each municipality j with GPs, the number of GPs Sj was counted and the population living in the physician catchment area i so located within a threshold drive time dmax from the GP's service center j was estimated. Then, the provider-to-population ratio Rj within the physician catchment area of j was determined with Equation 3:

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \leq d_{max}\}} P_i * w_{ij}} \qquad \text{Equation (3)}$$

where Pi is the population in the municipality i the centroid of which falls within the physician catchment area j (i.e. dij < dmax), Sj is the number of GPs available in the municipality center j, and Wij is the weighting coefficient relating to the distance[6].

Step 2: For each population location i, all municipalities j that were within the threshold driving time dmax from location i so the patient catchment area were estimated, and all Rj for the patient catchment area were summed to calculate the Index of Spatial Accessibility (Ai) at location i taking into account Wij the weighting coefficient relating to the distance. (Equation 4):

$$A_i = \sum_{j \in \{d_{ij} \leq d_{max}\}} R_j \, w_{i,j} \qquad \text{Equation (4)}$$

- *3SFCA indicator*

To minimize the demand overestimation problem of gravity-based spatial access models mentioned above, we proposed a three-step floating catchment area (3SFCA) method in this study (Wan and Luo 2012; Luo 2014).

The 2SFCA type measures consider that the probability of using the supply decreases when the distance to access increases, until it becomes zero beyond a certain threshold. The 3SFCA type measures consider that the probability of using the supply decreases with the distance but also with the volume of accessible supply in proximity. In other words, the 2SFCA accepts, or rather assumes, that people do not consult a doctor too far from home and that they give preference to the various services available nearby. The 3SFCA starts from the same assumption but qualifies it: individuals prefer proximity all the more if a local supply is accessible and available.

This method was implemented in three steps, as follows:

Step 1: for each municipality j with GP's service within the threshold driving time dmax from location i the weighting factors (probability of use) G(i,j) are calculated by measuring the supply available in j, Sj weighting by the coefficient relating to the distance W(i,j**) in relation to** the weight of all alternative supply k available in the patient catchment area of the municipality i.

$$G_{i,j} = \frac{S_j W_{i,j}}{\sum_{k \in \{d_{i,k} \leq d_{max}\}} S_k * w_{ik}} \qquad \text{Equation (5)}$$

6 Here we use the same distance thresholds as for the LPA. Wij is therefore equal to 1 within 10 minutes, 2/3 between 10 and 15 minutes and 1/3 between 15 and 20 minutes. The dmax is equal to 20 minutes.

Step 2: for each municipality j with GP's service the provider-to-population ratio Rj within the physician catchment area of j was determined by relating the quantity of available doctors Sj to the populationliving in the physician catchment area Pi weighted by the probability of recourse Gij estimated in the previous step and by the coefficient relating to the distance W(i,j**).**

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \leq d_{max}\}} P_i * Wij * G_{ij}}$$ Equation (6)

Step 3: Compute the spatial access of each municipality i by summing for all municipalities j with GP's service that were within the patient catchment area of i, the ratio of provider-to-population Rj multiplied by the probability of recourse Gij and by the coefficient relating to the distance W(i,j**)**.

$$A_i = \sum_{j \in \{d_{ij} \leq d_{max}\}} R_j \, G_{i,j} W i, j$$ Equation (7)

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