MEASURING SPATIAL ACCESSIBILITY TO HEALTHCARE FACILITIES IN ISFAHAN METROPOLITAN AREA IN IRAN

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ABSTRACT:

Appropriate spatial accessibility to healthcare facilities is an important component of the efficient delivery of healthcare. This study aims to measure spatial accessibility to healthcare facilities in Isfahan Metropolitan Area, a rapidly growing megacity in Iran. We used two methods of population-weighted fuzzy analytic hierarchy process and the two-step floating catchment area (2SFCA) to measure spatial accessibility to urban healthcare facilities, including hospitals, pharmacies, clinics, and laboratories. The results of these two methods were compared. Not surprisingly, the center of Isfahan has the highest accessibility scores for healthcare facilities, and the peripheral areas of the city have the lowest levels. Despite the existence of higher numbers of healthcare facilities in northern parts of Isfahan, accessibility to healthcare facilities is low because of the large population. Both methods show that healthcare services are not evenly distributed in Isfahan. Some areas with a high population have low accessibility to health facilities. Ideally, these areas would be prioritized for future health infrastructure investment. The methods used here can help urban healthcare policymakers identify spatial inequalities in access to care and thus target the areas in need.

1. INTRODUCTION

The world's population is predicted to increase from 7.8 billion in 2020 to 9.7 billion by 2050, and the urban population will increase from 55 percent in 2018 to 68 percent by 2050 (Cilluffo and Ruiz, 2019). This increase will put more pressure on urban infrastructure, and especially healthcare infrastructure (Hussain et al., 2015; Galea, Vlahov, 2005; Rana, 2009). The provisioning of sufficient healthcare facilities is increasingly demanding, particularly in developing countries where population growth is rapid, often accompanied by poverty, and there is a general lack of economic and other infrastructural resources (Ujoh, Kwaghsende, 2014).

Measuring spatial accessibility to existing facilities and determining the optimal location or site selection of new facilities is crucial for urban managers and health policy designers (Jamali et al., 2012; Durand et al., 2011; Guagliardo, 2004). Evaluating the distribution of population and urban services can be useful in measuring spatial equality and in formulating plans to meet citizens' basic needs for urban facilities and services (Okabe, 2016; Yuan et al., 2017).

A Geographical Information System (GIS) enables researchers to study spatial accessibility to healthcare facilities and services (Cromley and McLafferty, 2011). There are many different methods of measuring spatial accessibility, including distance-time, gravity, utility-based accessibility, two-step floating catchment area (S2FCA), and measuring cumulative opportunity (Ashik et al., 2020; Deboosere, El-Geneidy, 2018; Miller, 2018). Accessibility can be measured by adopting two distinctive perspectives: topological accessibility and continuous accessibility (Rodrigue et al., 2016). For example, from a topological accessibility perspective, accessibility is measured using the transport network through nodes and routes (Huang et al., 2020), and from a continuous accessibility perspective, accessibility is measured over space without any specific physical barriers (Rabiei-Dastjerdi et al., 2018). Some of these methods are theoretically and mathematically simple, and some are more complex (Huang et al., 2020; Martín and Reggiani, 2007; Talen, 2003; Xing et al., 2018). The two-step floating catchment area method (2SFCAM) is a topological accessibility-based method to measure spatial accessibility (Matthew et al., 2009; Matthew et al., 2015; Ngui, Apparici, 2011; Xing et al., 2020). In topological data, the most important reason for using the 2SFCA method is its suitability for determining low-accessibility areas, whereas, in other similar methods, including the gravity method, there is a tendency to report higher accessibility levels in what are low-accessibility areas (Luo, Qi, 2009; Luo, Wang, 2003). Another method is the fuzzy analytical hierarchy process (FAHP) is a cumulative opportunity method based on the continuous accessibility utilized when only the locations of urban (healthcare) facilities and services are

available (Rabiei-Dastjerdi., et al, 2018; Unal et al., 2007; Kiran et al., 2020).
The current study was conducted to measure spatial accessibility to healthcare facilities and services in the Isfahan Metropolitan area (hereafter Isfahan) using both the FAHP and 2SFCA methods and compare results to answer the following questions:

- Where within the Isfahan Metropolitan Area are the areas with the highest/lowest access to health service infrastructure?
- Do the different methods—2SFCA and FAHP—generate different results in regard to health accessibility Isfahan?

The remainder of this article is organised as follows. Section 2 describes the case study, the data, and two implemented methodologies, including the Population-Weighted Fuzzy Analytic Hierarchy process and Two-Step Floating Catchment Area. Section 3 presents results and associated maps and the main findings of this study. Finally, Section 4 discusses the generalisation of results, limitations, and suggestions for future research.

2. MAIN BODY

2.1 Case Study

Isfahan, the capital city of Isfahan province, is the third most populated city in Iran, with a population of approximately two million. The city includes 15 districts and 200 neighbourhoods (Figure 1). In the last century, Isfahan has experienced the rapid and scattered development of the urban surface (Amini et al, 2022; Alimohammadi et al., 2004; Rabiei-Dastjerdi, Matthews, 2018).

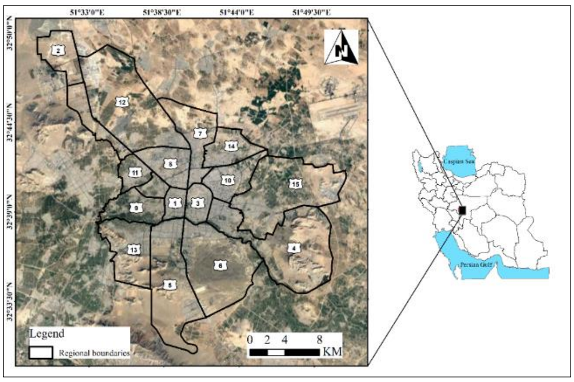


Figure 1. Map of Isfahan Metropolitan Area in Iran.

Figure 2. is the population density of Isfahan and the 15 official administrative districts of the city. This map shows that the population distribution in the city is geographically uneven, and the density of the population is higher in districts close to the historical core of the city.

2.2 Data

Table 1 shows the types and the number of urban healthcare services in Isfahan, and Figure 3 shows the spatial distribution of these different urban health facilities—hospitals, clinics, pharmacies, and medical labs—and population density within Isfahan. All data were provided by the municipality of Isfahan based on the 2016 survey and confirmed using Google Earth, with some information supplemented by OpenStreetMap (OSM) data. These data were prepared in ESRI shapefile format and georeferenced with the Universal Transform Mercator (UTM) zone 39 coordinate system in ArcGIS software.

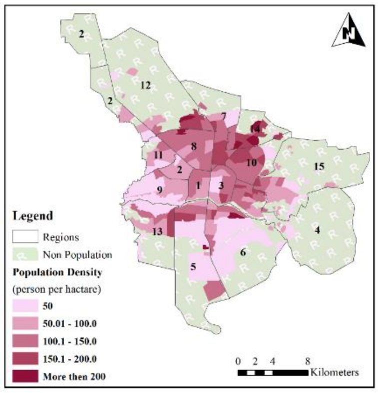
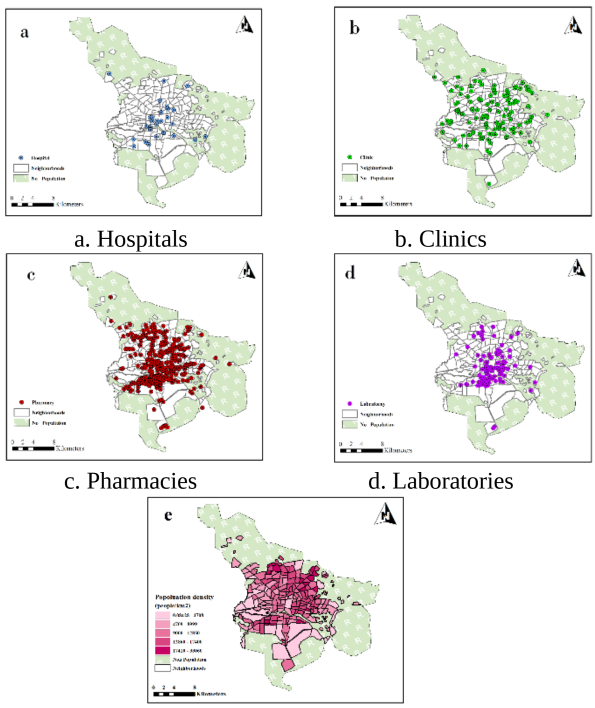


Figure2. Population density.

Population data was assigned to points and turned into a raster layer using interpolation methods and ultimately prepared in the fuzzy form in which its range is between 0 to 1. The highest population density areas are in the northern parts, and the lowest parts are in the western and suburbs, Figure 2.

No	Name	Number of Services
1	Hospital	29
2	Clinic	127
3	Pharmacy	549
4	Laboratory	178

Table 1. Table 1: List of Data.



a. Hospitals
b. Clinics
c. Pharmacies
d. Laboratories
e. Population

Figure 3. Distribution of healthcare services and population.

2.3 Methodology

Travel cost often is the best criterion to measure the accessibility to facilities that people face within the city (Rabiei-Dastjerdi et al., 2018). Travel costs can be decomposed into travel time and distance to represent spatial accessibility. Due to a lack of transportation network data and map, Euclidean distance was used as a proxy of travel distance (or) to measure the distance to healthcare facilities. This method requires less data input as it does not consider travel speed and travel time (Ashik et al., 2020) and is useful in studies where accurate transportation data is not available (Delamater et al., 2012). Although topological accessibility using transportation networks measures distance more accurately, Euclidean distance can be used when this information is not available (Rabiei-Dastjerdi et al., 2018; Ashik et al., 2020; Koenig, 1980). In this paper, we measure continuous accessibility using the Population-Weighted Fuzzy Analytic Hierarchy Process (PWFAHP) method and topological accessibility via the 2SFCA which are explained in the following sections

Population-Weighted Fuzzy Analytic Hierarchy process

The Analytic Hierarchy Process (AHP) method is a comprehensive approach to Multi-attribute Decision-Making (MADM). Spatial multi-criteria decision analysis can be seen as a process that combines and transforms spatial data into a resultant decision (Drobne, Lisec, 2009; Saaty, 2008). First, to prepare each facility or service's cost layer, the Euclidean distance from them was measured. Then a weighting system was designed to combine standardized layers. The weighting system for inserting the functional importance of each urban health facility was designed based on the knowledge and opinion of 10 experts, researchers, and managers of health facilities and services in this field (Table 2). Weights indicate the impact of each layer in a composite map (Saaty, 2008). The highest and lowest weights were allocated to the hospitals and the laboratories as 0.1 and 0.4, respectively (Table 2). Equation 1 shows the calculation applied in the FAHP model:

$$\mathrm{FAHP} = \mathrm{Hos} * 0.4 + \mathrm{Cl} * 0.3 + \mathrm{Phar} * 0.2 + \mathrm{Lab} + 0.1 \quad (1)$$

Name	Weight
Hospital (Hos)	0.4
Clinic (Cl)	0.3
Pharmacy (Phar)	0.2
Laboratory (Lab)	0.1

Table 2. Weighing system.

The Kriging interpolation method (Oliver and Webster, 1990) was used to interpolate the population map, in which the value of each specific cell indicates the number of populations in that particular cell. Accessibility to services was calculated by dividing the potential layer of spatial accessibility by the population layer, Equation 2.

$$\mathrm{PWFAHP} = (\mathrm{FAHP})/\mathrm{P} \quad (2)$$

Where FAHP is spatial accessibility to healthcare facilities and services in Isfahan, P is population. PWFAHP is the population-weighted spatial accessibility and is shown in (Figure 6. The map reveals, as is to be expected, that different parts of the city in their levels of spatial accessibility to health service infrastructure.

Two-Step Floating Catchment Area (2SFCA)

The two-step floating catchment area (2SFCA) is one method for measuring accessibility that has been used extensively (Chen and Jia, 2019; Kanuganti et al., 2016; Xing et al., 2020), and has been applied to the study of healthcare facilities and services (Kiani et al., 2018; Matthew et al., 2015). The 2SFCA method is a special case of the gravity method and thus not only keeps most of the advantages of the previous model (such as gravity), but is also intuitive to interpret, as it generates basically a special form of healthcare services for population ratio and capacity of an urban service (here bed size of a hospital). In the context of Isfahan, the location of hospitals and data on their bed capacity were used (Table 3), and the population layer for 2016 was prepared for each census area within the city. The 2SFCA method includes two steps as follow:

Step 1. Each hospital's service area was allocated to the population in the area of influence of that hospital (within a specific distance radius or point in polygon(s) approach), which in this study was considered 4 km. The distance between the locations' supply (urban facility or service) and demand (users or citizens) of urban services is essential in measuring urban spatial accessibility (Apparicio et al., 2003). Various methods for estimating this factor from Euclidean distance as a proxy of cost, including travel time, are mentioned in the literature (Lasser et al., 2006; Yan et al., 2009; Cervigni et al., 2008). In different cities of the world, depending on the level of access to urban health services and the efficiency and quality of these services, the travel distance to a hospital may be different for citizens or users. For example, in a study in Iran, a travel distance of 1 to 1.5 KM was used (Kiani et al., 2021). In another study in Montreal, this distance was set between 3 to 10 km (Ngui, Apparicio, 2011). Due to the knowledge of the authors on the current situation in Isfahan, the people of Isfahan prefer to travel up to 4 km to reach each hospital from their place of residence, so a travel distance of 4 km was used in this study. Equation 3 illustrated the ratio of the hospital to the population in each catchment area.

$$R_j = \frac{S_j}{\sum_{k\epsilon(d_{kj}\le d_0)} P_k} \quad (3)$$

where:
Rj: hospital's ratio to the population at point j,
Sj: number of hospitals at point j,
Pk: population in the catchment area of k and
dkj: travel time between k and j points.

Step 2: These ratios are calculated at the center of each catchment area. The ratios calculated in the previous step were aggregated with overlapping catchment areas, which ultimately indicates that residents have access to several hospitals. Following equation 4, for each population point i, all hospitals (j) are specified within the distance threshold d0 from point i (catchment influence i), and all hospital ratios to the population associated with point i are aggregated. Figure 4 presents the flowchart of the methodology.

$$A_i^F = \sum_{j\epsilon(dij\le d_0)} R_j = \sum_{j\epsilon(dij\le d_0)} \frac{S_j}{\sum_{k\epsilon(d_{kj}\le d_0)} P_k} \quad (4)$$

where:
Aif is t accessibility rate of the residential area i.
Rj: ratio of hospital to the population at point j,
Sj numbers of hospitals at point j,
Pk: the populatiothe n of catchment area of k
, and
dkj: travel time between k and j points.

No	Names	C [1]	No	Names	C
1	Gharazi	237	16	Emam Hossein	168
2	Amin	181	17	Ahmadiyeh	39
3	Shahid Beheshti	118	18	Feiz	118
4	Dr. Ali Shariati	361	19	Isfahan	56
5	Imam Musa Kazim	96	20	Mehregan	62
6	Shahid Sadoughi	267	21	Amir-Al-Momenin	108
7	Khanevadeh Specialty	113	22	Isabn-e-Maryam	114
8	Zahraye Marzieh	146	23	Shahid Chamran	216
9	Sepahan	89	24	Asgarieh	252
10	Saadi	145	25	Hojjatieh	46
11	Seyed o-Shohada	166	26	Sina	118
12	Kashani	194	27	Alrasoul	60
13	Hazrat-e Zahra	817	28	Noor	224
14	Milad	254	29	Roz	24
15	Farabi	342	-		

Table 3. List of hospitals and their capacities by the number of beds in Isfahan.

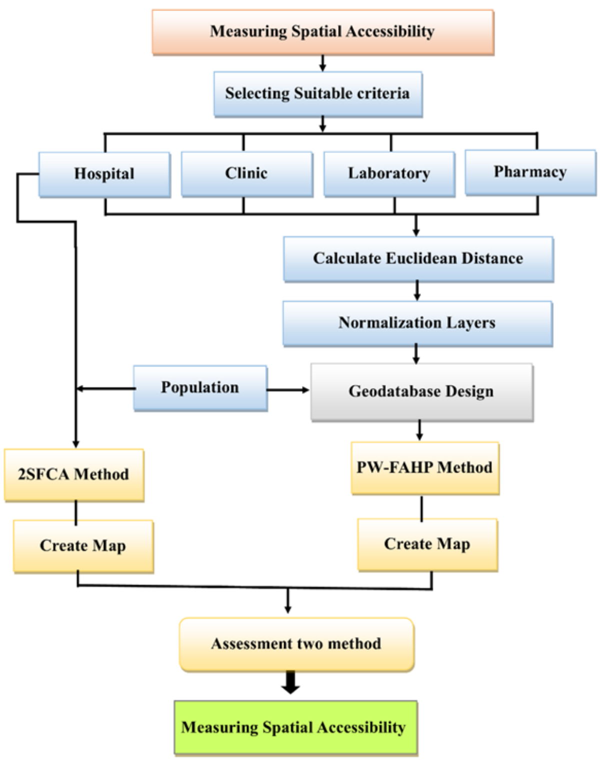
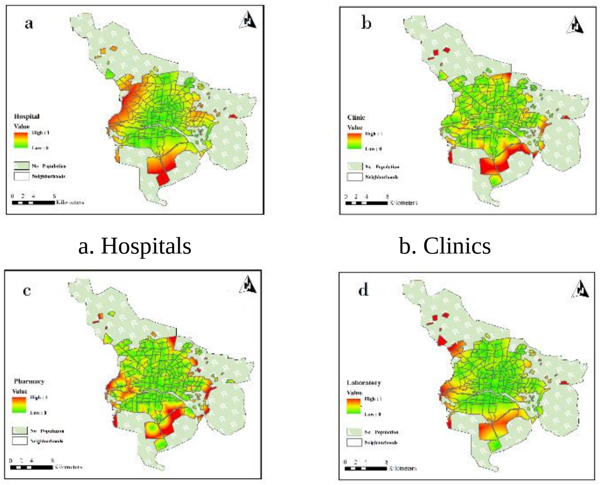


Figure 4. An overview of the proposed methodology and workflow

2.4 Results and Discussion

The result of the PWFAHP method, raster layers, in which each pixel shows the distance to the nearest desired healthcare facility or service, are shown in Figure 5. On these four maps, the areas in green are those locations of the city that a closer (more accessible) to the specified health service and the longer distances (less accessible) are shown in red. These maps show that the spatial accessibility to urban health services is high in the city centre because of the concentration of these services in the central business district (CBD) of the city, and they are more dispersed in outlying areas, especially in the northern and eastern edges of the city.



a. Hospitals b. Clinics

c. Pharmacies d. Laboratories

Figure 5. The maps of distance to the nearest healthcare services.

Figure 6-a shows spatial accessibility to healthcare facilities and services in Isfahan and the location of a recently established public-private partnership urban megaproject, Shahrak Salamat (which means Health Town in English) (Rabiei-Dastjerdi, Matthews, 2018), based on the FAHP method and the PWFAHP method in Figure 6-b. Since the 2SFCA method focused on accessibility to hospitals, we compared the two methods by only examining hospitals (Figure 6-c and Figure 6-d). In this study, we had some findings that can be listed as follow:

- Data limitation: in conventional studies, the focus of the literature is on spatial accessibility to hospitals (Zheng et al., 2019; Zhao et al., 2020; Kalogirou, Foley, 2006; Huotari et al., 2017). In this study, we measured spatial accessibility to other healthcare services as well, which can show other pictures of urban spatial inequality, but more data and layers of healthcare and services in the city can improve this picture. To name a few, we did not have access to urban transport data. Public transport, which is very essential for citizens to provide access to all public and private urban facilities and services, can partially compensate for different types of spatial inequality. Due to our limitation to this data, we were not able to study the role of public transport in enforcing or compensating for unequal spatial accessibility to urban health infrastructure. Also, we did not have access to attributes of our health services, such as the age of health services and facilities, but the rapid population growth is well documented. This limitation highlights the importance of access to open data for researchers. Volunteered geographic information (VGI) such as OSM has a high potential to complete other sources of data, but they are not complete, especially layers such as pharmacy (Rabiei-Dastjerdi et al., 2020).
- Heterogeneity in need: in the PWFAHP method, we impose the weighting based on experts' opinions, but we are fully aware that other weighing systems might be more appropriate. For example, some experts believe that pharmacies should have higher weights compared to hospitals because ordinary people have to go to a pharmacy for basic needs more often, and a hospital is more important for sick and older people.

[1] Capacity

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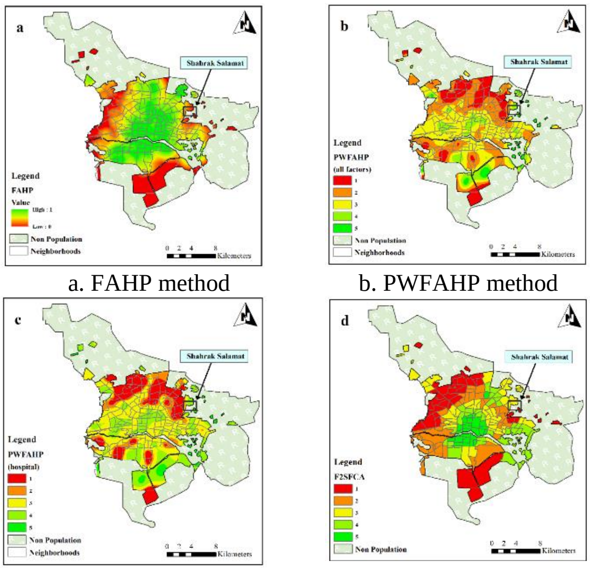
Consequently, weighing systems should be carefully designed based on the aim of healthcare policy for the provisioning of health service infrastructure in the city. Therefore, age and health condition segmentation of the population can be considered if the focus is on a segment of the population, such as the elderly or people who are suffering from rare diseases. Put simply, the results and outputs are sensitive to the implemented weighting system (Chen et al., 2013).



a. FAHP method

b. PWFAHP method

c. PWFAHP method (hospitals)

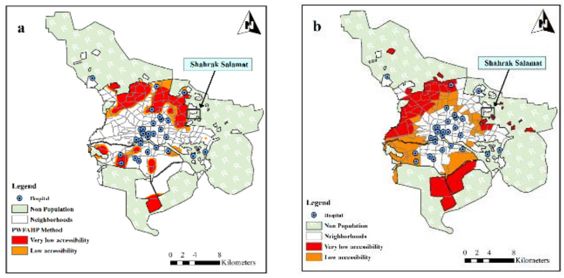
d. 2SFCA method

Figure 6. (a). spatial accessibility to hospitals by the FAHP method (b). spatial accessibility to healthcare services by the PWFAHP method (c). spatial accessibility to hospitals by PWFAHP (d). spatial accessibility to hospitals by the 2SFCA method.

• Modifiable Areal Unit Problem (MAUP) (Fotheringham, Wong, 1991): all citizens do not use a health service based on their home residence, and they might use other urban health services in other urban areas which are more convenient for them regardless of distance (aggregation or scale effect) (Learnihan et al., 2011; Hewko et al., 2002). In addition, the edge effect has significant impacts on the results of the study and the value of spatial accessibility to urban health services, for example, city users who live in peripheral areas of the city or satellite cities because of the cost of housing (Rabiei-Dastjerdi, McArdle, 2021) and other people far from Isfahan, even from other provinces come to the city to receive different health services (Rabiei-Dastjerdi, Matthews, 2018). The role of these city users has not been studied in this research. To put it in a nutshell, in this study, we based our models only on residents (data), and we did not include commuters and visitors.

• Evolution of the city: current inequality of health service spatial accessibility is reflecting the historical evolution of the city from the city centre where the spatial accessibility to health infrastructure is high to edge areas which are suffering from low spatial accessibility. The evolution of the Isfahan is a series of urbanisation processes and forms such as suburbanisation of people similar to the western countries where the rich people moved to areas with better environmental conditions (e.g., south), urban sprawl, or unplanned development (Karakayaci, 2016) when the city sprawled to different directions, especially to the north due, and suburbanistion of poverty (Kneebone and Garr, 2010) when the low-income people moved to the satellite cities of this metropolitan or city-region (Parr, 2005).

• Public health application: The results of this study can be used by public health and urban planners in the future, for example, in the site selection of new hospitals in the city. Figure 7 shows areas with red colour that have high priorities for building new hospitals based on two methods we used in this study. In other words, in these areas, spatial accessibility to health care services is low.



a. FAHP b. 2SFCA

Figure 7. High priorities areas for health and urban planners.

3. CONCLUSIONS

Inequality is a multidimensional concept that includes various inequalities, including inequality in healthcare. Urban planners and healthcare policy designers need to use methods to measure spatial accessibility to healthcare services. In this study, the spatial accessibility to urban healthcare and services in the Isfahan metropolitan area was measured using two methods of PWFAHP and S2FCA. In general, the results reveal a mismatch in services for the resident population in 2016, likely related to the differences in population growth and the provisioning of urban health infrastructure in the city.

The PWFAHP method found low levels of accessibility in the northern parts of Isfahan, while the 2SFCA method showed that residents in central areas have the highest accessibility to hospitals. Some outlying areas do not have adequate access to health services. Given the observed patterns of spatial accessibility, there are opportunities to coordinate and plan new health facilities (of all types) in those areas with underserved populations. Given continuous population growth and without attention to the delivery of healthcare and medical services could exacerbate health disparities within the city.

Although urban (health) facility services infrastructure is a product of different private, public, and government actors, socioeconomic, technological, cultural factors, and planning mechanisms (Zeaiean et al, 2005; Lowe et al., 2015; Chapple, 2014; Garau, Pavan, 2018; Bibri, Krogstie, 2017; Rabiei-Dastjerdi, Matthews, 2021; Rabiei-Dastjerdi et al, 2022), this study aimed to highlight the problem the spatial accessibility to urban health services in Isfahan, a major city in Iran as a developing country, for health policy designers and urban planners through mapping different indexes of accessibility. The implemented methods in this article can be used in other cities with similar spatial structures and socioeconomic contexts, especially in developing countries where access to data is a serious barrier to research in public health and urban studies. It is worth noting that the 2SFCA model used is based on the gravity model but expresses the model in a more intuitive way. However, it is limited in that it assumes equal access for all populations within the catchment. On the other hand, the E2SFCA and

3SFCA methods were designed to overcome the limitation of the basic 2SFCA method, and represent a more reasonable implementation of the basic method. Thus, for the assessment of spatial access to healthcare, we suggest two E2SFCA and 3SFCA methods for future studies, because these models are based on a more reasonable assumption of healthcare demand for medical services.

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