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Transport Research Arena (TRA) Conference

# Assessment of spatial accessibility to public hospitals in Casablanca by car

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## Abstract

Equity in healthcare is ensured to a large degree by access to public hospitals. By considering the spatial distribution of residents, the efficiency of such hospitals can be increased in terms of their locations and capacities. Conversely, accessibility metrics are a powerful tool for assessing the interaction between spatial distribution and supply and demand. Indicators from the Floating Catchment Area (FCA) family, a set of measures built on the gravity model and used to quantify spatial accessibility, have proven to be very suitable for studying spatial accessibility to health services. In this study, we use various FCA metrics to assess spatial accessibility to public hospitals by car. Our result shows spatial segregation in accessibility values. The result could be a starting point for the government to ensure equitable distribution of health services by car.

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**Keywords:** Spatial accessibility; Transport planning; FCA metrics; Access by car

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## 1. Introduction

The city of Casablanca, located in the Central-Western part of Morocco, is a large African metropolis. It is growing with new opportunities, services, and recently constructed transportation infrastructure. During recent decades in Morocco, a demographic transition has begun, most notably in the city of Casablanca, in which there are 4.2 million inhabitants. Casablanca is also home to the nation's largest youth population HCP (2014).

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Therefore, spatial accessibility to different services and opportunities will likely become an essential component in Casablanca's development strategies in the next few years. This paper sheds new light on the reality of spatial accessibility in Casablanca. We aim to use the Floating Catchment area (FCA) metrics to assess the spatial accessibility to public hospitals by car. These are a series of methods derived from the gravity model, intuitive and easily interpretable, mainly because their result can be interpreted as the ratio of the service capacity per number of people, called a provider-to-population ratio (PPR).

## 2. Literature review

The regional availability approach has long been utilized by policy makers as a means of assessing the effectiveness of health care facilities. Regional availability is simply the supply-demand ratio within given administrative borders. However, this approach was not without its drawbacks given that it did not account for the spatial differences within the same region, nor did it consider that people may search for health services outside given border limits Yang et al. (2006). Conversely, regional accessibility reveals the spatial interaction between supply and demand locations. The gravity method is the combination of regional availability and regional accessibility.

The two-step floating catchment area (2SFCA), one of the initial FCA indicators, has been used in many applications, including health accessibility in Kanuganti et al. (2016a); Lavi and Mamdoohi (2013). However, several studies have revealed the limitations of this method, particularly the failure to consider the distance decay. Such studies have proposed various improved metrics to compensate for this shortcoming. For example, the enhanced two-step floating catchment area (E2SFCA) Luo and Qi (2009) addresses the distance decay problem by dividing the catchment area into several zones, each subzone with a different weight value; KD2SFCA Dai and Wang (2011) modified E2SFCA by applying continuous weights based on the continuous decay function (Fig. 2). The three step FCA (3SFCA) Wan et al. (2012b) adjusts the population's demand by assuming that the availability of other medical facilities influences the population's healthcare demand. The modified two-step FCA (M2SFCA) Delamater (2013) takes into account the optimality of the system's configuration. Numerous works focused on the application of these various FCA family of metrics to assess the spatial accessibility to healthcare services of different types: Kanuganti et al. (2016b) used enhanced two-step floating catchment area (E2SFCA) to access health care spatial accessibility in rural areas, The same latter method was explored in Luo et al. (2018) to measure and analyze the spatial accessibility to medical services for the elderly in Wuhan, China. Zhang (2015) measured primary health care accessibility in Mississippi state using an Extended Kernel Density 2SFCA (KD2SFCA) Method. Rekha et al. (2017) investigated spatial accessibility to healthcare facilities using the 3SFCA. More recently, following the start of the COVID-19 pandemic, various studies have been launched to examine spatial accessibility to ICU beds Ghorbanzadeh et al. (2021) and, vaccination sites Escobar et al. (2020) using FCA metrics.

In this article, four well-known benchmarking FCA measures were chosen (E2SFCA, KD2SFCA, 3SFCA, and M2SFCA) to compare spatial accessibility in Casablanca.

## 3. Methodology

We use the Qgis GIS software (presented in QGIS) for our experiment. This essentially free resource integrates network analysis features and Python scripts tool for plug-in building. In order to facilitate the implementation of our spatial accessibility measures, we propose a methodology diagram as shown in Fig. (1). The methodology includes data collection, data preprocessing, cost Matrix Generation, and the FCA metrics computation phase. We imported the road network of Casablanca city from OpenStreetMap (OSM) and used it as the basis for the cost matrix computation. The network comprises 34510 nodes and 92270 edges. Public hospital data has been collected from (Healthsites) and the official website of the Moroccan Ministry of Health. We successfully added coordinates for the health facilities using Google Maps. We then extracted population data from a population density map downloaded from (WorlPop) and preprocessed said data utilizing a raster conversion tool known as Polygonize in Qgis. The population data contains 288 centroid points. Each centroid point represents the population that lives within  $1 \text{ km}^2$ . We performed a Cost matrix calculation using the network analysis tool called QNEAT3; the latter computes a distance matrix between the geometric center points in the population grid and the health facilities points within the road network.

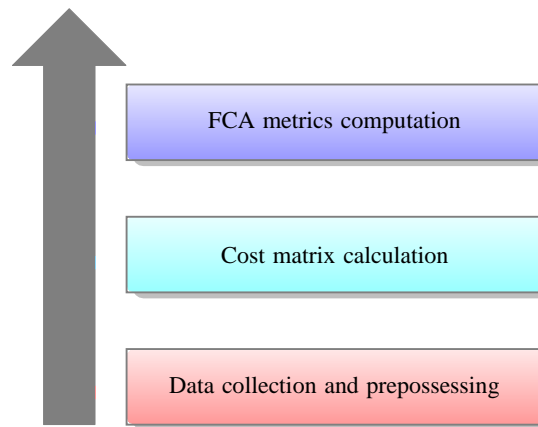


Fig. 1 .Methodology

The FCA metrics were calculated using the formulas presented in Table 1 and typically in two steps for the E2SFCA, M2SFCA, KD2SFCA, and following three steps for the 3SFCA.

For E2SFCA, KD2SFCA, and M2SFCA: The first step is to calculate the supply and demand ratio within the catchment area, and the second step is to calculate the sum of the weighted supply and demand ratio within the catchment. For 3SFCA, the first step is to choose weights for all population and facility pairings. In steps two and three of 3SFCA, one takes the weight value and incorporates it into the second and the third steps of the E2SFCA. We chose a Gaussian decay function presented in equation (1) to calculate the weights. In the literature, we found others, mainly gravity, exponential, inverse power, and logistic-based functions Dai and Wang (2011). According to Wang et al. (2017), the distance decay effect displayed by this model is superior to available alternatives. For the E2SFCA, we implemented a discrete Gaussian function with 5-minute rings. For the other metrics, we used a continuous Gaussian function.

Many authors have proposed using thirty minutes as a catchment size for their computation model (Lee, 1991; Luo and Wang, 2003; Lin et al., 2018; Ma et al., 2018; McGrail, 2012; Paul and Edwards, 2019). This study extends the catchment size to 35 minutes, as the average travel time by car in Casablanca is 35 minutes (CasaTransport). This will include people willing to travel 35 minutes to reach hospitals.

$$W_{ij} = \begin{cases} \frac{e^{-(t_{ij})^2}}{\beta} & t_{ij} \leq 35 \\ 0 & 35 < t_{ij} \end{cases} \quad (1)$$

$W_{ij}$  is the weight value provided by the distance decay,  $\beta$  is the impedance coefficient and,  $t_{ij}$  is the travel time between  $i$  and  $j$ . The impedance coefficient,  $\beta$ , reflects how willing people are to travel over time. The value 0.01 is considered to be the critical value of the Gaussian function close to 0 Kwan (1998). As shown in Fig. 2, for travel cost equal to 35 minutes, the  $\beta$  value of 266 corresponds to the Gaussian value of 0.01. Therefore, the minimum value of  $\beta$  is set to 266 so that the Gaussian value is always greater than 0.01. The maximum value of  $\beta$  is set to 1066 because the curve is relatively flat at this point. We chose to use a strong distance impedance and therefore  $\beta$  was set to 266. The full implementation of the methodology is accessible on Github.

### 4. Results and discussions

Fig. 6 (6a,6b,6c,6d) show the spatial distribution of accessibility results, calculated using the FCA metrics described previously. The four indexes generate similar accessibility patterns, with a higher accessibility values in

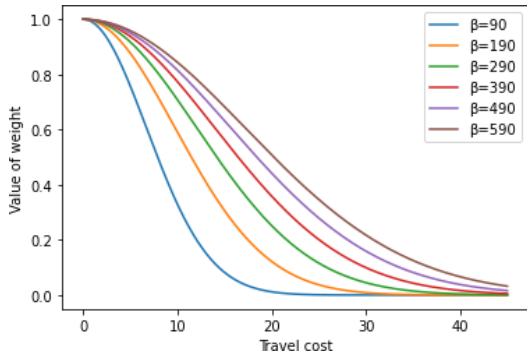


Fig. 2. Gaussian based Weight values used in 2SFCA, area of E2SFCA and, KD2SFCA for a catchment size of 35 minutes

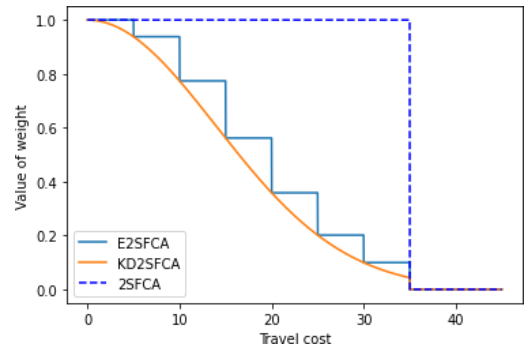


Fig. 3. Gaussian function values for a catchment 35 minutes and different values of beta

Table 1: Formulas of spatial accessibility metrics from FCA family, where  $S_j$  is the supply of service,  $P_i$  is the population of location  $i$ , and  $W_{ij}$  is the weight value provided by the distance decay.

Metric	Formula
The enhanced two-step floating catchment area (E2SFCA)	$\sum_j \frac{S_j}{\sum_{i \in [d_{ij} < d]} P_i W_{ij}} W_{ij}$ <span style="float: right;">(2)</span>
The modified two-step floating catchment area (M2SFCA)	$\sum_j \frac{S_j W_{ij}}{\sum_{i \in [d_{ij} < d]} P_i W_{ij}} W_{ij}$ <span style="float: right;">(3)</span>
The kernel density two-step floating catchment area (KD2SFCA)	$\sum_j \frac{S_j}{\sum_{i \in [d_{ij} < d]} P_i W_{ij}} W_{ij}$ <span style="float: right;">(4)</span>
The three-step floating catchment area (3SFCA)	$\sum_j \frac{S_j}{\sum_{i \in [d_{ij} < d]} P_i W_{ij} \frac{W_{ij}}{\sum_{i \in [d_{ij} < d]} W_i}} W_{ij} \frac{W_{ij}}{\sum_{i \in [d_{ij} < d]} W_i}$ <span style="float: right;">(5)</span>

city center and lower farther away. For example, Sidi Maarouf, Ahl Laghlam, and Sidi Bernoussi are parts of the city with the lowest spatial accessibility results with respect to all the methods used. Areas with the highest accessibility values are clustered around the city center, particularly in Moulay Youssef, Sidi Belyout, Mers Sultan, El Fida, and El Maarif. Most of these neighborhoods have accessibility scores above 0.768. As the distance from the city center increases, there is a tendency toward decreasing accessibility, mainly because hospitals with the most considerable capacity are located in the city center.

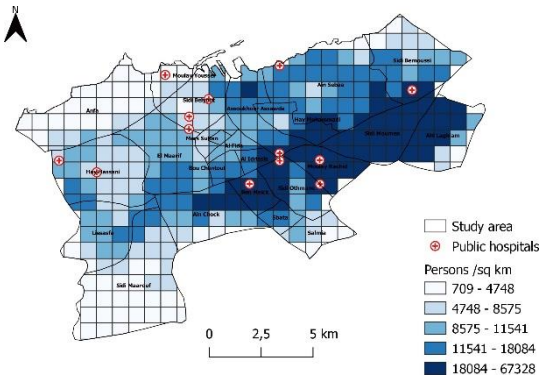


Fig. 5. Spatial distribution of population within the study area

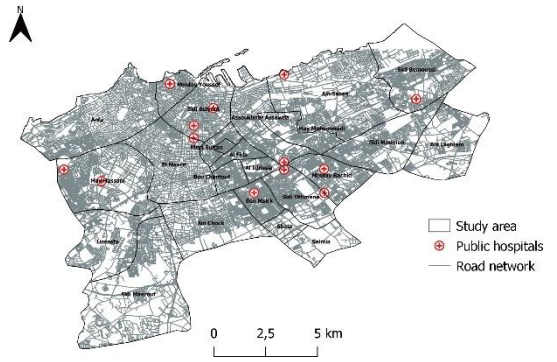


Fig. 4. Public hospitals and road network within the study area

Table 2 presents the statistical summary of spatial accessibility results, using the four metrics. The E2SFCA have a range from 0.015 to 1.46, with an average of 0.7 and standard deviation of 0.42. Values of the M2SFCA are close to the average: 0.42. Values in the results from the 3SFCA are farther away from its mean: 0.78.

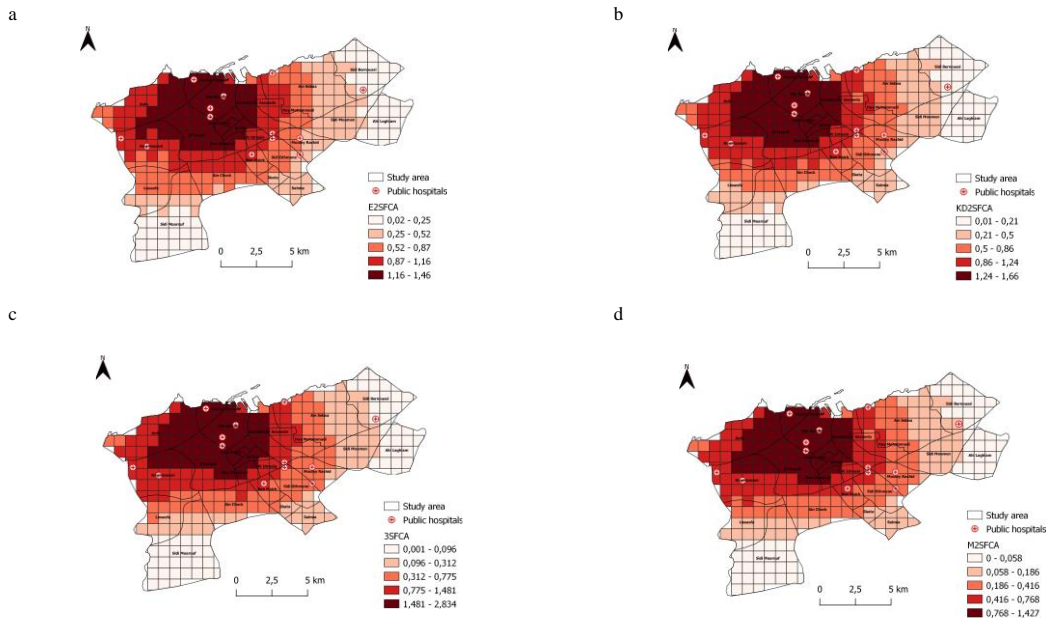


Fig. 6. (a) Spatial distribution of accessibility using the E2SFCA; (b) Spatial distribution of accessibility using the KD2SFCA; (c) Spatial distribution of accessibility using the 3SFCA; (d) Spatial distribution of accessibility using the M2SFCA

Fig. 7 shows sensitivity analysis of the spatial accessibility: results from different population-grid cells, as used by one of the FCA metrics, compared to another metric. As illustrated in Fig. 7 (7e,7f), the E2SFCA and the KD2SFCA tend to overestimate spatial accessibility compared to the M2SFCA. The latter underestimates spatial accessibility compared to the 3SFCA (Fig. 7 c). The 3SFCA overestimates the results in some of the parts located in the city center, mainly those with results above ( $> 1$ ), and underestimates it when the spatial accessibility

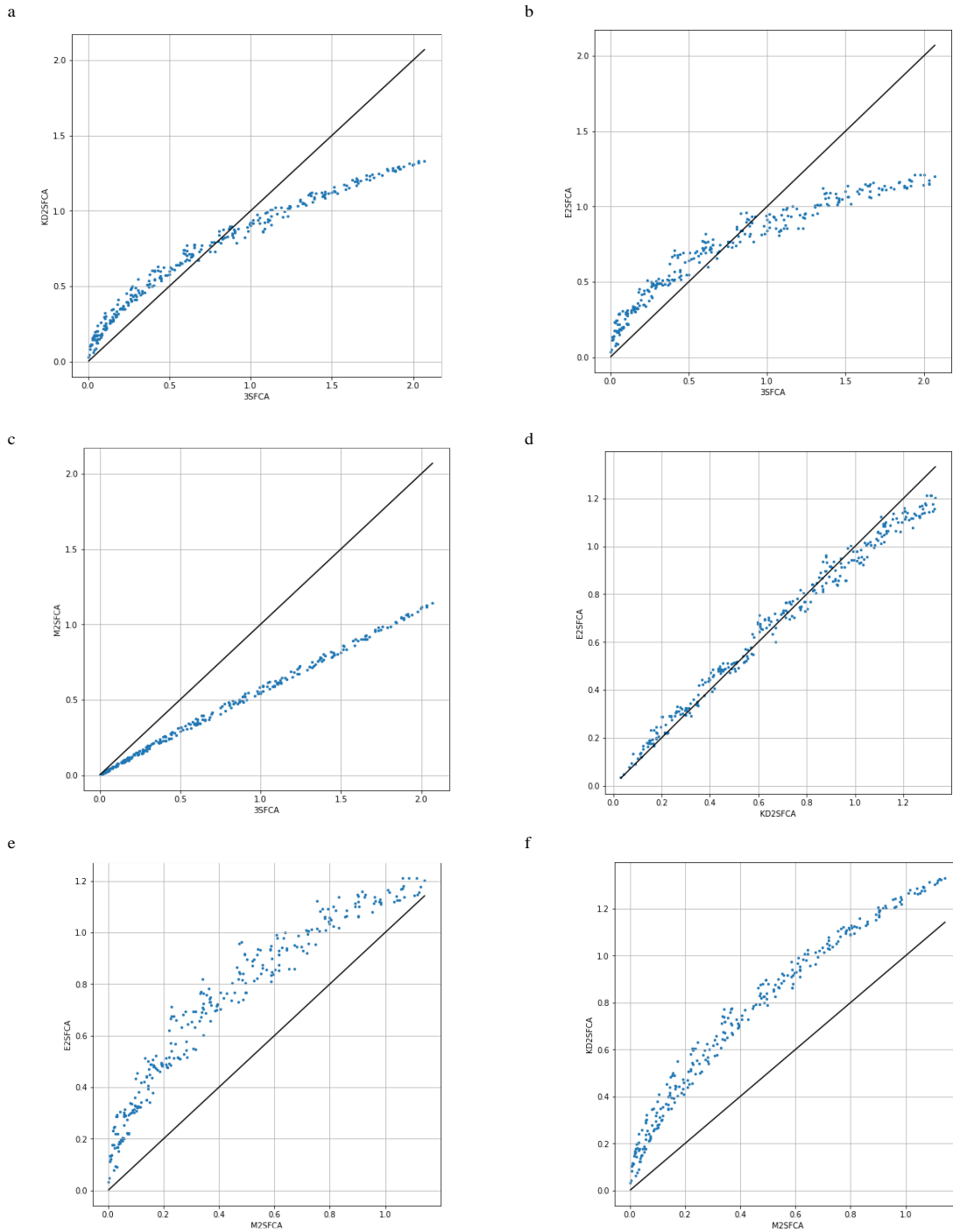


Fig. 7. (a) KD2SFCA compared to 3SFCA; (b) E2SFCA compared to 3SFCA; (c) M2SFCA compared to 3SFCA; (d) E2SFCA compared to KD2SFCA; (e) E2SFCA compared to M2SFCA; (f) KD2SFCA compared to M2SFCA

is relatively low ( $< 1$ ) compared to the E2SFCA and the KD2SFCA (Fig. 7 (7a,7b)). Results with E2SFCA and KD2SFCA are comparable (Fig. 7 (7c,7d)).

A comparison can be drawn between our results and the hospital availability data of the WorldBank (2017) which states that there is one hospital bed per 1,000 people in Morocco, including those in public and private healthcare facilities. The metric aims to help the world bank identify weaknesses and areas where investments may be necessary. However, it does not consider how people and hospitals are spatially segregated between regions and within the same region, nor the transport dimension people use to access hospitals.

Table 2: Statistics of spatial accessibility, computed using E2FCA, KD2SFCA, 3SFCA, and M2SFCA

FCA metrics	Min	Max	Mean	Std.Dev
E2FCA	0.015306	1.462474	0.700711	0.422864
KD2SFCA	0.013343	1.663618	0.716449	0.482134
3SFCA	0.000588	2.833951	0.785950	0.772401
M2SFCA	0.000311	1.427156	0.410149	0.388893

## 5. Research limitations

According to scientific literature, cars are mainly used to access medical facilities Xiao et al. (2021). Therefore, this study focused on driving as a mode of transportation. However, not all of the population uses cars to reach public hospitals. Future research will focus on incorporating other forms of transportation, such as public transportation, to see how this could lead to different results. Thirty-five minutes has been considered an appropriate catchment size to analyze healthcare accessibility by car in Casablanca. However, variable catchment area size would lead to more realistic results Luo and Whippo (2012). On the other hand, the impedance coefficient was set at 266. Though it would be more realistic to see how outcomes might change if different coefficient values were used Wan et al. (2012a). The study did not include hospitals outside of the study area. This may affect accessibility results, especially at the border of the study area, as people may travel from where they live to hospitals around the city like those in Mediouna, Mohammadia, Bouskoura, and Dar Bouazza.

## 6. Conclusion

This study described and implemented various Floating catchment area metrics to compute spatial accessibility to public hospitals in Casablanca. The results present spatial accessibility patterns within the city. Our work shows how spatial accessibility metrics can be used to help the development of healthcare spatial distribution. The proposed car-centric model as a means of accessing primary health care facilities in Casablanca serves as a continuous incentive for future research on accessibility using different transportation modes and facilities. Future work needs to consider public transportation, public hospitals in areas around the city, variable catchment size, and variable impedance coefficient.



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