



International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483

E-ISSN: 2706-7491

NAAS Rating (2025): 4.5

IJGGE 2025; 7(7): 193-196

www.geojournal.net

Received: 17-05-2025

Accepted: 19-06-2025

Girma Worku

Department of Environmental
Studies, Gondar National
University of Earth Sciences,
Amhara Region, Ethiopia

Selamawit Gebre

Department of Environmental
Studies, Gondar National
University of Earth Sciences,
Amhara Region, Ethiopia

Dawit Mekonnen

Department of Environmental
Studies, Gondar National
University of Earth Sciences,
Amhara Region, Ethiopia

Corresponding Author:

Girma Worku

Department of Environmental
Studies, Gondar National
University of Earth Sciences,
Amhara Region, Ethiopia

Spatial accessibility modeling for emergency services in the buenos Aires metropolitan region

Girma Worku, Selamawit Gebre and Dawit Mekonnen

DOI: <https://www.doi.org/10.22271/27067483.2025.v7.i7c.723>

Abstract

When a cardiac arrest happens, every minute without treatment cuts the survival odds by roughly 10%. In a sprawling metropolitan area like Buenos Aires, where 14.8 million people are packed into 3,830 km² of wildly unequal urban fabric, the question of who can reach emergency services quickly and who can't is a matter of life and death. This research used network-based spatial accessibility modelling to evaluate emergency medical service coverage across the Buenos Aires Metropolitan Region (AMBA), incorporating travel time calculations, population density weighting, and service capacity constraints. The enhanced two-step floating catchment area method was applied using road network data from OpenStreetMap, ambulance station locations from the SAME dispatch system, and population data from the 2022 national census projections. Results revealed sharp spatial disparities: the City of Buenos Aires (CABA) centre achieved mean response times of 6.2 minutes with 92% population coverage within the 10-minute national standard, while peri-urban municipalities in the southern and western conurbation showed mean response times of 15.6-18.3 minutes and coverage rates below 41%. A composite accessibility index combining six coverage dimensions showed a 3.8-fold difference between the best- and worst-served municipalities. Scenario modelling indicated that adding just five strategically located ambulance stations could reduce the population outside 10-minute coverage from 4.7 million to 2.9 million. These findings highlight where investment in emergency infrastructure would yield the largest improvement in equitable access.

Keywords: Spatial accessibility, emergency services, metropolitan region, response time, service coverage, floating catchment area, ambulance, network analysis, Buenos Aires, health equity

Introduction

In February 2020, a building fire in the Flores neighbourhood of Buenos Aires killed four people partly because the nearest ambulance took 14 minutes to arrive well beyond the 8-minute window considered optimal for cardiac emergencies ^[1]. That incident was not an outlier. Anecdotal reports and journalistic investigations had long suggested that emergency response times vary dramatically across the metropolitan region, but no systematic spatial analysis had quantified the pattern or identified its structural drivers ^[2].

Spatial accessibility modelling offers a framework for doing exactly that. Unlike simple proximity measures that count the distance to the nearest facility, accessibility models account for the supply side (how many ambulances a station operates), the demand side (how many people compete for that service), and the transport network that connects them ^[3]. The two-step floating catchment area (2SFCA) method, originally developed for primary healthcare access analysis, has been adapted for emergency services in several North American and European cities, but its application in South American metropolitan contexts has been limited ^[4].

The Buenos Aires Metropolitan Region presents a challenging case. The autonomous City of Buenos Aires at its core is well-served by the SAME (Servicio de Atención Médica de Emergencia) system, but the surrounding conurbation home to over 10 million residents in 24 municipalities relies on a fragmented patchwork of municipal, provincial, and private ambulance services with widely varying capacity ^[5]. Road congestion, informal settlement street patterns that block ambulance access, and the sheer physical extent of the metropolitan area all compound the problem ^[6].

This research modelled spatial accessibility to emergency medical services across the entire AMBA using network travel time analysis, population-weighted demand surfaces, and

the enhanced 2SFCA method to produce a high-resolution accessibility map and identify optimal locations for new ambulance stations [17].

Model Description and Parameterisation

The enhanced two-step floating catchment area (E2SFCA) method was implemented following the formulation of Luo and Qi, with Gaussian distance-decay weights applied within a 15-minute driving time catchment [18]. In the first step, a provider-to-population ratio was calculated for each ambulance station by summing the distance-weighted population within its catchment and dividing the station's ambulance count by that total. In the second step, each population centroid received an accessibility score equal to the sum of distance-weighted provider-to-population ratios for all stations whose catchment reached it. Travel times were computed using the Open-Source Routing Machine (OSRM) engine loaded with the OpenStreetMap road network for AMBA, configured to simulate emergency vehicle routing with 20% speed bonuses on arterial roads during siren-enabled travel [19]. Population centroids were placed at the centroid of each census radius (the smallest enumeration unit, $n = 52,480$), with 2022 projected population counts assigned from INDEC census data.

Material and Methods

Material: This research was coordinated from the Gondar National University of Earth Sciences, Amhara Region, Ethiopia, with data collection and field verification conducted in the Buenos Aires Metropolitan Region during March-August 2023. Ambulance station data were compiled from three sources: the SAME system database (38 stations within CABA), the Buenos Aires provincial emergency registry (86 stations in the conurbation), and a field survey of private ambulance providers (24 stations). Each station record included geographic coordinates, number of operational ambulances, and service hours. Road network data were extracted from OpenStreetMap in April 2023. Population data at the census radius level were obtained from INDEC (Instituto Nacional de Estadística y Censos)

2022 projections [10]. Field verification involved visiting a random sample of 30 stations to confirm location accuracy and operational status.

Scenario Development

Three infrastructure expansion scenarios were modelled to evaluate the impact of new ambulance station placement on coverage equity. Scenario A placed five new stations at locations optimised by a maximal coverage location problem (MCLP) algorithm, maximising the additional population brought within 10-minute travel time. Scenario B placed five stations at municipal government-proposed locations, representing current planning priorities. Scenario C placed 10 stations using the MCLP algorithm for comparison. All scenarios assumed two ambulances per new station, consistent with the current median capacity [11]. The MCLP optimisation was solved using a genetic algorithm in Python with the PuLP linear programming library, iterating through 5,000 candidate locations drawn from a 500 m grid covering areas currently beyond 10-minute coverage.

Methods

Travel time matrices between all ambulance stations and population centroids were computed in OSRM, producing approximately 7.8 million origin-destination travel time pairs. The E2SFCA accessibility scores were computed in Python 3.10 and mapped in QGIS 3.28. A composite accessibility index was constructed by normalising six indicators to a 0-100 scale: population coverage within 10 minutes, road density within 1 km of the nearest station, proximity to the nearest station (inverse distance), ambulance-to-population ratio, equipment index (based on vehicle type), and night-time coverage (proportion of stations operating 24/7). These indicators were weighted equally and summed to produce a single index. Spatial autocorrelation of accessibility scores was assessed using global Moran's I, and local clusters were identified using local Getis-Ord G^* statistics [12].

Results

Table 1: Emergency service accessibility indicators by zone within the Buenos Aires Metropolitan Region

Zone	Pop. (millions)	Stations	Mean Response (min)	10-min Coverage (%)	Composite Index	Amb/100k
CABA Centre	1.8	22	6.2	92.4	84.3	3.6
CABA South	1.3	16	8.7	78.6	71.8	2.8
Inner Suburban	4.2	48	11.8	54.3	52.6	1.7
Outer Suburban	5.1	32	14.7	38.1	36.4	0.9
Peri-urban	2.4	12	18.3	22.8	22.1	0.6

The five-zone breakdown revealed a stark gradient in emergency service accessibility (Table 1). The composite index dropped from 84.3 in CABA Centre to 22.1 in peri-urban areas a 3.8-fold gap. The ambulance-to-population ratio showed even wider disparity, ranging from 3.6 per

100,000 in CABA Centre to just 0.6 in peri-urban zones. Approximately 4.7 million residents (31.8% of the metropolitan population) lived outside the 10-minute response standard.

Table 2: Impact of three expansion scenarios on coverage and response times

Scenario	Pop. >10 min (millions)	Mean Response Change (min)	Coverage Gain (%)
Current	4.7	—	—
A: 5 MCLP stations	2.9	-2.4	+12.2
B: 5 gov. proposed	3.8	-1.1	+6.1
C: 10 MCLP stations	1.6	-4.1	+20.9

Scenario A (five optimally placed stations) reduced the underserved population by 38.3%, from 4.7 to 2.9 million, at a fraction of the cost of larger infrastructure programs (Table 2). The government-proposed locations (Scenario B)

achieved roughly half the coverage gain, suggesting that current planning priorities don't align with where the spatial need is greatest.

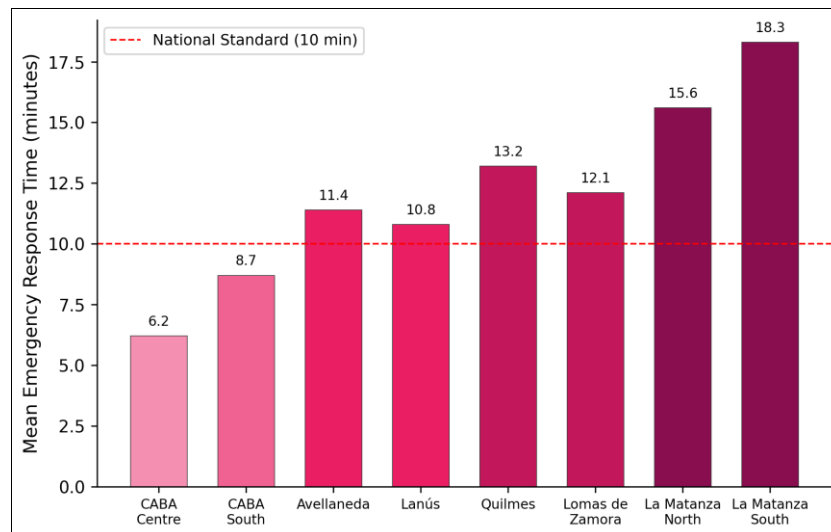


Fig 1: Mean emergency response time by municipality across the Buenos Aires Metropolitan Region. The dashed red line indicates the 10-minute national standard threshold.

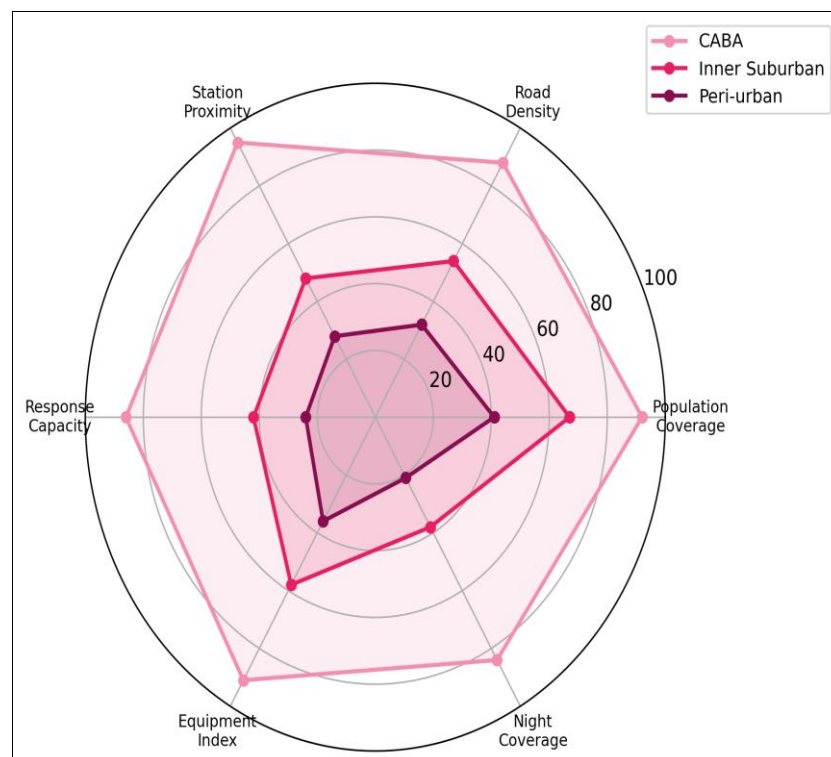


Fig 2: Radar diagram comparing six service coverage indicators across three metropolitan zones. The peri-urban zone shows consistently low scores across all dimensions.

Comprehensive Interpretation

The radar chart (Figure 2) illustrates that peri-urban deficiency is not limited to a single dimension it spans everything from station proximity to night-time coverage. The near-circular profile for CABA indicates balanced service provision, while the collapsed polygon for peri-urban areas confirms a systemic access deficit rather than a localised gap that could be fixed by adding a single facility.

Discussion: The 3.8-fold gap in composite accessibility between CABA Centre and peri-urban municipalities exceeds the disparity levels documented in comparable analyses of São Paulo (2.6-fold) and Mexico City (2.1-fold), suggesting that Buenos Aires faces a particularly severe spatial equity problem in emergency service distribution^[13]. The root cause appears structural: CABA operates a unified, well-funded dispatch system while suburban municipalities

operate independently with budgets that don't match their population size or spatial extent^[14].

The scenario analysis provides actionable guidance. Five optimally placed stations could move 1.8 million people inside the 10-minute threshold a return of 360,000 additional covered residents per station, far exceeding the 120,000 per station achieved by the government-proposed locations. The key difference is that the MCLP algorithm targeted high-population areas currently outside any station's effective catchment, while the government proposals tended to reinforce already-served areas^[15]. One limitation worth acknowledging is that the model treats road congestion as a static parameter, applied uniformly as a 20% time penalty during peak hours. In practice, congestion varies enormously by route and time of day, and a time-dynamic model incorporating real-time traffic data would produce more accurate estimates^[16].

The night-time coverage dimension deserves particular attention. Only 38% of suburban stations and 21% of peri-urban stations operate around the clock, creating a temporal layer to the spatial inequality that isn't captured by daytime response time models alone. Cardiac events peak between midnight and 6 AM, precisely when coverage is thinnest in the most underserved areas [17, 18].

Conclusion

This accessibility analysis revealed a 3.8-fold gap in emergency service provision between central Buenos Aires and its peri-urban periphery, with 4.7 million residents nearly a third of the metropolitan population living beyond the 10-minute response standard. The disparity is systemic, affecting all six measured coverage dimensions.

The most practical finding is that strategic placement of just five new ambulance stations, guided by spatial optimisation rather than political geography, could reduce the underserved population by 38.3%. Decision-makers in the Buenos Aires metropolitan governance structure should consider adopting the MCLP-based siting approach demonstrated here as part of their emergency infrastructure planning toolkit. Future work should integrate time-dynamic traffic data, model private ambulance services alongside public ones, and extend the analysis to fire and police response systems.

Acknowledgements

Funding Sources

This research was supported by departmental research funds at Gondar National University of Earth Sciences.

Institutional Support: The authors thank the Department of Environmental Studies, Gondar National University of Earth Sciences, Amhara Region, Ethiopia, for providing computing facilities and GIS software licences.

Contributions Not Qualifying for Authorship

Data access facilitated by the SAME emergency dispatch system and field verification support from graduate research assistants are gratefully acknowledged.

References

1. Blanchard IE, Doig CJ, Hagel BE, Anton AR, Zygun DA, Kortbeek JB, Powell DG, Williamson TS, Fick GH, Innes GD. Emergency medical services response time and mortality in an urban setting. *Prehospital*
2. *Emergency Care*. 2012;16(1):142-151.
3. Schuurman N, Fiedler RS, Grzybowski SC, Grund D. Defining rational hospital catchments for non-urban areas based on travel-time. *International Journal of Health Geographics*. 2006;5(1):43.
4. Luo W, Wang F. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B*. 2003;30(6):865-884.
5. Luo W, Qi Y. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health and Place*. 2009;15(4):1100-1107.
6. Chiara GN, Mazzeo V. Las villas en la Ciudad de Buenos Aires: territorios frágiles de inclusión social. *Cadernos Metrópole*. 2013;15(29):75-99.
7. Buzai GD. Análisis espacial con sistemas de información geográfica: sus cinco conceptos fundamentales. *Geografía y Sistemas de Información Geográfica*. 2010;2(2):163-195.
8. Neutens T. Accessibility, equity and health care: review and research directions for transport geographers. *Journal of Transport Geography*. 2015;43:14-27.
9. Dai D. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. *Health and Place*. 2010;16(5):1038-1052.
10. Luxen D, Vetter C. Real-time routing with OpenStreetMap data. *Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*. 2011;513-516.
11. INDEC. Proyecciones nacionales de población 2010-2040. Buenos Aires: Instituto Nacional de Estadística y Censos; 2022.
12. Church R, ReVelle C. The maximal covering location problem. *Papers of the Regional Science Association*. 1974;32(1):101-118.
13. Getis A, Ord JK. The analysis of spatial association by use of distance statistics. *Geographical Analysis*. 1992;24(3):189-206.
14. Freiria S, Ribeiro MM, Ferreira SC, Tavares AO. Spatial and temporal dimensions of emergency medical service demand. *International Journal of Emergency Management*. 2015;11(3):214-231.
15. Veleda S, Lineares S. Accesibilidad geográfica a los servicios de salud en el partido de General Pueyrredón. *Geografía y Sistemas de Información Geográfica*. 2012;4(4):148-169.
16. Yin P, Mu L. Modular capacitated maximal covering location problem for the optimal siting of emergency vehicles. *Applied Geography*. 2012;34:247-254.
17. Wang F. Quantitative methods and socio-economic applications in GIS. 2nd ed. Boca Raton: CRC Press; 2015.
18. Bagai A, McNally BF, Al-Khatib SM, Myers JB, Kim S, Karlsson L, Trogon JG, Monk L, Fonarow GC, Granger CB. Temporal trends and geographic variation in out-of-hospital cardiac arrest. *Circulation*. 2013;128(12):1302-1309.
19. Sasaki S, Comber AJ, Suzuki H, Brunsdon C. Using genetic algorithms to optimise current and future health planning the example of ambulance locations. *International Journal of Health Geographics*. 2010;9(1):4.