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GEOGRAPHIC ACCESSIBILITY ANALYSIS USING THE E2SFCA MODEL IN HOSPITALS LOCATED IN ARMENIA, QUINDÍO

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Abstract: This research applies the Enhanced Two-step Floating Catchment Area method to determine the accessibility conditions of to the health care network in an intermediate Colombian city. This research aims to evaluate the medical personnel supply concerning the geospatial position of health care services in Armenia, Colombia, considering the operational and geometric particularities of the private transportation network. As a method, the Enhanced Two-step Floating Catchment Area is proposed, complemented with socio-demographic analyses. The most important result is about the level of medical coverage for socioeconomic strata 1, 2, and 3, which are below the average established by the World Bank.

Key words: E2SFCA, health, planning, accessibility, coverage

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INTRODUCTION

Hospital coverage in terms of physicians availability, points of care and available beds (Escobar et al., 2020), as well as the level of service complexity in the care center, as a result of the capacities and available elements of each city. This coverage behavior has a functional design associated with population growth and social development, in addition to the resources available to the public administration and private entities operating in the sector, resulting in a coverage level following the population's requirements. Despite these functional designs, some atypical events generate an excess demand for health services, which must be faced and assumed by the existing infrastructure eventuality. A clear example of this is the health services collapse due to the COVID-19 pandemic, in which the limit of supply allowed for ICU (Intensive Care Unit) eventualities in Colombia was reached. It required governmental decisions to mitigate the pandemic, forcing the population's preventive isolation and applying other necessary control measures (Presidencia de la República de Colombia, 2020). This eventuality generated an impact in matters of health services available at a worldwide level, thus giving the necessary justification for the current research, which is intended to diagnose accessibility to health care services concerning the physicians available in the population's area of influence. It also contrasts the indicators published by the OECD and the World Bank regarding the number of doctors per 1000 inhabitants in different cities of the world (OECD and World Bank, 2020).

At the local level, alerts were made to the attention of medical services in Colombia. These are related to the high levels of contagion that had to be reported continuously on the Ministry of Health's website, which showed the population figures affected by Coronavirus at a national and local level (Ministerio de Salud, 2022), allowing to know the pandemic's behavior and status. Likewise, it was necessary to restrict the number of facilities, improve equality in healthcare services and provide easy access to the population (Wang, 2012). Coverage maximization is achieved with this research using geostatistical analysis such as accessibility, which considers that interaction is relevant to the potential of opportunities (Hansen, 1959). This case would focus on the users' interaction with Armenia's city health system. Considering the capacity of care in the potential demand and the proximity of the services provided, it is crucial to implement the methodology in spatial accessibility, which seeks to assess the potential access of patients to health services (Garrocho and Alanís, 2006). The concept of accessibility is determined by a series of assumptions and data inputs, where the level of opportunities in immediate accessibility is achieved under a predefined threshold for travel impedance. Dual accessibility seeks to establish travel impedance, where it is necessary to reach a predefined threshold level using the number of opportunities (Wu and Levinson, 2020). As a structure and planning guide in transport, accessibility is of great importance for a consensus opinion, which for the concept

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of transport is considered the demand as a derivation of the population's needs about reaching their destinations (Levine, 2020). Accessibility in our case study is a service access measure, where various modes and calculation methods have been found that demonstrate its wide use. Among these are demographic analysis (Kotavaara et al., 2011), economic development that is associated with the quality of transport infrastructure within a given region (MacKinnon et al., 2008), and the concept of transport infrastructure (MacKinnon et al., 2008), and the operational concept of transport modes (Younes et al., 2016), commerce (Montoya et al., 2017), education (Walsh et al., 2015), tourism (Pathmanandakumar et al., 2023; Abdeljawad et al., 2023) among others. Considering the importance and breadth of the methodology used, our case study seeks to ensure accessibility based on transport for essential facilities such as medical centers in a city, aiming to provide healthcare services to the population regardless of different socioeconomic levels (Freeman et al., 2020), in addition to the assessment of some characteristics such as mode of transport, land use, travel patterns, objectivity and habits presented by specific communities regarding their travel practice (Gutiérrez, 2012).

Based on the above, the most appropriate accessibility evaluation procedure is determined for the research, where the Enhanced Two-step Floating Catchment Area - E2SFCA (Luo and Wang, 2003) method was chosen, seeking that the travel time obtained with the distance decrement function focuses on the spatial accessibility of the municipality (Aziz et al., 2022). This method is applied with basic steps such as: Data preprocessing, accessibility measurement, correlation analysis and inequality assessment (Park et al., 2023). It aims to establish the sectors or communities that are not considered and located in places of a greater distance to the center of the city of analysis, i.e., the city's periphery. On this method it is important to consider that the characteristics in service levels and their medical resources in hospitals are fundamental to solve critical illnesses, where a factor related to the type of road infrastructure network of the study sector is included, seeking to analyze the potential demand that can improve its medical care service (Li and Wang, 2022). With the location of hospitals, the method above has been used to calculate their spatial accessibility and to be able to measure the accessibility of primary care and hospitals regarding their georeferencing (Huang et al., 2019). Considering the importance in the different accessibility studies in developed countries where they have determined in the decay function the travel time of 60 minutes for emergency care in injured or sick people to achieve their displacement (Chen et al., 2023). However, in other studies, they determine that the distance decay starts after 10 minutes, but the maximum travel time threshold for spatial accessibility using the E2SFCA method is 30 minutes, evaluating primary care centers with blocks within a 50 km radius (Hong et al., 2023). Notably, some studies conducted in Colombia were identified and evaluated with the E2SFCA method focused on accessibility in the health sector, with great importance for the research development and focused on the provision of hospital service to meet the emergencies suffered by the population in the ICU (Intensive Care Unit). For this, the access assessment to services located in the capital of the department of Caldas is considered, taking into account the travel times (Escobar et al., 2020), as well as the accessibility of rabies vaccination posts with a robust analysis method of (Monsalve et al., 2016), in addition to similar research by Infante for the city of Bogotá (Infante, 2013). In our case the objective of the research is to determine the conditions of territorial accessibility offered by the road network in the capital of the department of Quindío to the health care service delivery nodes. The study area of this research focuses on Armenia, located in central-western Colombia and georeferenced in the coordinates between 04º 04' 41" and 04º 43' 18" north latitude and between 75º 23' 41" and 75º 53' 56" west longitude, i.e., its location is on the left side of the Central mountain range (Gobernación del Quindio, 2022). This municipality has an area of 121 km² and is at an average altitude of 1,551 masl (meters above sea level), with a population of 295,208 inhabitants (DANE, 2022). The study area is shown in Figure 1.

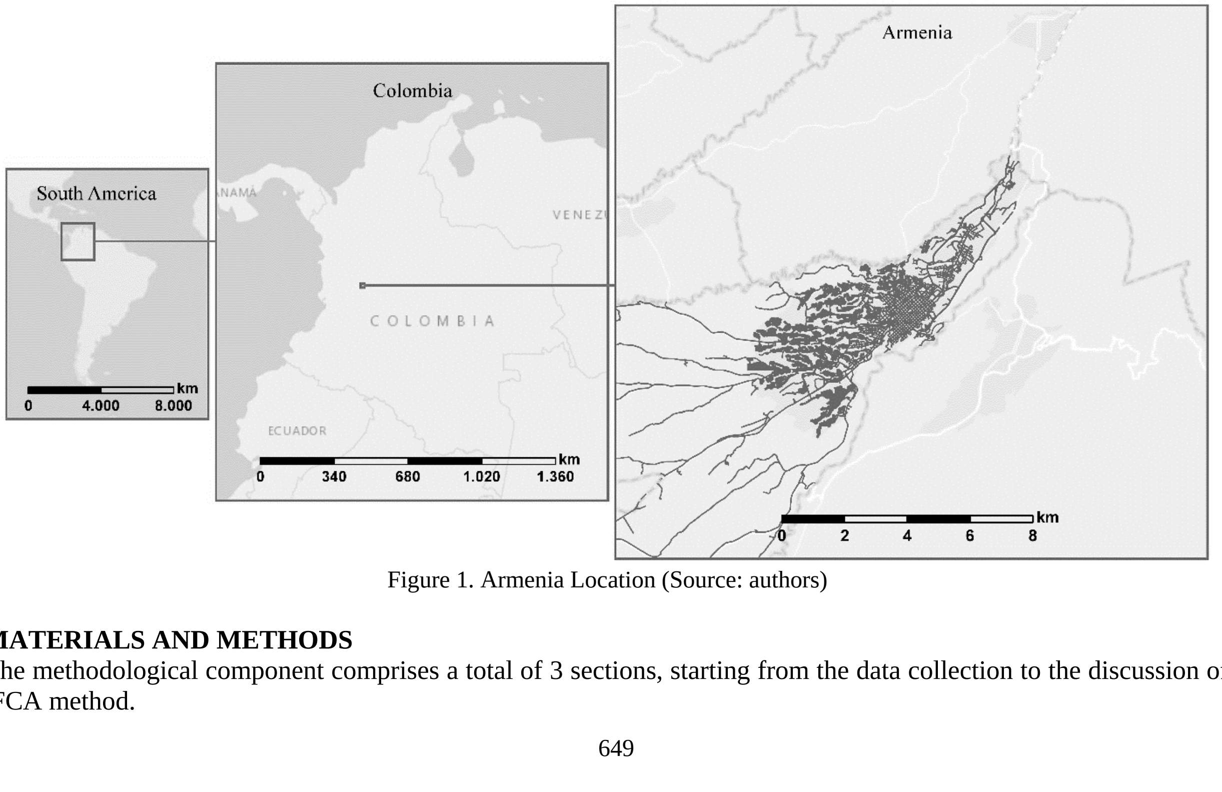

Figure 1. Armenia Location (Source: authors)

MATERIALS AND METHODS

The methodological component comprises a total of 3 sections, starting from the data collection to the discussion of the E2SFCA method.

Phase 1 - Data update and validation. This research is based on the Armenia road network in shapefile duly georeferenced with their corresponding speeds for private vehicles, as well as node and arc attributes with the characteristics of each operating section, such as length, slope, and directionality. Likewise, the calculation was performed by applying the Enhanced Two-step Floating Catchment Area - E2SFCA method to obtain detailed accessibility at the block level, seeking to identify the sectors that present areas with high and low impact on accessibility concerning the demand for hospitals (Ghorbanzadeh et al., 2021). Additionally, as relevant information on hospitals, it was necessary to consult what has been published on the (REPS, 2021) web page matrix containing the "Special Registry of Health Service Providers", where the levels of the health care nodes and the number of health care services per hospital were found. It was also necessary to seek information consulted directly at the Quindío Government's Planning Secretariat, where they provided the shapefile with the georeferencing (longitude, latitude) of the hospitals in the municipality of analysis. In the National Administrative Department of Statistics (DANE, 2022), the population information was obtained georeferenced in polygons at the level of detail by block with its corresponding code.

Phase 2- Geospatial analysis scenario. In this phase, the comprehensive accessibility calculated for each hospital was developed, considering the ease of reaching each desired destination node based on the number of opportunities available to the resources used to travel from a place of origin in the sector to the urban destination in the city (Bocarejo and Oviedo, 2012). With the data mentioned in phase 1, the statistical modelling is performed with the attributes available to the network (Network dataset). It proceeds to plot the integral accessibility isochrones with periods of 5 minutes in each hospital of the municipality, considering the road network conditions for private vehicles. The calculations and modelling carried out in this document were performed with ArcGIS® software and internal modelling tools such as Spatial Analyst® and Geostatistical Analyst®, which are classified as ESRI ArcMap® software applications. The population polygon per block was overlapped on the isochrone curves of each hospital to determine the number of inhabitants with accessibility in periods of 5, 10 and 15 minutes to find the population coverage in the mentioned time periods, as shown in Table 4.

Phase 3 - Calculation of E2SFCA. Step No. 1 of the E2SFCA method is calculated, considering the number of physicians and the population data per hospital to apply Equation 1 (Luo and Qi, 2009) in the established periods, being 5, 10 and 15 minutes for this research. Rj: Supply-demand ratio for each hospital; *S*j: number of physicians in each hospital; *P*k: population located in each travel time subarea (Cj); Cj: travel time j.

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \leq c_j)} P_k W_{kj}} \qquad (1)$$

Subsequently, step 2 of the Enhanced Two-step Floating Catchment Area - E2SFCA methodology is applied, where the calculation of an origin-destination (OD) matrix containing the travel times from the centroid of each block to each hospital in the area of analysis is performed considering the arcs and directions that make up the municipality's road network. With this, it was necessary to establish the criterion of travel times below 15 minutes. The Rij factor of doctors obtained in step 1 is applied; this is supported by adequate time to travel and attend to an emergency in an accident at a health center, which is essential considering that trips outside this time range are classified as inaccessible in an emergency (Luo and Wang, 2003). In this step, d has been considered to calculate its travel time regarding the Wr weights, where it is established in subzones, and the Gaussian equation is used, starting from three common forms of f(d) (Kwan, 2010; Pan et al., 2015), presented in Equation 2 and 3 (Luo and Qi, 2009), Weight calculation formula.

$$W_r = f(d_{ij}) = e^{(-\frac{d_{ij}^2}{\beta})} \qquad (2)$$

$$A_i^F = \sum_{j \in \{d_{ij} \leq D_r\}} R_j W_r \qquad (3)$$

d_{ij}: Travel time between i and j; β: Friction coefficient of distance; A_i^F: Accessibility for the population through the location concerns i; R_j: Physician -to- population ratio at physician location j within the catchment area in population i; W_r: Distance weighting for the travel time zone calculated from the Gaussian function, reflecting the deterioration of the access distance to the physician j. Equation 2 of the E2SFCA method is calculated to obtain the number of physicians per 1,000 inhabitants and proceed to calculate the average between the factors of these variables in the blocks of the municipality of analysis and, thus, calculate the accessibility in the current scenario and make an alternative that improves the conditions in a future scenario. For Colombia, the World Bank, together with the OECD, publishes a value of 2.2 physicians per 1,000 inhabitants, which is based on comparative analyses with around 100 indicators on the Health system of the "Health at a Glance: Latin America and the Caribbean 2020" (OECD and World Bank, 2020). Regarding the above, an important criterion is the indicator for physicians in Latin American countries (Table 1), as reference values and highlights the following.

Table 1. Medical indicators overview of countries with similar conditions to Colombia (Source: authors)

Country	Physicians (Per 1,000 inhabitants)
33 latin American and Caribbean (LAC) countries	2.00
Chile	2.50
Bahamas	2.00
Barbados	2.50
Mexico	2.40
Venezuela	1.90
Brazil	1.80

RESULTS AND DISCUSSION

This research consists of two scenarios analyzed, where the actual situation of the municipality is the current scenario and a proposal for improving access to health care services in the sector of analysis referred to as the future scenario. For this purpose, Figure 2 shows the isochronous curves for travel times of 5, 10, and 15 minutes collected for seven (7) hospitals and health care services. The calculations of average travel times under the hypothesis that travel from each neighborhood to each hospital node, where the number of inhabitants within the time ranges was determined, and the variable (Rj) was calculated, regarding the supply of physicians. Likewise, areas that are not covered by the mentioned ranges were found. The isochronous curves were modeled in the future scenario in Figure 3, where the impact generated with two (2) new hospital nodes is displayed. Its benefits of greater coverage are presented in the isochrones with ranges of 0 - 5 minutes and 5 - 10 minutes. However, this decreases for the isochrones of 10 minutes, as shown in Table 2.

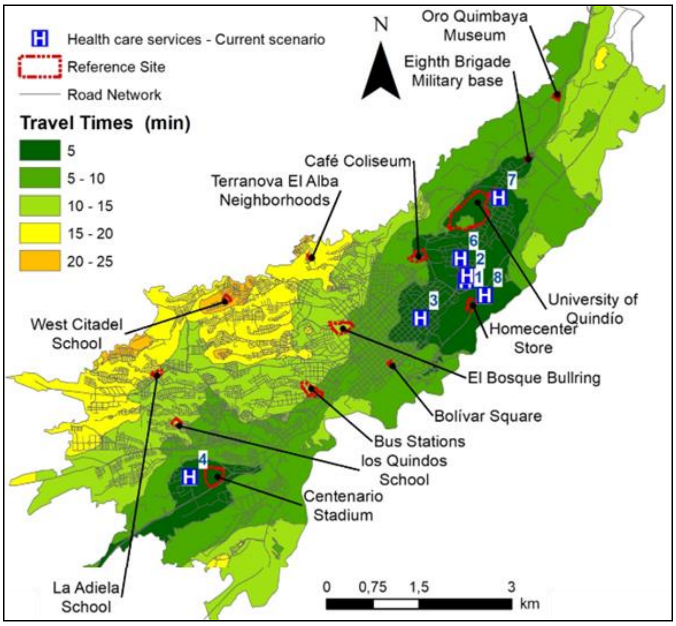

Figure 2. Isochronous curves calculated for the current scenario of health care services in Armenia (Source: authors)

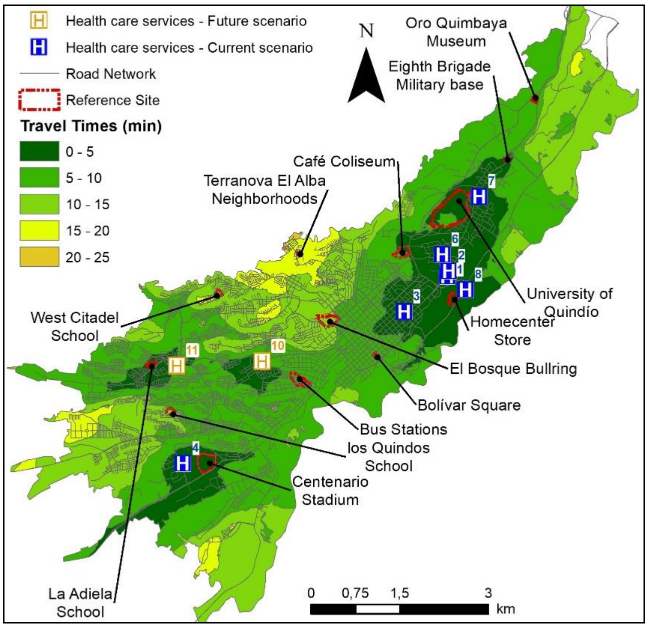

Figure 3. Isochronous curves calculated for the future scenario of health care services in Armenia (Source: authors)

Table 2. Coverage area and population comparison based on travel time isochrones (Source: authors)

Travel Time (min)	Current Scenario				Future Scenario			
	Isochrone area (hectares)	Isochronous coverage (%)	Number of inhabitants	Coverage Population (%)	Isochrone area (hectares)	Isochronous coverage (%)	Number of inhabitants	Coverage Population (%)
0-5	508.46	15.42	42,799	15.95	593.00	17.98	60,266	22.45
5-10	1,136.86	34.47	78,870	29.39	1,525.90	46.26	126,188	47.02
10-15	1,123.63	34.07	86,616	32.27	1,020.14	30.93	67,049	24.98
>15	529.35	16.05	60,102	22.39	159.45	4.83	14,884	5.55
Total	3,298.30		268,387		3,298.49		268,387	

Table 1. Step 1 calculation of the E2SFCA Rij method in Armenia's current scenario (Source: authors)

ID	Hospital Name	Number of Inhabitants Period of 0 - 5min	Number of inhabitants Period of 5 - 10	Number of inhabitants Period of 10 - 15 min	Rj (physicians x 1000 inhabitants)
Current Scenario - Hospitals Classified in Low Complexity					
4	Red Salud Armenia	9,469	36,550	71,428	0.32
6	Sociedad Cardiovascular del Eje	11,697	43,912	40,498	0.27
Current Scenario - Hospitals Classified as Medium and High Complex Hospitals					
1	Clínica Café Dumian Medical	6,591	42,029	44,856	1.79
2	Clínica Central del Quindío SAS	3,637	40,623	44,121	2.05
3	Clínica La Sagrada Familia SAS	12,188	46,226	56,005	2.00
7	Hosp. Univ. San Juan De Dios	14,135	30,320	34,127	3.24
8	Oncólogos de Occidente S.A.S.	3,673	30,984	54,281	1.57

Based on the indicators published in the document "Health at a Glance: Latin America and the Caribbean 2020" of the World Bank Group (OECD and World Bank, 2020) where the parameters obtained in the current scenario were relatively low in physicians as found in Table 3 and an alternative was structured to determine a future scenario in the municipality to meet the indicator established for Colombia or in the indicators of Latin American countries presented in Table 1, it seeks to improve the coverage of the inhabitants in the municipality, that for the future situation with an alternative that shows the same conditions in the current hospitals and proposing to implement two (2) new hospitals that are classified in service levels of medium and high complexity with parameters that are not high and is to attend emergencies and hospital issues similar to the Clínica Central del Quindío SAS. Results are in Table 4. Subsequently, the parameters for physicians in Armenia's health services were obtained by the E2SFCA method considering the importance of accessibility to medical centers, by generating the Rij parameters as step 1 of the method for a current scenario of seven (7) hospitals with 710 beds and where it has a capacity of 170 physicians as shown in Table 2, posing a future scenario with 573 physicians as shown in Table 3.

Table 4. Step 1 calculation of the E2SFCA Rij method in Armenia's future scenario (Source: authors)

ID	Hospital Name	Number of inhabitants Period of 0 - 5 min	Number of inhabitants Period of 5 - 10 min	Number of inhabitants Period of 10 - 15 min	Rj (physicians x 1000 inhabitants)
Current Scenario - Hospitals Classified in Low Complexity					
4	Red Salud Armenia	9,469	36,550	71,428	0.96
6	Sociedad Cardiovascular del Eje	11,697	43,912	40,498	0.49
Current Scenario - Hospitals Classified as Medium and High Complex Hospitals					
1	Clínica Café Dumian Medical	6,591	42,029	44,856	5.22
2	Clínica Central del Quindío SAS	3,637	40,623	44,121	5.78
3	Clínica La Sagrada Familia SAS	12,188	46,226	56,005	5.68
7	Hosp. Univ. San Juan De Dios	14,135	30,320	34,127	9.38
8	Oncólogos del Occidente S.A.S.	3,673	30,984	54,281	4.62
10	Hospital Nuevo 1	3,134	26,132	63,650	5.34
11	Hospital Nuevo 2	8,978	34,203	59,214	3.01

The above applies the results obtained in Equation 1 of the method, which is related to the supply-demand of each hospital Rj and the value Sj with the information of total general practitioners in Tables 2 and 3. These tables also show the number of inhabitants in ranges of travel time represented in the variable Pk. The periods Cj in this research were established with values of 5, 10, and 15 minutes considering travel times for care of any medical emergency.

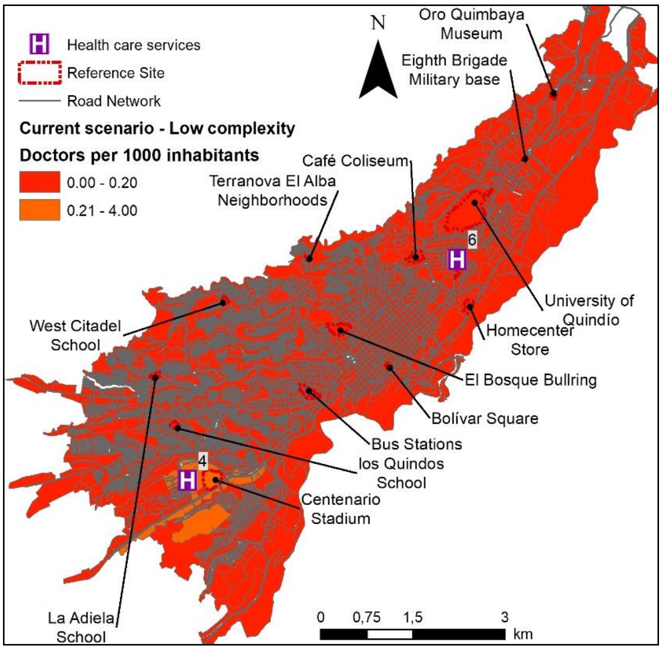

Figure 1. Accessibility to low complexity medical services per 1000 inhabitants in the current scenario based on the E2SFCA method

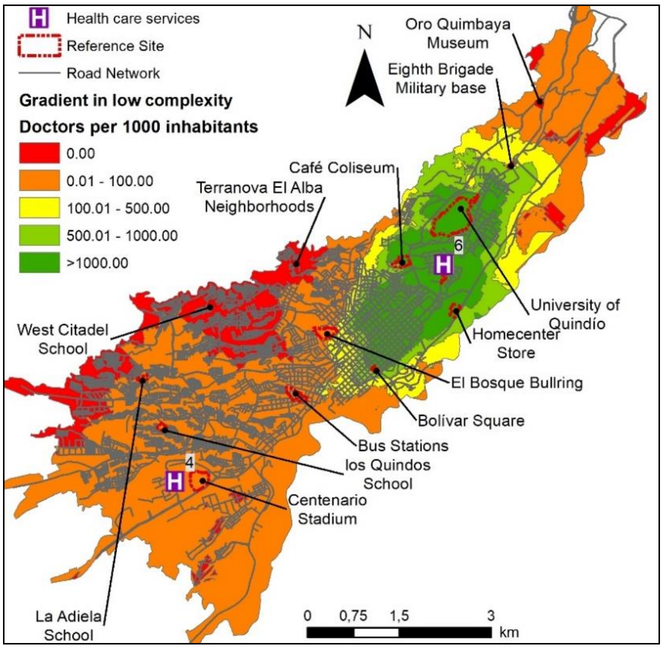

Figure 2. Savings gradient in low complexity hospitals per 1000 inhabitants applying the E2SFCA method (Source: authors)

Concerning Equation 2, it is intended to determine the decrease in accessibility related to care in a given number of physicians. For this purpose, it relates the weight variable Wr, where the Gaussian function is represented for the travel time by the weight of the distance. In this study, β has been calculated, which is equivalent to a value of 34, considered in the hypothesis that a critical weight (Wr) of 0.01. Additionally, on the factors of the variable dij in the ranges of weights for periods of 0-5 minutes is a factor of 2.5, in the time range of 5-10 minutes is a value of 7.5, and in the time range 10-15 minutes a value of 12.5 is established. In the second step of the E2SFCA method, the Origin and Destination matrix was structured with the travel time calculation in the nodes detail represented in each city block that analyzes each existing medical care node and those projected in the future scenario. The research defines the sector of influence for each hospital in a period determined in the matrix with a maximum value of 15 minutes, which indicates that it is the maximum time to attend an emergency in these hospitals. With the mentioned concept, it is necessary to adjust the travel time matrix leaving the travel times below 15 minutes, which are the ones to which the Rij factor determined in Equation 3 is applied. The E2SFCA methodology was calculated for the nodes of hospitals that provide low complexity medical care services where they represent the accessibility of physicians per thousand inhabitants, whose result is shown in Figure 4, with a value in the current scenario equivalent to 4 physicians per thousand inhabitants and represents the maximum value to cover the areas surrounding the medical center nodes in Armenia located in Red Salud Armenia Unidad Intermedia del Sur and Clínica Cardiovascular del Eje Cafetero S. A. A. Concerning the nodes of low complexity hospitals in the future scenario, the aim was to improve their accessibility conditions, as shown in Figure 5, which contains the Gradient where more excellent coverage and positive impact is observed in the Clínica Cardiovascular del Eje Cafetero S.A. and the Red Salud Armenia Unidad Intermedia del Sur hospital.

Figure 6 shows the detailed accessibility of medical services in medium and high-complexity hospitals in Armenia that have coverage in sectors of the city, such as Homecenter, Universidad del Quindío, and Plaza de Bolívar. With these results, an alternative is calculated to improve accessibility conditions for the population by adding two nodes with a classification to attend emergencies in Medium and High Complexity. As a result, it improves accessibility in the northwest of the city. Figure 7 shows the Gradient map where the most significant impact is on the New Hospitals where the coverage of the isochronous curves has impacts greater than 1000%, as expected. The proposed improvements in the current health nodes of Medium and High Complexity are evident, with coverage of up to 500%.

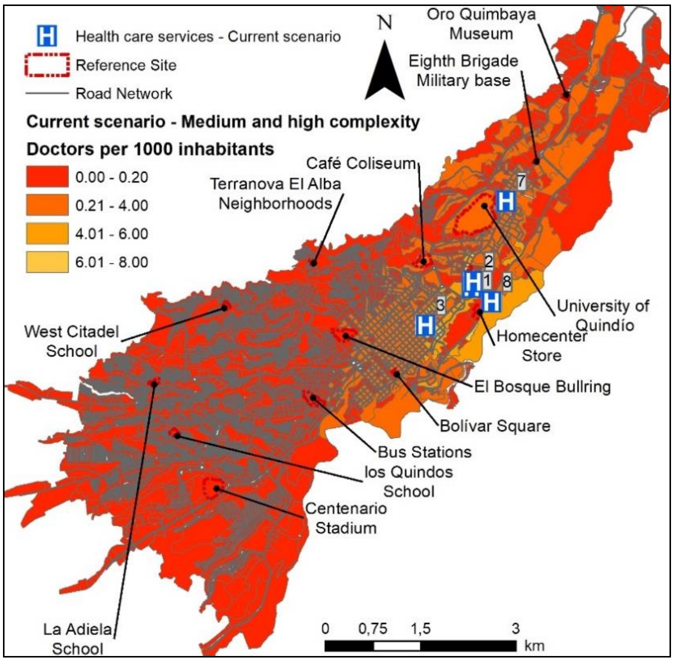

Figure 3. Accessibility to medium and high complexity medical services per 1000 inhabitants in the current scenario based on the E2SFCA method

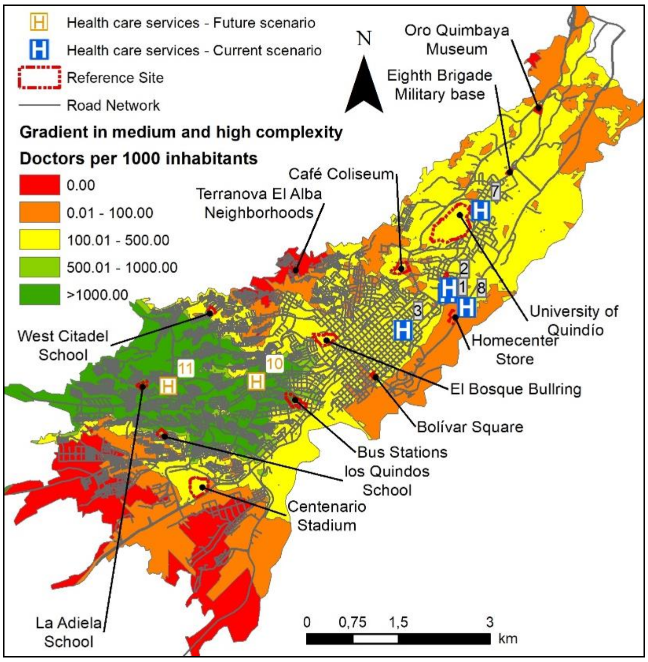

Figure 4. Savings gradient in medium and high complexity hospitals per 1000 inhabitants applying the E2SFCA method (Source: authors)

Table 2. the maximum and average value of physicians applying the E2SFCA method calculation in hospitals in Armenia for current and future scenario (Source: authors)

E2SFCA Average Physicians	E2SFCA Maximum Value Physicians	E2SFCA Physicians Average Physicians - Low complexity	E2SFCA Maximum Value Physicians - Low Complexity	E2SFCA Average Physicians Medium and High Complexity	E2SFCA Maximum Value Physicians - Medium and High Complexity
CURRENT SCENARIO					
0.56	6.45	0.02	0.49	0.54	7.58
FUTURE SCENARIO					
2.22	22.98	0.07	0.80	2.15	22.58

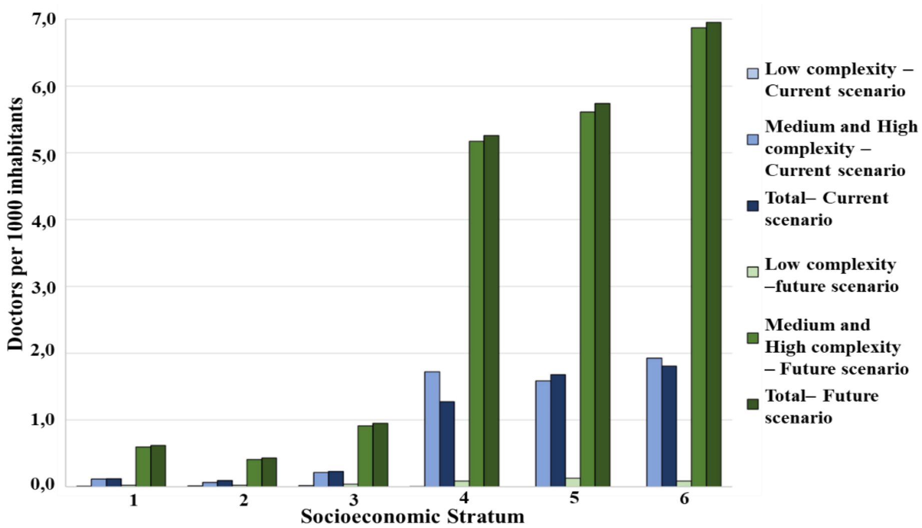

Figure 5. The number of physicians according to the complexity of care, based on socioeconomic status in current and future scenarios (Source: authors)

In compliance with the indicator of doctors published for Colombia (OECD and World Bank, 2020), in Armenia, the result obtained in the current scenario was the average accessibility of 0.56 physicians per 1,000 inhabitants. Likewise, with the alternatives proposed and more excellent coverage in the future scenario, the method used in this research yielded a future scenario of accessibility of 2.22 physicians per 1,000 inhabitants, complying with the conditions in Colombia based on the indicator published as shown in Tables 5.

Applying the E2SFCA method, the information obtained was classified by socioeconomic stratum. Figure 8 shows that the most significant coverage in medical accessibility is in strata 4, 5, and 6. Similarly, the research planning method with the alternative presented and its georeferencing would benefit the vulnerable strata 1, 2, and 3, which are located mainly in the northwestern sector of the city.

In Tables 2 and 3, the diagnosis of accessibility to physicians in the city is established, where the current scenario displays average values that do not comply with those published for Colombia (OECD and World Bank, 2020). In this research's planning method, the alternatives proposed in this document have considerable increases on the indicator of accessibility of physicians, aimed at not exceeding the number of beds that hospitals have in the city of Armenia.

CONCLUSION

The following main conclusions can be drawn from the arguments, their discussion, and the background literature exposed throughout the article.

The importance of the E2SFCA method is reflected in evaluating the status and behavior of accessibility in the healthcare nodes, where it was determined that Armenia, disregarding accessibility in the current scenario, does not comply with the established indicator published by the OECD and World Bank in Colombia.

Interventions or adjustments in health have a positive impact on the accessibility indicator of doctors per 1,000 inhabitants, providing greater access to users in addition to ensuring better care services. All this is under the operating conditions of the current road network, which has favorable mobility that provides adequate access to current and future hospitals. Regarding the access condition by socioeconomic stratification, the current situation does not favor the lower strata of the city, causing higher travel costs and health problems for the most vulnerable population. However, the proposed analysis makes it easier for the administration to meet the population's requirements by including new hospital centers that guarantee more significant equity for the lower-income population.

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Conflicts of Interest: The authors declare no conflict of interest.

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