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Complete List of Authors:	Cuervo, Luis Gabriel; Universitat Autònoma de Barcelona, Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine Martinez-Herrera, Eliana; Universidad de Antioquia, Facultad Nacional de Salud Pública Osorio, Lyda; Universidad del Valle Facultad de Salud, Escuela de Salud Pública Hatcher-Roberts, Janet; University of Ottawa Faculty of Medicine, School of Epidemiology and Public Health; Bruyere Research Institute Cuervo, Daniel; IQuartil SAS Bula, Maria Olga; Egis Consulting Pinilla, Luis Fernando; Universidad de La Sabana, Correct email is LuisFerPinilla@gmail.com (system does not allow fixing it) Piquero, Felipe; Consumer advocate; Author of "Opportunities Amidst Uncertainty: My life with one kidney and without it", Published in English and Spanish Jaramillo, Ciro; Universidad del Valle, School of Civil and Geomatic Engineering Collaborative Group, AMORE Project; AMORE Project Collaborative Group; Universitat Autonoma de Barcelona
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Title

Cross-sectional equity analysis of accessibility by automobile to tertiary care emergency services in Cali, Colombia, in 2020

Luis Gabriel CUERVO,(1) Eliana MARTINEZ HERRERA,(2) Lyda OSORIO,(3) Janet HATCHER ROBERTS,(4) Daniel CUERVO,(5) María Olga BULA,(6) Luis Fernando PINILLA,(7) Felipe PIQUERO,(8) Ciro JARAMILLO,(9) on behalf of the AMORE Project Collaboration.

(1) *Corresponding author. PhD Candidate, Universitat Autònoma de Barcelona, Spain:* LuisGabriel.Cuervo@autonoma.cat
(2) Faculty at the National School of Public Health, Universidad de Antioquia, Medellín, Colombia
(3) Faculty, School of Public Health, Universidad del Valle, Colombia.
(4) Brùyere Research Institute and Adjunct School of Epidemiology and Public Health, University of Ottawa.
(5) Partner at Iquartil SAS. Industrial Engineer, MBA, Certified Data Analyst.
(6) MSc in urban planning, Egis Consulting.
(7) Universidad de la Sabana. Lecturer in the Operations Management Specialization.
(8) Attorney in administrative law and healthcare legislation. Consumer advocate and book author
(9) Associate Professor in the School of Civil and Geomatic Engineering, Universidad del Valle, Colombia; PhD thesis director, Universitat Autònoma de Barcelona.

Abstract

Objectives: Assess accessibility to tertiary care emergency services during free-flow and peak traffic congestion.

Setting and Participants: the registered population in Cali, Colombia (2.258 million) according to travel times obtained in July and November 2020.

Primary and secondary outcomes: travel times from the registered zone of residence to the nearest tertiary care emergency department.

Results: This study shows that traffic congestion sharply reduces accessibility to tertiary emergency care, with the greatest impact falling on specific ethnic groups, people with less educational attainment, and those living in low-income households or on the periphery of Cali. These populations face longer average travel times to health services than the average population, increasing their risk of worse outcomes. Differences in geographic accessibility to health services can lead to health inequities that hide in plain sight. New technologies can reveal these inequities by integrating sociodemographic data with accurate estimates of travel times to health services.

Conclusions: This study argues for prioritizing travel time over distance when planning for health services and land use. This study presents a new approach to health services and land-use planning that merits testing by concerned stakeholders. This approach delivers simple metrics, such as travel times to the nearest health service, that is easy for relevant stakeholders to share and interpret to spur intersectoral action.

- **What is already known on this topic** – dynamic travel times are not yet systematically integrated into urban and service planning; static spatial analyses fail to reflect reality; accessibility to health services is a determinant of health.

- **What this study adds** – simple metrics that all concerned stakeholders can interpret directly; a reference that considers traffic congestion dynamics and equity analysis of accessibility; a new hypothesis for other studies addressing health inequities.

- **How this study might affect research, practice, or policy** – by incentivizing the integration of dynamic travel times in plans and surveys that define land-use and health services planning.

Introduction

Background/rationale

Every minute counts in life-threatening emergencies (e.g., important blood vessel obstructions or ruptures, airway obstructions, asphyxiation or drowning, severe trauma, serious wounds) that do not leave time for referrals. The wellbeing of patients depends on getting immediate attention in a tertiary care facility. These facilities provide subspecialized care and access to highly trained personnel, sophisticated surgical theatres and intensive care.

This study delivers a baseline assessment of accessibility by automobile to such services in Cali, Colombia. This study assessed traffic congestion for Cali residents traveling by automobile (private or for-hire), which is how residents typically reach tertiary care facilities in emergencies.

Accessibility is a dynamic spatial attribute measured as the travel time needed to reach a health service from the origin of the demand.[1–7] It is dynamic because it changes as travel times fluctuate with traffic congestion. Poor accessibility is a recognized barrier to health equity that has until now been difficult to study and monitor.[4,8]

Traditional assessments of accessibility in urban planning seldom consider that accessibility is dynamic. Origin-destination studies and surveys lack a dynamic assessment of how traffic congestion or changes in infrastructure or populations affect accessibility.[9,10] These traditional assessments are usually done every five to ten years and are expensive. The conditions they assess may have changed by the time results become public, which can render any proposed solutions irrelevant.[11,12] This study integrated new data and exposes the important links between equity and accessibility to tertiary care emergency services.

These innovative approaches for integrating data and accessible web-based platforms offer an important opportunity for evidence-based decisions and planning to improve health coverage. These approaches capitalize on, for example, big data from smartphones, which can feed accurate travel time estimates. We could therefore use dynamic, affordable, and updatable assessments that account for traffic congestion, thus focusing on travel time to hospitals instead of distance from them.[5,10,12–16] We also integrated equity-relevant data that we used to perform equity analyses.

Objectives

This study aims to characterize accessibility to tertiary care emergency health services in urban Cali and the relationship of accessibility to sociodemographic factors relevant to health equity.

Methods:

Study Population and setting

This study assesses an aspect of emergency care: emergencies requiring attention in tertiary care institutions. By early July 2020, COVID-19 pandemic-related quarantine and stay-at-home orders had been lifted and traffic projections showed substantial congestion. By November 2020, these measures had been reinstated, car travel was restricted by license number, and traffic projections showed a reduction in travel times.[17–19]

This cross-sectional study was carried out using data downloads obtained in the urban area of the city of Cali, in Southwest Colombia. Cali is the third-largest city in Colombia and the largest urban center in the country's southwest and Pacific regions, with 2.258 million residents in 2019. About half of the population lives in low-income households, 42% in middle-income households, and 8% in high-income households. Housing stratification does not necessarily represent the income of residents. For example, domestic workers living in mansions and receiving the minimum wage would still be counted as living in a high-income stratum.[20,21]

About 84% of the population identifies as white, 14% as Afro-Colombian, and a small proportion as indigenous or nomadic people like the Rrom. In December 2020, unemployment rates in Cali were 26.7% for women and 18.5% for men, a one-year increase of 12.5% and 8.8%, respectively. The situation is worse among young people and an estimated 52% of women and 47.2% of men rely on working in the informal economy. The COVID-19 pandemic punished the local economy. While 1 in 5 people are unemployed, the rates are higher among people in low-income households. From 2016 to 2020, Cali also absorbed 139,000 migrants from Venezuela, 25,000 in 2020 alone.[22]

Poverty, inequity, and discrimination drove social unrest that led to violence after a 2021 national strike.[23,24]

The city government is dividing its 22 communes into a six to eight districts, which might lead to negotiations over resources and issues such as access to essential services. [25,26]

Looking to the future, identifying and proposing public policy plans and partnerships could improve health equity and bring hope to residents. These measures could also reduce social injustices, including the burden of the inverse care law that vulnerable populations pay more to access essential health services.[4,27,28]

Targeted Sites/Participants

We targeted the 14 tertiary care institutions with emergency departments registered in the Ministry of Health Special Registry of Health Services Providers (REPS, in Spanish). We searched the registry twice, in July 2020 and January 2021. We verified that all tertiary care institutions provide surgery and intensive care services and listed those institutions on Supplemental File 1.[29]

Supplemental File 1 Tertiary care emergency departments in institutions with intensive care and surgery, ordered as displayed in REPS[29]

Study design

This is a cross-sectional study that used digital technologies and analytics to integrate publicly available data sources. The study generated new knowledge that shows the potential value of examining an evidence-based approach to accessibility and health equity. The study used updatable data to assess travel times and evaluate the effects of interventions and changes in the infrastructure, service provision, traffic congestion, and population.
Study methods:

- Used dynamic assessments of travel times to account for traffic variations.
- Used input from diverse stakeholders to create an interactive platform that displays intersectoral data on dashboards so stakeholders can interpret data quickly and accurately.
- Offered disaggregated data to enable straightforward equity analysis of accessibility.
- Enabled situational analysis of accessibility in an urban setting and supported monitoring and evaluation of health equity related to accessibility.

The cross-sectional study data was obtained from an internet-based platform, the AMORE Platform (https://www.iquartil.net/proyectoAMORE), hosted by iQuartil SAS, an analytics company, and developed under the leadership of the principal investigator (LGC).

The AMORE Platform integrates data from:

- 2018 National Census Data for Cali, obtained from the public official databases of the Colombian National Department of Statistics – DANE.[20,21]
- The administrative divisions of Cali obtained from Colombia's IDESC Geoportal, Traffic Analysis Zones (TAZ), and census block sectors.[11,30]
- Google's Distance Matrix API. For this baseline assessment of the urban area of Cali, we downloaded the data of predicted travel times on July 3, for the week of 6 – 12 July

2021, and on October 27, 2020, for the week of 23 – 29 November 2020. Travel times varied substantially during the COVID-19 pandemic and it is unclear how this influenced Google Distance Matrix algorithms.[31] Empirical and anecdotal reports suggest they remained accurate.

- The 14 tertiary care institutions with emergency department in Cali, identified using REPS.[29]

Databases were integrated and tested between August 2020 and October 2021 using KNIME® and Python™ software (back end) and the interface (front end) was developed in Microsoft PowerBi™.

Patient and public involvement

The involvement of diverse stakeholders and sectors have been part of the design, conduct, and reporting of this study, and the dissemination plans. This is reflected in the composition of the authors and the AMORE Project Collaborative Group (

Acknowledgements). These stakeholders represent diverse elements of governance: authorities, service providers, service users, organized civil society including academics, advocates, and experts from diverse fields of knowledge.

Results

The AMORE Platform dashboards and visualizations provide simple indicators such as colored maps, dials, bars, and data. These indicators show travel time to the nearest tertiary care emergency room and descriptive statistics for each urban sector at a given traffic congestion level.

The AMORE Platform displays a situational analysis of accessibility in simple visualizations with filters that let users disaggregate data by sociodemographic characteristics for an equity analysis.[32] The upper part of the Platform filters scenarios (Figure 1) and has nine traffic congestion clusters that represent the schedules for a regular week. A dial shows the share of the population within travel time thresholds set in a slider.

Figure 1 AMORE Platform situational analysis

The middle section displays a population pyramid and maps with the 14 tertiary care emergency departments, travel times, and population density (Figure 1). The choropleth maps can be expanded and rotated for 3D-display that uses the height of sectors to represent population density (Supplemental File 2).

Supplemental File 2 Travel times and population density, tertiary care institutions, peak traffic, November 2020

The choropleth maps consist of 508 TAZs established by MetroCali (Integrated Massive Transit System) in 2015 for the urban area and linked to the geotagged census block information, matching the population with these TAZs.[11] The origin-destination times were estimated from the population-adjusted geographic centroid of each TAZ to the centroid where each institution was located.

In 2019, Colombia's National Department of Statistics recommended adjusting the 2018 population of Cali upward by 18% from the original census data because of underregistration.[21,33] To make the adjustment, a random selection of 18% of the individual records from the unadjusted census were duplicated with all their original information, adding 495,219 people to complete the 2,258,823 records in the adjusted census. In verifying the records, we found a matching distribution of the variables and results with the unadjusted census. The AMORE Platform lets users toggle the census adjustment (Figure 1, "Data type").

The right section displays sociodemographic characteristics. The graph bars activate filters for data on selected demographics (Figure 1).

Variables

The AMORE Platform displays the absolute and relative figures for the georeferenced data. This is done for the city or for selected TAZs within a travel time schedule Figure 2. The variables integrated in the platform are listed in Table 1.

Figure 2 Situational analysis, filters and visualizations, Nov 2020

The census was done by interviewing an adult in each household. Data was stored linking it to a city block code to anonymize it. The AMORE Platform used the census microdata categorizations and, for a few variables, aggregate groups for simplification (e.g., education was simplified with guidance from an expert in Colombia's education system, Psychologist Myriam Lorena Rosero Hernández, ME).

Data sources / measurements

Table 1 Census data included in the AMORE Platform dashboards and maps

Geotagged variables	Platform display
Age in completed years grouped by quinquennium (census)	Population density per Sector/TAZ
Ethnicity, self-described	Health service: tertiary care emergency departments
Health status (Sick / Healthy)	Absolute and relative figures of modified aggregation
Highest education level attained	Travel time thresholds (slider + choropleth heatmap)
Literacy	Travel times and population per TAZ
Marital status	Overall accessibility for filtered population
Population pyramid by gender and age	
Report of disability / physical condition	

School attendance	
Household inhabitants	
Housing inhabitants	
Housing socio-economic stratum	
Housing type	

We used the controls listed in Table 2 to conduct univariate and bivariate analyses.

Table 2 AMORE Platform displays resulting from integrating travel times, services, origin sectors, and census data

Variables that change according to traffic, travel time threshold, and other filters
Travel time threshold filter for the analysis.
Drop-down list with institutions that can be toggled for inactivation.
Drop-down list to select people registered by the census, the 18% adjustment, or the total adjusted census data.
Traffic levels according to clusters identified with a K-means clustering algorithm.
Absolute and relative figures provided for each variable.
Maps are organized according to TAZs or sectors.
Intensive care beds data for selected institutions taken from REPS.
People with accessibility for a selected time threshold and traffic level.
Blocks with accessibility for a selected time threshold.
TAZs within the time threshold by level of traffic.
Household inhabitants
Housing inhabitants
Housing by power bill economic stratum

Bias

Each source is susceptible to biases and imprecisions, but these are unlikely to change our conclusions substantially. Some of the data sources and the timing of their updates can introduce a source of bias. For example, the census is updated every five years, and there has been a significant flow of migrants to Cali since the last census, in 2018, and job losses rose during the COVID-19 pandemic.[22,34] These developments likely resulted in some internal displacement and may make our results more positive than reality.

Traffic patterns may have changed with the imposition and lifting of pandemic-related restrictions, thus altering traffic predictions. Stay-at-home orders and traffic restrictions may have reduced traffic congestion, causing an overestimate of accessibility. Google Distance Matrix API may have more accurate travel times for areas where more people travel with mobile phones.

Populations are not evenly distributed across TAZs. We therefore adjusted TAZ geographic centroids by weighing the population distribution. Because centroids had irregular forms, population weighed centroids could end outside the boundaries of a TAZ. This required relocating the adjusted centroid to the nearest border, generating some imprecision that could likely result in some seconds or minutes of imprecision in travel time estimates.

It is possible that the relevance of our findings could change if a new tertiary care facility is registered in REPS (i.e., a new institution opens, or an existing institution is reclassified as tertiary, changing the results). However, the interactive platform would allow for prompt updates and reanalysis in response to these contingencies.

Income categorization is determined by the individual household electricity bill, which is graded from 1 to 6, with 6 representing the highest-income households. It is possible that some households were misclassified (e.g., due to error or corruption) and that low-income people are living in higher-income households. Low-income people may live with relatives or work as maids or support staff. This kind of misclassification could introduce some bias by representing low-income populations as having higher income.

We developed nine traffic clusters for the city. Traffic patterns are not homogeneous within a city or sector; traffic flow patterns vary in time and direction. The nine traffic congestion levels for Cali were sorted in incremental order for each TAZ so that level 9 would always represent the heaviest traffic and level 1 the lightest. Figure 3 the clusters and typical times at which traffic is higher in the city, but it is not in every single sector of the city, as these have their own variations. For example, traffic congestion has directional patterns and affects almost every sector being higher at noon on Saturdays and early evenings of weekdays, but not all.

Figure 3 Travel-time clusters from free flow to peak traffic, by time and day

The Colombian census recognizes ethnicity, but some people likely found it difficult to choose their ethnicity. The census lacks an option for residents of white or mestizo descent, two large groups not specifically listed on the census. Similarly, people with multiethnic parents may find it difficult to choose one ethnic category.

The definition of an acceptable travel time threshold to reach a tertiary care emergency department is arbitrary. For this analysis, we chose a threshold of 15 minutes at peak traffic congestion times. Notably, the distribution of traffic levels is skewed towards heavy congestion from Monday to Saturday between 6:00 and 22:00, with a mode of traffic level 8 (40/168 hours in the week, 24% of the time). The 168 hours in a week are distributed in the 9 clusters (right hand side), showing that heavy traffic is the norm in Cali.

Results / Outcomes

Participants

The study included all the population data from the adjusted, 2,258,823 people from 596,051 households, living in 582,814 housing units. Most of the population is mestizo or white (83.7 %) or Afro-descendants (326,492; 14.5%). Islanders and Rrom people represent less than 1% of the population.

Descriptive data

The analysis found that with traffic, most of the low-income population was unable to reach the nearest tertiary care emergency department within 15 minutes, whether in November 2020 or

July 2020 (Supplemental File 2 and Supplemental File 3, respectively). The analysis also shows how accessibility is an access barrier for people living in low-income households, in areas with high population density, and for those living in the peripheral sectors.

Supplemental File 3 Travel times by auto to nearest emergency, with peak traffic, July 2020

Main results

The effects of traffic disaggregated by household income level, ethnicity, gender and age, education level, and civil status are presented in Figure 4, Figure 5, and Table 3.

Figure 4 Accessibility by income to tertiary care comparing July and November 2020

Figure 5 Accessibility by sociodemographic characteristics in July and November 2020

Traffic variations and their effect (July vs November 2020)

6 – 12 July vs 23 – 29 November 2020

While the July travel time predictions pointed to 831,982 people (36.8%) living within 15 minutes of travel time from tertiary care emergency services, in November this increased to 1.28 million (56.7%). The distribution of accessibility when disaggregating data by income level indicated lower accessibility for the poor and those living in peripheral sectors (Figure 4, Figure 5, and evident in **Error! Reference source not found.** and Supplemental File 3 to those familiar with the demographic distribution of Cali). These populations also have a higher representation of people from minority ethnic groups and people with lower educational attainment.

Table 3 shows the data obtained from the AMORE Platform for the July 2020 and November 2020 assessments, which lets users explore equity considerations.

Other analyses

Figure 6 compares accessibility by socio-economic stratum at peak and free flow traffic congestion. It illustrates how people living in low-income households have longer travel times and are more impacted by traffic congestion, forcing them to invest more resources in accessing services.

Figure 6 Impact of traffic congestion on accessibility, by economic stratum, July 2020

Discussion

Key results

The analysis shows substantial variations in equitable access to tertiary care emergency services due to traffic congestion and the impact that social determinants of health might have on accessibility. The two points of estimate were for early July and late November 2020, and their substantial variations stress the importance of having updatable sources.

The unusually light traffic congestion of November 2020 might have been due to the mobility restrictions associated with the COVID-19 pandemic. Lighter traffic congestion improved accessibility for an additional 448,338 people, most of them living in low-income households. These were the people who were also within the 15-minute threshold (Figure 4) and their location can be visualized by comparing **Error! Reference source not found.** and Supplemental File 3. Table 3 shows accessibility at peak traffic hours disaggregated by sociodemographic characteristics relevant to equity.[35–37]

Table 3 Accessibility by auto within fifteen minutes to tertiary care in July and November, Cali 2020

15 min accessibility to the nearest tertiary care emergency service	Jul 2020 (%)	Nov 2020 (%)	Variation	Jul 2020 (#)	Nov 2020 (#)	Variation (#)	Total Population	%	Accessibility July	Accessibility November	Subgroup variation
	36.8%	*56.7%*	*19.8%*	*831,982*	*1,280,320*	*448,338*	*2,258,823*		*36.8%*	*56.7%*	
Socio-economic stratum											
Low	7.7%	18.6%	10.8%	174,869	419,448	244,579	1,109,549	49.1%	15.8%	37.8%	*22.0%*
Middle	22.0%	30.0%	8.0%	496,558	677,967	181,409	935,699	41.4%	53.1%	72.5%	*19.4%*
High	7.0%	7.9%	0.9%	157,682	178,277	20,595	204,589	9.1%	77.1%	87.1%	*10.1%*
N.D.	0.1%	0.2%	0.1%	2,873	4,628	1,755	8,986	0.4%	32.0%	51.5%	*19.5%*
Ethnicity											
Afrodescendent	3.1%	5.6%	2.5%	70,394	126,298	55,904	325,865	14.4%	21.6%	38.8%	*17.2%*
Rrom (nomadic)	0.0%	0.0%	0.0%	37	53	16	102	0.0%	36.3%	52.0%	*15.7%*
Indigenous	0.2%	0.3%	0.2%	3,571	7,103	3,532	11,112	0.5%	32.1%	63.9%	*31.8%*
Islander/Raizal	0.0%	0.0%	0.0%	182	251	69	382	0.0%	47.6%	65.7%	*18.1%*
Other (Caucasian, Mestizo)	32.9%	49.9%	17.0%	743,469	1,126,671	383,202	1,890,491	83.7%	39.3%	59.6%	*20.3%*
Palenque	0.0%	0.0%	0.0%	29	176	147	245	0.0%	11.8%	71.8%	*60.0%*
N.D.	0.6%	0.9%	0.2%	14,300	19,768	5,468	30,626	1.4%	46.7%	64.5%	*17.9%*
Educational level											
Graduate degree	2.1%	2.7%	0.5%	47,785	60,019	12,234	72,441	3.2%	66.0%	82.9%	*16.9%*
Bachelor Degree	7.4%	9.9%	2.5%	166,816	223,602	56,786	295,319	13.1%	56.5%	75.7%	*19.2%*
Technical	4.3%	6.5%	2.2%	97,733	147,634	49,901	244,160	10.8%	40.0%	60.5%	*20.4%*
Middle	8.7%	14.0%	5.3%	196,674	316,810	120,136	608,429	26.9%	32.3%	52.1%	*19.7%*
High School	4.7%	7.6%	2.9%	105,509	171,843	66,334	337,065	14.9%	31.3%	51.0%	*19.7%*
Primary	6.3%	10.5%	4.3%	141,309	237,344	96,035	468,206	20.7%	30.2%	50.7%	*20.5%*
Pre-school	0.5%	0.8%	0.3%	11,158	18,636	7,478	36,294	1.6%	30.7%	51.3%	*20.6%*
No data	2.9%	4.6%	1.7%	64,998	104,432	39,434	196,909	8.7%	33.0%	53.0%	*20.0%*
Literacy											
Literate	33.8%	51.7%	17.9%	764,426	1,168,883	404,457	2,043,041	90.4%	37.4%	57.2%	*19.8%*
No literacy	0.8%	1.4%	0.6%	17,927	32,006	14,079	66,383	2.9%	27.0%	48.2%	*21.2%*
N.A.	1.6%	2.7%	1.1%	36,401	61,180	24,779	121,140	5.4%	30.0%	50.5%	*20.5%*
N.D.	0.6%	0.8%	0.2%	13,228	18,251	5,023	28,259	1.3%	46.8%	64.6%	*17.8%*
Gender/Sex											
Fem	19.9%	30.5%	10.6%	449,188	688,160	238,972	1,208,617	53.5%	37.2%	56.9%	*19.8%*
Masc	16.9%	26.2%	9.3%	382,794	592,160	209,366	1,050,206	46.5%	36.4%	56.4%	*19.9%*
Civil status											
Single	13.4%	20.7%	7.3%	303,645	468,447	164,802	821,536	36.4%	37.0%	57.0%	*20.1%*
Married or cohabitation	14.6%	22.6%	7.9%	330,460	509,814	179,354	896,958	39.7%	36.8%	56.8%	*20.0%*
Divorced or separated	2.9%	4.2%	1.3%	65,978	95,928	29,950	163,980	7.3%	40.2%	58.5%	*18.3%*
Widow	1.9%	2.6%	0.8%	42,743	59,804	17,061	95,611	4.2%	44.7%	62.5%	*17.8%*
N.A.	3.4%	5.7%	2.3%	76,821	129,370	52,549	254,492	11.3%	30.2%	50.8%	*20.6%*
N.D.	0.5%	0.8%	0.2%	12,335	16,957	4,622	26,246	1.2%	47.0%	64.6%	*17.6%*
Age											
0-4	1.6%	50.5%	48.9%	36,401	61,180	24,779	121,140	5.4%	30.0%	50.5%	*20.5%*
0-14	5.4%	50.9%	45.6%	121,111	204,055	82,944	400,527	17.7%	30.2%	50.9%	*20.7%*
5-14	3.8%	51.1%	47.4%	84,710	142,875	58,165	279,387	12.4%	30.3%	51.1%	*20.8%*
15-24	5.3%	53.9%	48.6%	120,001	195,693	75,692	363,311	16.1%	33.0%	53.9%	*20.8%*
15-59	23.8%	56.4%	32.7%	536,754	836,078	299,324	1,482,069	65.6%	36.2%	56.4%	*20.2%*
15-64	25.9%	56.7%	30.8%	585,558	904,942	319,384	1,595,016	70.6%	36.7%	56.7%	*20.0%*
60+	7.7%	63.8%	56.1%	174,117	240,187	66,070	376,227	16.7%	46.3%	63.8%	*17.6%*
65+	5.5%	65.1%	59.5%	125,313	171,323	46,010	263,280	11.7%	47.6%	65.1%	*17.5%*
80+	1.5%	69.0%	67.6%	33,380	44,248	10,868	64,100	2.8%	52.1%	69.0%	*17.0%*
	36.8%	*56.7%*	*19.8%*	*831,982*	*1,280,320*	*448,338*	*2,258,823*				

Easing of traffic congestion brought an additional 22% (244,579) people in low-income household within the 15-minute threshold and 19.4% (181,409) more people living in middle-income households.

Minority ethnic groups like the Palenque Afro-descendants and indigenous people that represent 0.5% of the population of Cali, benefitted the most from the traffic congestion reduction. The noticeable improvement among the Palenque resulted from most of their communities being in the neighborhoods of El Morichal, El Retiro, El Vallado, and Ciudad Córdoba that fell within the 15-min threshold as traffic improved in November (Figure 7).

Figure 7 Location of the Palenque people

Improvements were not significantly disparate among the different groups in terms of sex, educational attainment and literacy, age, and civil status. In terms of education, people with higher educational attainment (a bachelor's degree or higher) were less impacted by traffic changes (69,020 people benefitted) and those with lower educational attainment were more highly impacted (e.g., 282,505 people with primary, middle, or high school education). Although the variations are not dramatic in relative figures, the absolute numbers are high considering that an additional 332,406 people with primary, middle, high, or technical school education were included as congestion eased.

Comparing age groups, children and the young and working-age populations gained more accessibility with the changes in traffic, as the elderly tend to live closer to health services.

The distance and congestion within that distance impact more on the poor, on people with lower educational attainment, and in the age brackets of children, the youth and working-age population.

Variations in congestion resulted in a substantial improvement, nearly half a million more people being within a 15-minute accessibility threshold, nearly 20% of the population.

Despite improved accessibility, accessibility consistently remained lower for people in low-income households, those without a college education, Afro-descendants and indigenous communities, the young and working-age people, and residents of peripheral areas. Supplemental File 2 and Supplemental File 3 illustrate that tertiary care health services are far from where most of the population lives. Geospatial analysis, big data, and predictive and prescriptive analytics could be used to inform service planning in ways that maximize accessibility if new services are to address these limitations.

Planners and service providers who want to combat social injustices must examine this new evidence that distance and congestion combine to exclude the most vulnerable and socioeconomically disadvantaged from critical health services. Planners and service providers must then consider bringing services closer to these populations. This new evidence creates an opportunity to make a difference for the future, correct injustices, and help people feel they are included and heard in community planning. This evidence makes the case for using travel time in planning and equity in accessibility when monitoring and evaluating the quality of health services.

Limitations

The AMORE Platform uses data modelling and clustering to estimate travel times between the origin and destination sectors, lowering the cost of big data. Operational costs are thus low and platform updates for monitoring and evaluation are affordable. The tradeoff for affordability is that small imprecisions in estimates are possible. These imprecisions are more likely to correspond to populations living near the 15-minute threshold and those further away from TAZ centroids with heavy traffic congestion.

Predicted travel times from the Google Distance Matrix API are known to be accurate and are fed by bigdata from smartphones. Other databases, such as Waze Transport SDK API can be used for estimates. Providers do not release prediction algorithms, making it impossible to know the magnitude and variations introduced by unforeseen events, like restrictions associated with the pandemic, and to estimate errors or biases thus introduced on estimates.

Colombian law requires hospitals to treat patients in emergencies. Modeling for this study assumed that people would always go to the nearest hospital in an emergency, but they may not. People may go to a more distant hospital if they know it better, their insurer recommended it, or it has a good reputation. AMORE Platform estimates may thus be more optimistic than reality.

The study assesses travel times from the place of residence to the nearest hospital. Although the maps allow to look at the travel times from a specific sector, the figures do not reflect the fact that the origin of a trip will not always be the place of residence, and that this limitation will spread differently at different moments and for different populations.

Interpretation

The AMORE Platform reveals accessibility and its health equity implications, providing new dynamic data that accounts for the effects of traffic. It does so with more precision and at a fraction of the costs of household surveys and origin-destination studies, providing a new tool to inform service plans, programs, and policies.

The use of a platform that integrates publicly available data from public sources might be a breakthrough that improves evidence-informed decisions regarding the location and provision of health services. Visualizations might help stakeholders to interpret the data and agree on a common objective and metric: painting the city green by covering its entire population and offering equitable accessibility to all people.

Updating the AMORE Platform is cheaper and faster than updating other origin-destination studies, its assessments are sensitive to variations, and it can be used to monitor evaluate changes. In emergencies such as earthquakes, the platform might help having a better situation analysis by feeding real-time data downloads rather than predictions.

These findings suggest that with congested traffic in peak hours, most (63%) Cali residents are beyond the 15-minute travel time threshold by car to the nearest tertiary care emergency department. However, this figure fell to 43% when traffic congestion eased.

Reduced accessibility is unevenly distributed and reflects the inverse care law: people who live in low-income households or have less education face longer travel times to tertiary care emergency departments. Incidentally, heavy traffic also affects people on the periphery of Cali, including some high-income households, as congestion clogs roads they use to reach tertiary emergency care facilities.

Accessibility is one of many potential access barriers to health services, and a critical one. Other factors that affect access to health care (e.g., rights, quality, or supplies) are meaningless if patients cannot reach tertiary emergency care in a crisis. Other access barriers to health services (such as non-compliance with Colombian law, quality, and institutional and reputation) are beyond the scope of this study but also merit consideration.

Researchers and planners can use data mining to optimize locations for new tertiary care emergency services and maximize coverage of populations. Data mining can inform construction of new institutions or improvements to existing ones. Optimizing accessibility could inform sound choices. This data is new and provides an opportunity to improve health services planning. Stakeholders and health equity advocates should consider encouraging the integration of accessibility considerations in urban planning processes.

Generalizability

This study is reproducible in other settings with dynamic travel time data (e.g., from Waze or Google Maps) and georeferenced service and population data that make situational analyses accessible. The accuracy of information depends on the accuracy of its sources (i.e., census data, service providers, travel time estimates or assessments) and the modeling used to make searches and maintenance affordable and data easy to interpret.

Other information

Funding

This study has not yet received external funding; costs have been covered by the principal investigator plus supplementary in-kind contributions by IQuartil SAS, and by Team33 as part of their training with the DS4A data science program. Costs associated to downloading of bigdata and labor costs of producing an advanced prototype of the AMORE Platform were covered by the principal investigator.

Ethical considerations

This observational study on quality improvement for health services planning does not involve human subjects. It integrates anonymized coded secondary data sources obtained from publicly available open records.[38,39] This study has not been subject to ethical review. No identifiable private information was used in the study. Oversight of the project has been provided by the Doctoral Programme on Methodology of Biomedical Research and Public Health at the Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine at the Universitat Autònoma de Barcelona.

Contributions and acknowledgements

Authors and contributors

The project and manuscript writing were led by the corresponding author and principal investigator, Luis Gabriel Cuervo. Substantive additional contributions and editing of the report were provided by (in alphabetical order): María Olga Bula, Daniel Cuervo, Janet Hatcher-Roberts, Ciro Jaramillo Molina, Eliana Martínez Herrera, Luis Fernando Pinilla, Felipe Piquero, and Lyda Osorio. All members of the AMORE Project Collaboration listed in Table 4 provided comments, conceptual contributions, or consumer perspectives. All those listed approved the manuscript and declared they stood by this research report.

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Table 4 Contributions by Members of the AMORE Project Collaboration approving the manuscript

Surname	Given name	Draft writing	Revision & comments	Conceptual contributions	User perspectives	Stands by manuscript	Approved final version
Agredo Lemos	Freddy Enrique		●	●	●	●	●
Avila Rodriguez	German				●	●	●
Bula	María Olga	●	●	●	●	●	●
Concha-Eastman	Alberto			●	●	●	●
Cuervo	Daniel	●	●	●		●	●
Cuervo	Luis Gabriel	●	●	●		●	●
Franco	Oscar			●		●	●
Garcia	Crhistian			●	●	●	●
Guerrero	Rodrigo		●	●	●	●	●
Hatcher-Roberts	Janet	●	●	●		●	●
Jaramillo	Ciro		●	●	●	●	●
Martínez Arámbula	Fernando Rafael			●		●	●
Martínez Herrera	Eliana	●	●	●	●	●	●
Merino Juarez	Maria Fernanda		●	●		●	●
Osorio	Lyda		●	●	●	●	●
Ospina	Maria B			●	●	●	●
Paredes	Gabriel	●		●		●	●
Paredes-Zapata	David		●	●	●	●	●
Pinilla	Luis Fernando	●	●	●	●	●	●
Piquero	Felipe	●	●		●	●	●
Rojas	Oscar		●		●	●	●
Rosero Hernández	Myriam			●		●	●
Tobar-Blandón	Maria Fernanda		●		●	●	●
Zapata Murillo	Pablo			●		●	●

Competing interests

All authors have completed the ICMJE uniform disclosure form and declare: no financial support from any organisation for the submitted work; IQuartil SAS provided technical support to develop the AMORE Platform and was paid by the principal investigator (LGC) for consulting services; DC is a partner at IQuartil SAS and a sibling to LGC. LFP did consultancy at IQuartil SAS until March 2021.

LGC contributed to this work in his personal capacity and time. The views expressed in this article do not necessarily represent the decisions or policies of his employer, PAHO/WHO. Reproductions of this article should not include any suggestion that PAHO/WHO endorsed this research or is endorsing any specific organization, services, or products.

COI Declaration by other members of the AMORE Project Collaborative Group signing off the manuscript: FRMA is an engineer on roads and transportation who participated in his personal capacity and time; his contributions do not necessarily reflect the policies or decisions of his employer, the Municipality of Santiago de Cali. MFMJ participated in her personal capacity and time, and her contributions do not necessarily reflect the policies or decisions of her employer. PZM is a consultant at IQuartil SAS.

Data sharing statement

The data sources used in this study are in the public domain. The links to the sources are provided (see Study design) and the data constitutes a negligible risk to confidentiality because Colombia's census microdata was anonymized by sectors at the source. The file is downloaded from open access government websites, as required by law. Neither Google Maps Distance Matrix API nor REPS include personal information (see Ethical considerations).

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Figure Legends:

Supplemental File 4 – Tertiary care emergency departments in institutions with intensive care and surgery, ordered as displayed in REPS

Figure 1 – AMORE Platform situational analysis

Supplemental File 2 – Travel times and population density, tertiary care institutions, peak traffic, November 2020

Figure 3 – Travel-time clusters from free flow to peak traffic, by time and day

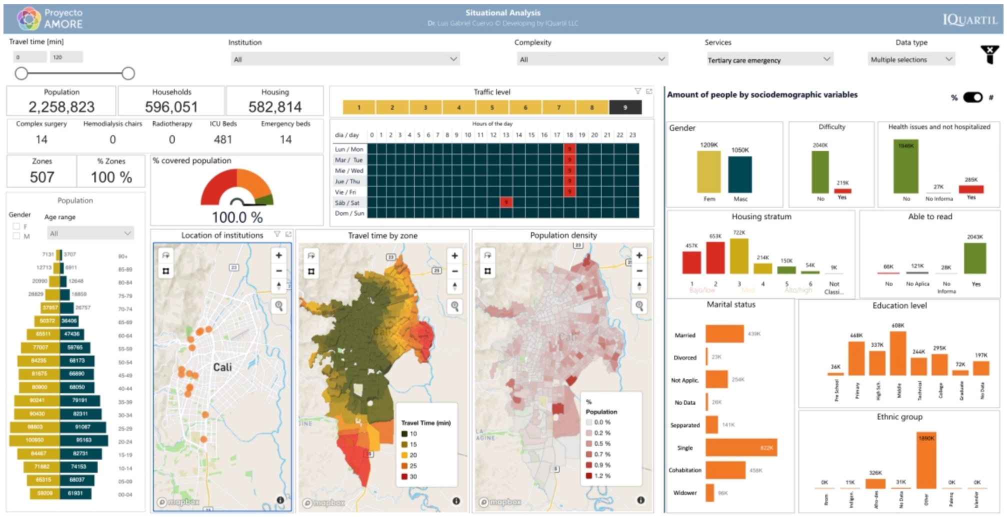
Supplemental File 3 – Travel times by auto to nearest emergency, with peak traffic, July 2020

Figure 4 – Accessibility by income to tertiary care comparing July and November 2020

Figure 5 – Accessibility by sociodemographic characteristics in July and November 2020

Figure 6 – Impact of traffic congestion on accessibility, by economic stratum, July 2020

Figure 7 – Location of the Palenque people



Travel time [min] 0 120

Institution All

Complexity All

Services Tertiary care emergency

Data type Multiple selections

Population 2,258,823

Households 596,051

Housing 582,814

Complex surgery 14

Hemodialysis chairs 0

Radiotherapy 0

ICU Beds 481

Emergency beds 14

Zones 507

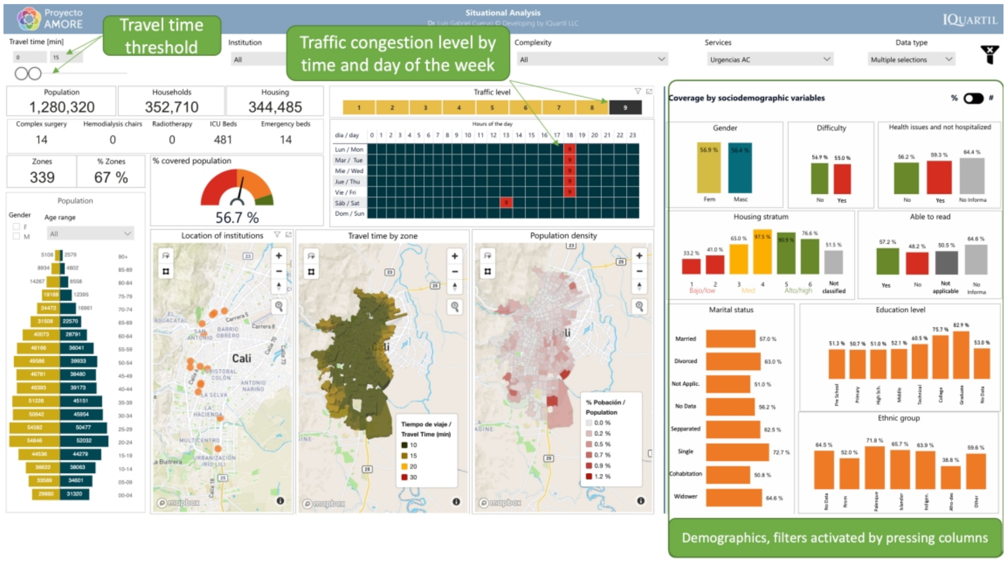
% Zones 100 %

% covered population 100.0 %

Age range All

Figure 1, AMORE Platform situational analysis

338x190mm (222 x 222 DPI)



Travel time threshold

Traffic congestion level by time and day of the week

Demographics, filters activated by pressing columns

Figure 2, Situational analysis, filters and visualizations, Nov 2020

338x190mm (222 x 222 DPI)

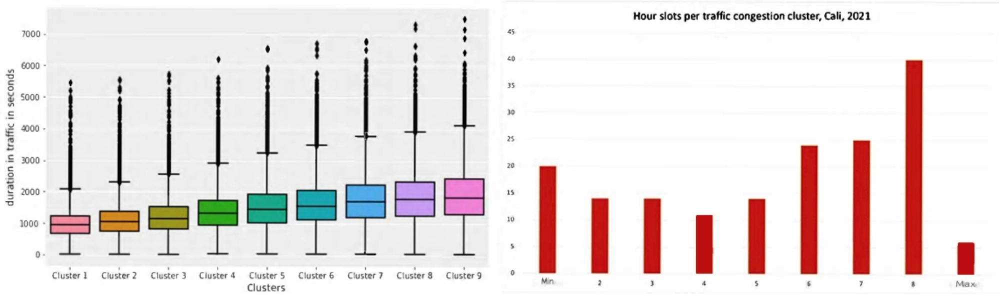


Figure 3, Travel-time clusters from free flow to peak traffic, by time and day

337x99mm (221 x 222 DPI)

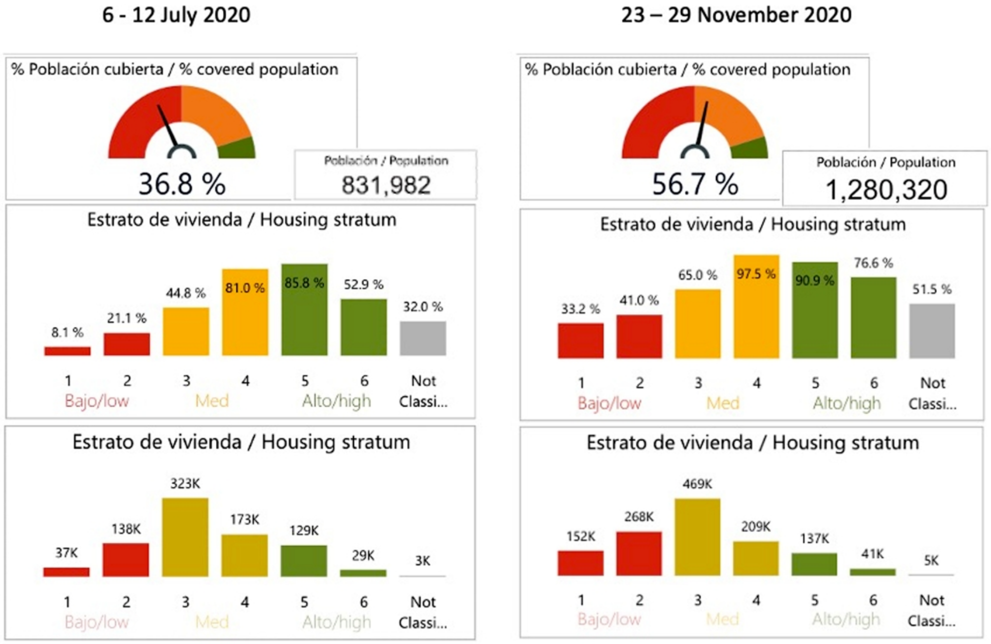


Figure 4, Accessibility by income to tertiary care comparing July and November 2020

284x186mm (222 x 222 DPI)

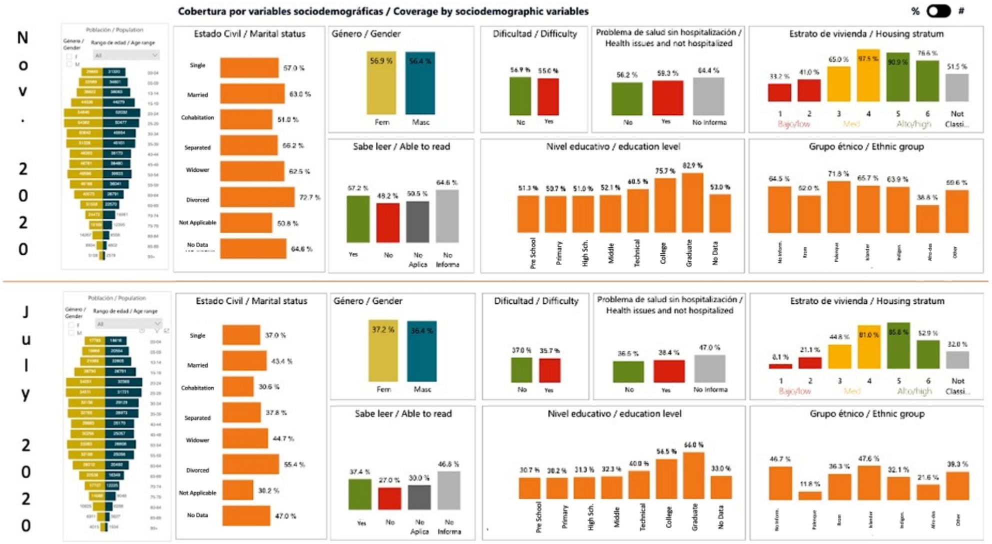


Figure 5, Accessibility by sociodemographic characteristics in July and November 2020

338x190mm (222 x 222 DPI)

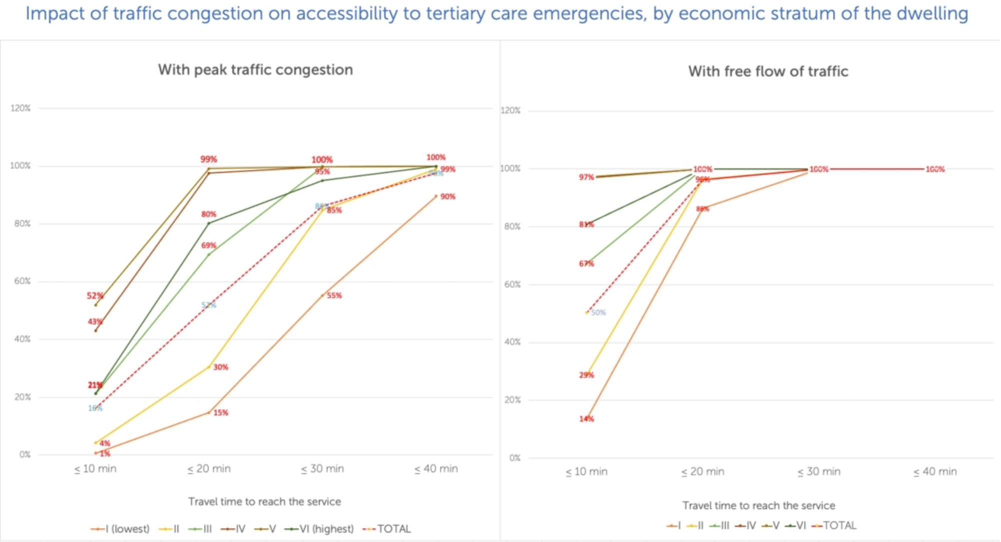
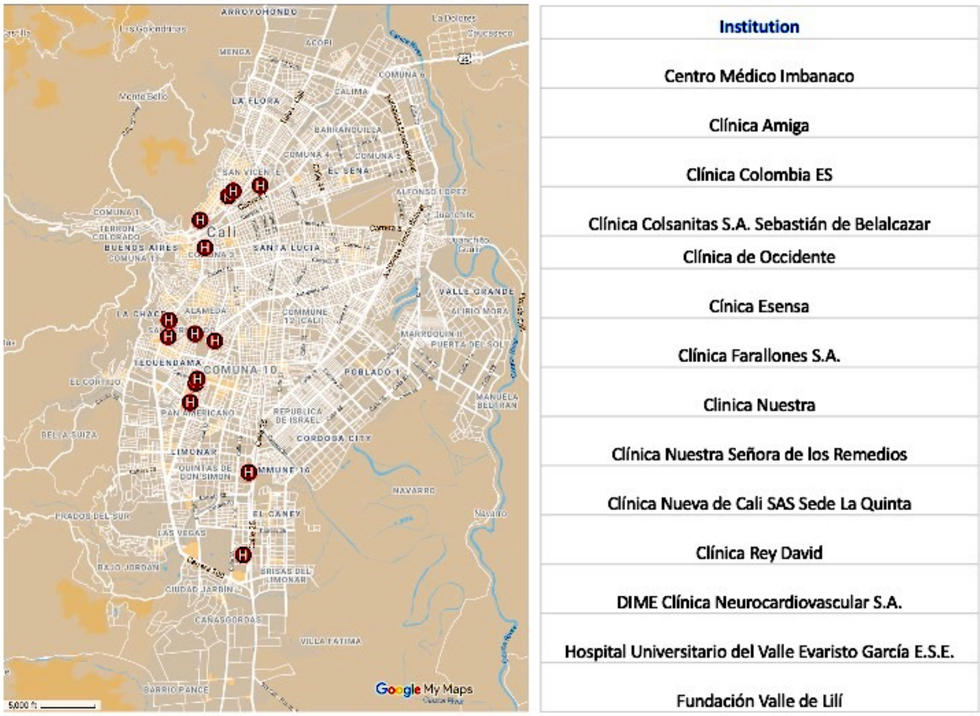


Figure 6 Impact of traffic congestion on accessibility, by economic stratum, July 2020

338x190mm (300 x 300 DPI)

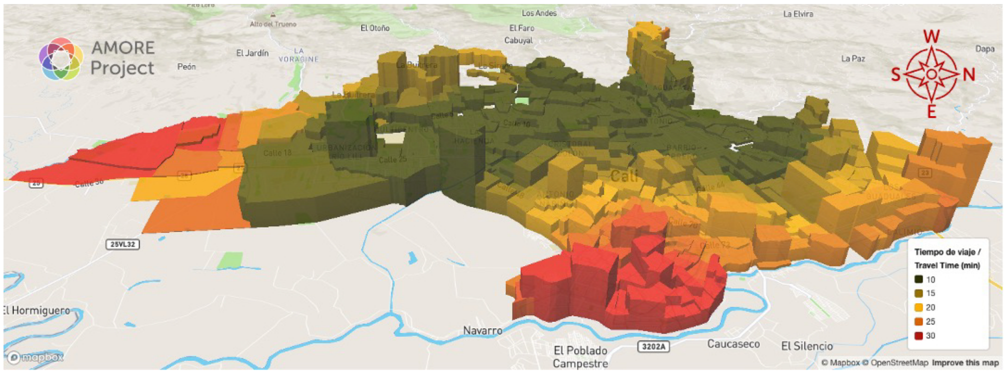
Figure 7, Location of the Palenque people

188x314mm (72 x 72 DPI)



Institution
Centro Médico Imbanaco
Clínica Amiga
Clínica Colombia ES
Clínica Colsanitas S.A. Sebastián de Belalcazar
Clínica de Occidente
Cínica Esensa
Clínica Farallones S.A.
Clinica Nuestra
Clínica Nuestra Señora de los Remedios
Clínica Nueva de Cali SAS Sede La Quinta
Clínica Rey David
DIME Clínica Neurocardiovascular S.A.
Hospital Universitario del Valle Evaristo García E.S.E.
Fundación Valle de Lilí

228x168mm (81 x 81 DPI)



338x123mm (81 x 81 DPI)

879x320mm (72 x 72 DPI)

Cross-sectional equity analysis of accessibility by automobile to tertiary care emergency services in Cali, Colombia in 2020

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	3,4
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4, 6-8
Bias	9	Describe any efforts to address potential sources of bias	7
Study size	10	Explain how the study size was arrived at	3, 8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6-7, 10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6, 10
		(*b*) Describe any methods used to examine subgroups and interactions	6, 10
		(*c*) Explain how missing data were addressed	7, 10
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed	10
		(b) Give reasons for non-participation at each stage	N.A.
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	10
Outcome data	15*	Report numbers of outcome events or summary measures	8-10

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9, 10
		(*b*) Report category boundaries when continuous variables were categorized	8- 10
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarize key results with reference to study objectives	9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12-13
Generalizability	21	Discuss the generalizability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13

*Give information separately for exposed and unexposed groups.

BMJ Open

Dynamic accessibility by car to tertiary care emergency services in Cali, Colombia, in 2020: cross-sectional equity analyses using travel-time big data from a Google API.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-062178.R1
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Complete List of Authors:	Cuervo, Luis Gabriel; Universitat Autònoma de Barcelona, Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine Martinez-Herrera, Eliana; Universidad de Antioquia, Facultad Nacional de Salud Pública Osorio, Lyda; Universidad del Valle Facultad de Salud, Escuela de Salud Pública Hatcher-Roberts, Janet; University of Ottawa Faculty of Medicine, School of Epidemiology and Public Health; Bruyere Research Institute Cuervo, Daniel; IQuartil SAS Bula, Maria Olga; Egis Consulting Pinilla, Luis Fernando; Universidad de La Sabana, Correct email is LuisFerPinilla@gmail.com (system does not allow fixing it) Piquero, Felipe; Consumer advocate; Author of "Opportunities Amidst Uncertainty: My life with one kidney and without it", Published in English and Spanish Jaramillo, Ciro; Universidad del Valle, School of Civil and Geomatic Engineering Collaborative Group, AMORE Project; AMORE Project Collaborative Group; Universitat Autonoma de Barcelona
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Title

Dynamic accessibility by car to tertiary care emergency services in Cali, Colombia, in 2020: cross-sectional equity analyses using travel-time big data from a Google API.

Luis Gabriel CUERVO,(1) *Eliana MARTINEZ HERRERA,*(2) *Lyda OSORIO,*(3) *Janet HATCHER ROBERTS,*(4) *Daniel CUERVO,*(5) *María Olga BULA,*(6) *Luis Fernando PINILLA,*(7) *Felipe PIQUERO,*(8) *Ciro JARAMILLO,*(9) *on behalf of the AMORE Project Collaboration.*

- *(1) Corresponding author. PhD Candidate, Universitat Autònoma de Barcelona, Spain:* LuisGabriel.Cuervo@autonoma.cat
- *(2)* National School of Public Health, Universidad de Antioquia, Medellín, Colombia
- *(3)* Faculty, School of Public Health, Universidad del Valle, Colombia.
- *(4)* Brùyere Research Institute and Adjunct School of Epidemiology and Public Health, University of Ottawa.
- *(5)* Partner at IQuartil SAS. Industrial Engineer, MBA, Certified Data Analyst.
- *(6)* MSc in urban planning, Egis Consulting.
- *(7)* Universidad de la Sabana. Lecturer in the Operations Management Specialization.
- *(8)* Attorney in administrative law and healthcare legislation. Consumer advocate and book author
- *(9)* Associate Professor in the School of Civil and Geomatic Engineering, Universidad del Valle, Colombia; PhD thesis director, Universitat Autònoma de Barcelona.

Abstract

Objectives: Provide a high-level assessment of dynamic accessibility and health equity to inform policies, plans and programs.

Design: The impact of traffic congestion on accessibility to tertiary care emergency departments was studied using a web-based digital platform that integrated publicly available digital data including sociodemographic characteristics of the population and places of residence with travel times, providing an equity perspective.

Setting and Participants: Cali, Colombia (population 2.258 million in 2020) using geographic and sociodemographic data. The study used predicted travel times downloaded for a week in July 2020 and a week in November 2020.

Primary and secondary outcomes: The share of the population within a 15-minute journey by car from the place of residence to the tertiary care emergency department with the shortest journey (i.e., 15-minute accessibility rate; 15mAR) at peak-traffic congestion hours. Sociodemographic characteristics were disaggregated for equity analyses. A time-series bivariate analysis explored accessibility rates versus housing stratification.

Results: Traffic congestion sharply reduces accessibility to tertiary emergency care (e.g., 15mAR was 36.8% during peak-traffic hours vs 84.4% during free-flow hours for the week of July 6 – 12, 2020). Traffic congestion sharply reduces accessibility to tertiary emergency care. The greatest impact fell on specific ethnic groups, people with less educational attainment, and those living in low-income households or on the periphery of Cali (15mAR: 8.1% peak traffic vs 51% free-flow traffic). These populations face longer average travel times to health services than the average population.

Conclusions: This study proposes that health services and land use planning prioritise travel times over travel distance and integrate them into urban planning. Existing technology and data can reveal inequities by integrating sociodemographic data with accurate travel times to health services estimates, providing the basis for valuable indicators.

The study offers a new approach to health services and land use planning

Strengths and limitations of this study

- The study shows it is possible to estimate dynamic travel times and their correlations with health equity using available and updateable data.
- Travel times change constantly; some changes are predictable and others part of an evolution. These changes can be identified at a scale that offers meaningful inputs for stakeholders, potentially shaping long-term urban and health services planning.
- Data downloads can become affordable and informative enough to guide decisions with data analytics.
- Travel time is not randomly distributed and assessing measurement errors for big data or the census can be impractical; even when the algorithms behind big data are unknown, these data can be superior to static travel-time estimations.
- The study shows it is possible to assess dynamic accessibility and its impact on vulnerable populations affordably.

Introduction

Background/Rationale

Every minute counts in life-threatening emergencies that do not leave time for referrals (e.g., insufficient tissue oxygenation, critical bleeding, significant tissue damage, poisoning). The well-being of patients depends on getting immediate attention in a tertiary care facility that offers essential subspecialised care by highly skilled personnel and sophisticated facilities, including specialised surgical theatres and intensive care units.

This study tests a new approach that allows stakeholders to explore different assumptions and scenarios. For example, different time-to-destination thresholds, traffic congestion levels, or accessibility for the whole or parts of the population.

The study delivers baselines for accessibility by car (automobile) to tertiary care emergency departments in Cali, Colombia. It assesses the impact of traffic congestion on accessibility and health equity, using a car (private or for-hire) as the means of transportation because it is how Cali residents typically reach tertiary care facilities in emergencies. This approach also makes it possible for future studies to analyse accessibility with other means of transportation or under different assumptions.

Accessibility is a dynamic spatial attribute measured as the travel time needed to reach a health service location (destination) from the origin of the demand (place of residence in this study).[1–8] Travel times fluctuate over time and with traffic congestion. Accessibility has been challenging to study and monitor, and poor accessibility can be detrimental to health equity.[4,8–10]

Traditional assessments of accessibility in urban planning seldom consider its dynamic nature; origin-destination studies and surveys usually lack a dynamic assessment showing the effects of infrastructure, population changes, or traffic on accessibility and health equity.[11,12]

Traditional assessments are onerous, done every five to ten years, using lengthy surveys that lack the specificity of health services and the geographical granularity of Traffic Analysis Zones, or TAZs (instead of more expansive neighbourhoods or communes). The conditions assessed may have changed when results become public, rendering any proposed solutions irrelevant.[8,13] This study explores an approach that addresses critical limitations of traditional accessibility assessments to expose the links between equity and accessibility to tertiary care emergency services.[10]

Innovative approaches using accessible web-based platforms are an opportunity for evidence-informed decision-making and planning to improve health coverage. These platforms allow stakeholders to test assumptions and reach conclusions and capitalise on features such as big data from smartphones that can provide accurate travel-time estimates. Therefore, dynamic, affordable, and updatable assessments that account for traffic congestion could be used, thus focusing on travel times instead of travel distances.[5,8,12,14–17] They might allow stakeholders to explore data, test assumptions better, and reach action-oriented conclusions.[18] This study integrates the equity-relevant data we used to perform equity analyses.

Objectives

This study aims to characterise accessibility to tertiary care emergency health services in urban Cali and the links between accessibility and sociodemographic factors relevant to health equity.

Methods:

Study population and setting

This study is about emergencies requiring attention in tertiary care institutions. By early July 2020, COVID-19 pandemic-related quarantine and stay-at-home orders had been lifted, and traffic projections showed substantial congestion. By November 2020, some measures had been reinstated, car travel was restricted by license number, and traffic projections showed reduced travel times, especially in central city areas.[19–21]

This cross-sectional study was conducted with data downloads for the urban area of Cali, the third-largest city in Colombia and the largest urban centre in the southwest and Pacific regions, with an estimated 2.258 million residents in 2020. About half of the population lives in low-income housing, 42% in middle-income housing, and 8% in high-income housing. Housing stratification does not necessarily represent the income of individuals.[22,23]

About 84% of the population identifies as white, 14% as Afro-Colombian and a small proportion as indigenous or nomadic people like the Rrom. In December 2020, unemployment rates in Cali were 26.7% for women and 18.5% for men, a one-year increase of 12.5% and 8.8%, respectively.

The situation was worse among young people, and an estimated 52% of women and 47.2% of men relied on the informal economy. The COVID-19 pandemic punished the local economy. While 1 in 5 people was unemployed, the rates were higher among people in low-income households. From 2016 to 2020, Cali also absorbed 139,000 migrants from Venezuela; 25,000 in 2020.[24]

Poverty, inequity, and discrimination drove social unrest that led to violence after a 2021 national strike.[25,26]

The city government is dividing its 22 communes into six to eight districts, which might lead to negotiations over resources and issues such as access to essential services.[27,28]

Targeted sites/Participants

The study targeted the 14 tertiary care institutions with emergency departments registered in the Ministry of Health Special Registry of Health Services Providers (REPS in Spanish). The registry listed the same institutions in July 2020 and January 2021; all provided surgery and intensive care services. Those institutions are listed in Supplemental File 1.[29]

Supplemental File 1 Tertiary care emergency departments in institutions with intensive care and surgery, ordered as displayed in REPS[29]

Study design

This study includes two cross-sectional analyses integrating publicly available data using digital technologies and analytics. The study generated new knowledge of potential value when implementing evidence-informed approaches to improve accessibility and health equity. The study used updatable data to measure travel times and evaluate the effects of interventions and changes to infrastructure, service provision, traffic congestion, and population. The following study methods seek to address current challenges for assessments of accessibility to health services:[10]

- Dynamic assessments of travel times to account for traffic variations.

- Inputs from diverse stakeholders to create an interactive platform that displays intersectoral data on dashboards so stakeholders can interpret data quickly and accurately.
- Disaggregated data to enable straightforward equity analysis of accessibility.
- Situational analysis of the accessibility to specific services for urban areas.
- An approach suitable for monitoring health equity related to accessibility.

The data for the cross-sectional analyses were obtained from the internet-based AMORE Platform (https://www.iquartil.net/proyectoAMORE), hosted by iQuartil SAS, an analytics company, and developed under the leadership of the Principal Investigator (LGC).

The AMORE Platform integrates data from:

- 2018 National Census Data for Cali, obtained from the official public databases of the Colombian National Department of Statistics (DANE in Spanish).[22,23]
- The administrative divisions of Cali were obtained from the Colombian IDESC Geoportal; Traffic Analysis Zones (TAZ) were matched to the census blocks.[13,30] The origin for each journey is the population-weighted centroid for the TAZ of the place of residence. Similarly, the destination is the centroid for the TAZ hosting the tertiary care emergency department with the shortest travel time.
- Google Distance Matrix API. For this baseline assessment of the Cali urban area, predicted travel times were downloaded on 3 July 2020 for the week of 6 – 12 July 2020, and on 27 October 2020, for the week of 23 – 29 November 2020. Travel times varied substantially during the COVID-19 pandemic and while it is unclear how this influenced Google Distance Matrix algorithms,[31] empirical and anecdotal reports suggest they remained accurate.
- The 14 tertiary care institutions with an emergency department in Cali were identified using REPS.[29]

Databases were integrated and tested between August 2020 and October 2021 using: KNIME® open-source data analytics reporting and integration platform, Python™ programming language software (back end), and an interface (front end) developed with interactive data visualisation software Microsoft PowerBi™.

Patient and public involvement

The AMORE Project Collaborative Group is diverse, with over two-dozen contributors representing different stakeholders and sectors. Group members participated throughout the design, conduct, and reporting of this study and the dissemination of results. The contributors and some public servants participated in the co-creation of knowledge and are listed in the Acknowledgements. These collaborators offer different governance perspectives: authorities, service providers, service users, and organised civil society, including academics, advocates, and experts from various fields of knowledge.[32,33]

Data integration and output

The AMORE Platform dashboards and visualisations provide descriptive indicators using simple maps, dials, bars, and data. These indicators show travel times using the shortest journeys and descriptive statistics for each urban TAZ at a given traffic congestion level. The displays for July and November can be accessed on this project website. The AMORE Platform allows users to perform equity analyses by disaggregating sociodemographic characteristics.[34] The top section of the Platform (Figure 1) has nine traffic-congestion clusters and their representation in the week. A dial shows the share of the population within the set travel-time threshold.

Figure 1 AMORE Platform situational analysis

The middle section displays a population pyramid and maps the 14 tertiary care emergency departments, travel times, and population density (Figure 1). Each section of the pyramid or map can be toggled to filter populations. The choropleth maps can be expanded and rotated for a 3D display, with TAZ height representing population density (Supplemental File 2). Selecting a TAZ displays its ID, population, and travel time.

Supplemental File 2 Travel times and population density, tertiary care institutions, peak traffic, November 2020

Choropleth maps consist of TAZs established by MetroCali (Integrated Mass Transit System) in 2015 for the urban area and linked to the geotagged census block information, matching the population with these TAZs.[13] The geometric matching of blocks and TAZs yielded 507 inhabited TAZs within the urban perimeter. The origin-destination times were estimated from the population-adjusted geographic centroid of each TAZ to the respective centroid where each institution was located.

The Colombian census was completed through interviews with an adult for each household. Data was stored, linking it to a city block code to anonymise it. The AMORE Platform used the census microdata categorisations and, for a few variables, aggregate groups for simplification (e.g., education was simplified with guidance from an expert in the Colombian education system, Psychologist Myriam Lorena Rosero Hernández, ME).

In 2019, DANE recommended adjusting the 2018 population of Cali upward by 18% from the original census data due to under-registration.[23,35] DANE advised making further adjustments due to intercensal growth, migration and updates.[24,36] These adjustments amounted to 28.1%, and DANE did not disaggregate the adjustment data. Therefore, 495,219 records were randomly selected and duplicated, reaching a population of 2,258,823 inhabitants, keeping the distributions. These are displayed in the AMORE Platform by toggling the census adjustment (Figure 1, “Data type”).

The right section of the platform displays sociodemographic characteristics (Figure 1).

The AMORE Platform displays the absolute and relative figures for the georeferenced data of inhabitants, both for the city or selected TAZs within a travel schedule Figure 2. The variables integrated into the platform are listed in Table 1.

Figure 2 Situational analysis, filters and visualisations, Nov 2020

Data sources/measurements

Table 1 Census data included in the AMORE Platform dashboards and maps

Geotagged variables	Platform display
Age in completed years grouped by quinquennium (census)	Population density per TAZ
Ethnicity, self-described	Health service: tertiary care emergency departments
Health status (Sick / Healthy)	Absolute and relative figures of modified aggregation
Highest education level attained	Travel-time thresholds (slider + choropleth heatmap)
Literacy	Travel times and population per TAZ
Marital status	Overall accessibility for filtered population
Population pyramid by gender and age	
Report of disability / physical condition	
School attendance	
Household inhabitants	
Housing inhabitants	
Housing socio-economic stratum	
Housing type	

We used the controls listed in Table 2 to conduct univariate and bivariate analyses.

Table 2 AMORE Platform displays resulting from integrating travel times, services, origin TAZ, and census data

Variables that change according to traffic, travel-time threshold, and other filters
Travel-time threshold filter for the analysis.
Drop-down list with institutions that can be toggled for inactivation.
Drop-down list to select people registered by the census, the 28.1% adjustment, or the adjusted census data.
Traffic levels identified with a K-means clustering algorithm.
Absolute and relative figures provided for each variable.
Maps are organized by TAZs.
Intensive care beds data for selected institutions taken from REPS.
People with accessibility for a selected time threshold and traffic level.
Blocks with accessibility for a selected time threshold.
TAZs within the time threshold by level of traffic.
Household inhabitants
Housing inhabitants
Housing by power bill economic stratum

Bias

Each source is susceptible to biases and imprecision, but these are unlikely to be of a magnitude that would change conclusions. Some of the data sources and the timing of their updates can introduce bias. For example, the census is updated every five years. Since the last census in 2018, there has been a significant flow of migrants to Cali and job losses rose during the COVID-19 pandemic.[24,37] These developments likely make our results appear more favourable than they are. The census had under-registration from failed or incomplete visits, underreporting of people living in households, or people absent in each of the three times registrars visited. The estimates for migrants and intercensal growth are broad and likely unevenly distributed among the population and no precise measurement errors are available.[23,24]

Traffic patterns may have changed with the imposition and lifting of pandemic-related restrictions, thus altering traffic predictions. Stay-at-home orders and traffic restrictions may have changed traffic congestion, causing unusual and uneven patterns of accessibility. Google Distance Matrix API may have more accurate travel times for areas where more people travel with mobile phones and in cars.

Income categorisation is determined by the individual household electricity bill, which is graded from 1 to 6, with 6 representing the highest-income households. Some homes may have been misclassified (e.g., due to error or corruption) and that low-income people are living in higher-income households. This is possible for relatives and domestic workers residing in high-income housing and earning minimum wages or having no income. This kind of misclassification would introduce some bias that would overrepresent high-income populations.

The Colombian census recognises ethnicity, but some people likely found it difficult to choose their ethnicity. The census lacks an option for residents of white or mestizo descent, two large groups not explicitly listed on the census. Similarly, people with multi-ethnic parents may find it challenging to choose one ethnic category.

Traffic restrictions linked to car license numbers affect households and neighbourhoods differently; more affluent families are more likely to own more cars and be less affected by these measures.[38]

To reduce data downloads, we performed a cluster analysis (using a K-means method) of the travel times on a sample of the total weekly hours. This allowed us to identify the hours of the week with similar traffic congestion levels by measuring the incremental changes against the minimum travel time. We determined that nine clusters allowed us to discriminate traffic congestion based on sensitivity analysis to represent the 168 hours of the week.

For each day and hour time band, we estimated the percentage difference between the minimum time of that trip and the travel for the time band. We calculated the average of this metric for all the journeys of the sample to obtain clusters. For example, the traffic from 6 to 7 p.m. on weekdays and from noon to 2 p.m. on Saturdays behaves similarly for this cluster, representing the highest traffic congestion. Creating these clusters again reduces information requirements and costs.

Using hourly assessments is arbitrary; travel times could be measured every minute or second. However, more frequent checks would increase costs (i.e., from data downloads, computing time, people time) by orders of magnitude without substantive changes in the conclusions. More frequent checks would thus be impractical and of little value. Details of the effects of these optimisations will be the subject of a future manuscript.

Using congestion clusters and TAZs for the 14 institutions made it possible to obtain the city estimates with a sample of 1,159,536 measurements downloaded from Google Distance Matrix API. The geometric matching of blocks and TAZs yielded 507 inhabited TAZs in the urban perimeter.

Populations are not evenly distributed across TAZs. We therefore adjusted TAZ geographic centroids by weighing population distribution. Because centroids had irregular shapes, population-weighted centroids could end outside the boundaries of a TAZ. This required relocating the adjusted centroid to the nearest border, potentially generating some seconds of imprecision in estimates. Similarly, using the TAZ of a hospital instead of the location of the emergency department entrance also generates imprecisions.

Traffic patterns are not homogeneous within the city or its TAZs; traffic flow patterns vary in time and direction. We therefore sorted traffic times so that cluster nine always represented the maximum traffic congestion, cluster one the minimum traffic congestion, and intermediate clusters were sorted accordingly. Figure 3 illustrates the clusters and variations.

Figure 3 Travel-time clusters from free-flow to peak traffic, by time and day.

The definition of an acceptable travel-time threshold to reach a tertiary care emergency department is arbitrary, and we found no international standard. For this analysis, we chose a threshold of fifteen minutes at peak-traffic congestion times that was the most frequently considered by interviewed local public servants and members of the AMORE Project Collaborative; it is within the thresholds found in the literature.[39–41]

Notably, the distribution of traffic levels is skewed towards heavy congestion from Monday to Saturday between 6:00 and 22:00, with the mode being cluster 8 (40/168 hours, or 24% of the week); Cali is a congested city.

Results/Outcomes

Participants

The study included the adjusted population of 2,258,823 people, representing 596,051 households living in 582,814 housing units. The size and representation of populations are disaggregated in Table 3.

Most of the population is mestizo or white (83.7 %) or Afro-descendants (14.5%). Islanders and Rrom people represent less than 1% of the population. Absolute and relative figures disaggregated by sociodemographic characteristics are presented in Table 3.

Descriptive data

The analysis found that most of the low-income population could not reach the nearest tertiary care emergency department within 15 minutes during peak-traffic times, whether in November 2020 (81.4%) or July 2020 (96.3%; Supplemental File 2 and Supplemental File 3, respectively).

The analysis also shows that accessibility is a substantial barrier to low-income households with high population density and those living in peripheral TAZs, amplifying inequities.

Supplemental File 3 Travel times by auto to the nearest emergency, with peak traffic, July 2020

Main results

The effects of traffic disaggregated by household income level, ethnicity, gender and age, education level, and civil status are presented in Figure 4, Figure 5, and Table 3. Figure 6 shows differential accessibilities by housing stratum during peak and free-flow traffic hours, with the differential being more detrimental to the poorest and more affected by peak-traffic congestion.

Figure 4 Accessibility by income to tertiary care comparing July and November 2020

Figure 5 Accessibility by sociodemographic characteristics in July and November 2020

Traffic variations and their effect (July vs November 2020)

6 – 12 July vs 23 – 29 November 2020

The July travel-time predictions pointed to 831,982 people (36.8%) living within 15 minutes of travel time from tertiary care emergency services, but this increased to 1.28 million (56.7%) in November. The distribution of accessibility when disaggregating data by income level indicated lower accessibility for the poor and those living in peripheral TAZs (Figure 4, Figure 5, and evident in Supplemental File 2 and Supplemental File 3 to those familiar with the demographic distribution of Cali). These populations also have a higher representation of minority ethnic groups and people with lower educational attainment.

Table 3 shows the data obtained from the AMORE Platform for the July 2020 and November 2020 assessments, which lets users explore equity considerations.

Other analyses

Figure 6 shows that people living in low-income households face longer travel times and are more severely impacted by traffic congestion; they thus invest more resources in accessing services.

Myriads of analyses can be done by modifying traffic congestion clusters, travel-time thresholds, or toggling population groups or institutions. For pragmatic reasons, this article focused on sticking to the 15-minute threshold and exploring accessibility at peak hours in more detail, which is a good scenario when planning for emergencies.

Figure 6 Impact of traffic congestion on accessibility, by economic stratum, July 2020

Discussion

Main findings

The analysis shows substantial variations in access to tertiary care emergency services due to traffic congestion and the links between geographical accessibility and other social determinants of health. The two points of estimate were for early July and late November 2020, and their substantial variations stress the importance of having updatable sources.

The unusually light traffic congestion of November 2020 might have been due to the mobility restrictions associated with the COVID-19 pandemic. Lighter traffic congestion improved accessibility for an additional 448,338 people, most living in low-income households. These people were also within the 15-minute threshold (Figure 4), and their location can be visualised by comparing Supplemental File 2 and Supplemental File 3. Table 3 shows accessibility at peak-traffic hours disaggregated by sociodemographic characteristics relevant to equity.[42–44]

The longest journeys were 46 minutes in July and November. These journeys started from densely populated, impoverished eastern neighbourhoods along the Cauca River (Aguablanca district) and sparsely populated wealthy villas in the southern edge of the city, bordering Jamundí.

Easing traffic congestion brought an additional 22% (244,579) of people in the low-income household and 19.4% (181,409) more people living in middle-income households within the 15-minute threshold.

Improvements were not notably disparate among the different groups (sex, educational attainment and literacy, age, and civil status). In terms of education, people with higher educational attainment (a bachelor’s degree or higher) were less impacted by traffic changes (69,020 people) and those with lower educational attainment were more highly impacted (e.g., 282,505 people with primary, middle, high, or technical school education). The variations seemed unimpressive in relative terms but are notable in absolute numbers, considering that an additional 332,406 people with primary, middle, high, or technical school education were included as congestion eased. Variations in congestion resulted in substantial accessibility improvement, with nearly half a million more people within a 15-minute accessibility threshold, almost 20% of the population.

Comparing age groups, children and the young and working-age populations gained more accessibility with the changes in traffic, as the elderly tend to live closer to health services.

Palenque, Islanders, Rrom, and indigenous people represent 0.5% of the population of Cali. Minority ethnic groups benefitted the most from the reduction in traffic congestion. The noticeable improvement among the Palenque resulted from most living in the south-eastern neighbourhoods of El Morichal, El Retiro, El Vallado, and Ciudad Córdoba, which fell within the 15-minute threshold when traffic eased in November (see **Error! Reference source not found.**).

Figure 7 Location of the Palenque people

Supplemental File 2 and Supplemental File 3 show that tertiary care health services are far from where most of the population lives. Geospatial analysis, big data, and predictive and prescriptive analytics could inform service planning in ways that maximise accessibility if new services address these limitations.

Table 3 Accessibility by auto within fifteen minutes to tertiary care in July and November, Cali 2020

15 min accessibility to the nearest tertiary care emergency service	Jul 2020 (%)	Nov 2020 (%)	Change	Jul 2020 (#)	Nov 2020 (#)	Change (#)	Total Population	%	Accessibility July	Accessibility November	Subgroup change
	36.8%	56.7%	19.8%	831,982	1,280,320	448,338	2,258,823		36.8%	56.7%	
Socio-economic stratum											
Low	7.7%	18.6%	10.8%	174,869	419,448	244,579	1,109,549	49.1%	15.8%	37.8%	22.0%
Middle	22.0%	30.0%	8.0%	496,558	677,967	181,409	935,699	41.4%	53.1%	72.5%	19.4%
High	7.0%	7.9%	0.9%	157,682	178,277	20,595	204,589	9.1%	77.1%	87.1%	10.1%
N.D.	0.1%	0.2%	0.1%	2,873	4,628	1,755	8,986	0.4%	32.0%	51.5%	19.5%
Ethnicity											
Afro descendent	3.1%	5.6%	2.5%	70,394	126,298	55,904	325,865	14.4%	21.6%	38.8%	17.2%
Rrom (nomadic)	0.0%	0.0%	0.0%	37	53	16	102	0.0%	36.3%	52.0%	15.7%
Indigenous	0.2%	0.3%	0.2%	3,571	7,103	3,532	11,112	0.5%	32.1%	63.9%	31.8%
Islander/Raizal	0.0%	0.0%	0.0%	182	251	69	382	0.0%	47.6%	65.7%	18.1%
Other (Caucasian, Mestizo)	32.9%	49.9%	17.0%	743,469	1,126,671	383,202	1,890,491	83.7%	39.3%	59.6%	20.3%
Palenque	0.0%	0.0%	0.0%	29	176	147	245	0.0%	11.8%	71.8%	60.0%
N.D.	0.6%	0.9%	0.2%	14,300	19,768	5,468	30,626	1.4%	46.7%	64.5%	17.9%
Educational level											
Graduate degree	2.1%	2.7%	0.5%	47,785	60,019	12,234	72,441	3.2%	66.0%	82.9%	16.9%
Bachelor's degree	7.4%	9.9%	2.5%	166,816	223,602	56,786	295,319	13.1%	56.5%	75.7%	19.2%
Technical	4.3%	6.5%	2.2%	97,733	147,634	49,901	244,160	10.8%	40.0%	60.5%	20.4%
Middle	8.7%	14.0%	5.3%	196,674	316,810	120,136	608,429	26.9%	32.3%	52.1%	19.7%
High School	4.7%	7.6%	2.9%	105,509	171,843	66,334	337,065	14.9%	31.3%	51.0%	19.7%
Primary	6.3%	10.5%	4.3%	141,309	237,344	96,035	468,206	20.7%	30.2%	50.7%	20.5%
Pre-school	0.5%	0.8%	0.3%	11,158	18,636	7,478	36,294	1.6%	30.7%	51.3%	20.6%
No data	2.9%	4.6%	1.7%	64,998	104,432	39,434	196,909	8.7%	33.0%	53.0%	20.0%
Literacy											
Literate	33.8%	51.7%	17.9%	764,426	1,168,883	404,457	2,043,041	90.4%	37.4%	57.2%	19.8%
No literacy	0.8%	1.4%	0.6%	17,927	32,006	14,079	66,383	2.9%	27.0%	48.2%	21.2%
N.A.	1.6%	2.7%	1.1%	36,401	61,180	24,779	121,140	5.4%	30.0%	50.5%	20.5%
N.D.	0.6%	0.8%	0.2%	13,228	18,251	5,023	28,259	1.3%	46.8%	64.6%	17.8%
Gender/Sex											
Female	19.9%	30.5%	10.6%	449,188	688,160	238,972	1,208,617	53.5%	37.2%	56.9%	19.8%
Male	16.9%	26.2%	9.3%	382,794	592,160	209,366	1,050,206	46.5%	36.4%	56.4%	19.9%
Civil status											
Single	13.4%	20.7%	7.3%	303,645	468,447	164,802	821,536	36.4%	37.0%	57.0%	20.1%
Married or cohabitation	14.6%	22.6%	7.9%	330,460	509,814	179,354	896,958	39.7%	36.8%	56.8%	20.0%
Divorced or separated	2.9%	4.2%	1.3%	65,978	95,928	29,950	163,980	7.3%	40.2%	58.5%	18.3%
Widow	1.9%	2.6%	0.8%	42,743	59,804	17,061	95,611	4.2%	44.7%	62.5%	17.8%
N.A.	3.4%	5.7%	2.3%	76,821	129,370	52,549	254,492	11.3%	30.2%	50.8%	20.6%
N.D.	0.5%	0.8%	0.2%	12,335	16,957	4,622	26,246	1.2%	47.0%	64.6%	17.6%
Age											
0-4	1.6%	50.5%	48.9%	36,401	61,180	24,779	121,140	5.4%	30.0%	50.5%	20.5%
0-14	5.4%	50.9%	45.6%	121,111	204,055	82,944	400,527	17.7%	30.2%	50.9%	20.7%
5-14	3.8%	51.1%	47.4%	84,710	142,875	58,165	279,387	12.4%	30.3%	51.1%	20.8%
15-24	5.3%	53.9%	48.6%	120,001	195,693	75,692	363,311	16.1%	33.0%	53.9%	20.8%
15-59	23.8%	56.4%	32.7%	536,754	836,078	299,324	1,482,069	65.6%	36.2%	56.4%	20.2%
15-64	25.9%	56.7%	30.8%	585,558	904,942	319,384	1,595,016	70.6%	36.7%	56.7%	20.0%
60+	7.7%	63.8%	56.1%	174,117	240,187	66,070	376,227	16.7%	46.3%	63.8%	17.6%
65+	5.5%	65.1%	59.5%	125,313	171,323	46,010	263,280	11.7%	47.6%	65.1%	17.5%
80+	1.5%	69.0%	67.6%	33,380	44,248	10,868	64,100	2.8%	52.1%	69.0%	17.0%
	36.8%	56.7%	19.8%	831,982	1,280,320	448,338	2,258,823				

Limitations

The AMORE Platform used data modelling and clustering to estimate travel times between the origin and destination TAZ, lowering the cost of using big data and still delivering accessibility. Operational costs are thus low, and platform updates for monitoring and evaluation are affordable. The trade-off for affordability is imprecisions in estimates. These imprecisions are more likely to affect populations living near the 15-minute threshold and those further away from TAZ centroids with heavy traffic congestion. However, these imprecisions are unlikely to change the overall urban assessment.

Predicted travel times from the Google Distance Matrix API are accurate and are fed by big data from smartphones. Other databases, such as Waze Transport SDK API, can be used to generate estimates, but these providers do not release prediction algorithms. It is thus impossible to know the magnitude and variations introduced by unforeseen events, like pandemic-related restrictions, and to estimate the impact of resulting errors or biases on estimates.

Colombian law requires hospitals to treat patients in emergencies. Modelling for this study assumed that people would resort to the hospital with the shortest travel time. But people may go to a different hospital if they know it better, their insurer recommends it or it has a good reputation. Our estimates are thus likely optimistic.

While choropleth maps allow users to explore the travel times from a specific TAZ, panels do not reflect that a origin of a journey will not always be the place of residence. This limitation will spread differently at different times and for diverse populations.

The relevance of our findings could change if the registered tertiary care facilities changed in REPS (i.e., a new institution opens, or an existing institution is reclassified as tertiary, changing the results). The interactive platform allows for prompt updates and reanalysis in response to these contingencies.

Interpretation

The AMORE Platform reveals accessibility and its health equity implications, providing new dynamic data that accounts for the effects of traffic. It does so more precisely and at a fraction of the costs of household surveys and origin-destination studies, providing a new tool to inform service plans, programs, and policies.

Integrating publicly available data from public sources might be a breakthrough that improves evidence-informed decisions regarding the location and provision of health services. Visualisations might help stakeholders interpret the data and agree on a common objective and metric: painting the city green by covering its entire population and offering equitable accessibility to all people.

Updating the AMORE Platform is cheaper and faster than updating other origin-destination studies; its assessments are granular and sensitive to variations and can be used to monitor and evaluate changes. In emergencies such as earthquakes, a modified platform could provide a prompt situation analysis by feeding real-time data downloads rather than predictions.

These findings suggest that with congested traffic in peak hours, most Cali residents (63%) are beyond the 15-minute travel-time threshold by car to the nearest tertiary care emergency department. However, this figure fell to 43% when traffic congestion eased.

Reduced accessibility is unevenly distributed and reflects the inverse care law: people who live in low-income households or have less education face longer journeys to tertiary care emergency departments. Incidentally, heavy traffic also affects people on the periphery of Cali, including some high-income households, as congestion clogs roads they use to reach tertiary emergency care facilities.

Accessibility is one of many potential access barriers to health services and a critical one. Other factors that affect access to health care (e.g., rights, quality, or supplies) are meaningless if patients cannot reach tertiary emergency care in a crisis. Additional barriers to accessing health services (such as non-compliance with Colombian law, quality, and institutional and reputation) are beyond the scope of this study and merit consideration.

Researchers and planners can use data mining to optimise new tertiary care emergency services locations that maximise accessibility. Data mining could inform which existing institutions should be prioritised for an upgrade to improve accessibility or point at the optimal location for new ones, thus informing sound choices. These data are unique and provide an opportunity to enhance health services planning. Stakeholders and health equity advocates should encourage the integration of accessibility considerations in urban planning processes.

Planners and service providers wishing to combat social injustices must examine this new evidence that distance and congestion combine to exclude the most vulnerable and socioeconomically disadvantaged from critical health services. Planners and service providers must then consider bringing services closer to these populations. This new evidence and approach raise opportunities to address inequities, improve indicators, and engage stakeholders in urban planning. Future studies will examine the impact of this approach. This evidence supports planning using travel time and monitoring accessibility and equity when assessing the quality of health services.[45–47]

This situational analysis is insufficient to drive change. Integrating evidence about accessibility and equity into stakeholder and intersectoral dialogues, decision-making processes and other strategies that seek the social appropriation of knowledge by stakeholders and sectors might be catalysts for implementation.[33,48]

This report is part of the broader AMORE Project. Future reports will explore the potential of optimising the location of up to two new emergency departments. Future studies will assess the use and appropriation of data, and the advocacy of stakeholders, including those in the AMORE Project Collaborative Group.[10,49]

Interactive platforms can help decision-makers explore different assumptions and myriads of other results of combining different thresholds and traffic levels, allowing data to speak for itself.[50,51]

Looking ahead, identifying and proposing public policy plans and partnerships could improve health equity and bring hope to residents of Cali. These measures could also reduce social injustices, including the burden of the inverse care law that vulnerable populations pay more to access essential health services.[4,52,53]

Generalisability and applicability

This study is reproducible in other settings with dynamic travel-time data (e.g., Waze or Google Maps) and georeferenced service and population data that make situational analyses accessible. Information accuracy depends on the accuracy of sources, the modelling used to conduct searches and maintaining data that is affordable and easy to interpret.

Travel times, infrastructure and populations change. Travel times and census data may thus need to be updated, and traffic clusters may need to be adjusted.

The proposed approach highlights the dynamic nature of travel times and uses TAZs to offer a granular assessment of the city. The scale of these assessments is suitable for informing short or long-term policies and plans and can be periodically revised as conditions change.

Other information

These results test an approach to provide a situational analysis. Defining potential improvements by adding services and using data by decision-makers and other stakeholders are part of the broader AMORE Project and the subject of future reports. Travel time is a continuous variable and could be the subject of myriad analyses beyond the purpose of this study. Our aim is to demonstrate the possibility of conducting an affordable situational analysis with existing data providing information that decision-makers and other stakeholders might use; something to be assessed in future studies.

The web-based platform allows users to change assumptions or variables, explore different scenarios or perform sensitivity analyses. The possibilities are numerous and include expanding the study with more bivariate and multivariate analyses that go beyond the objectives of this report.

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Ethical considerations

This observational study on quality improvement for health services planning does not research human subjects. It integrates anonymised coded secondary data sources obtained from publicly available open records.[54,55] This study has not been subject to ethical review. No identifiable private information was used in the study. Oversight of the project has been provided by the Doctoral Programme on Methodology of Biomedical Research and Public Health at the Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine at the Universitat Autònoma de Barcelona. Contributors to this study are members of the AMORE Project Collaborative Group and public servants in their official capacity; they are listed in the acknowledgements.

Contributions and acknowledgements

Authors and contributors

The corresponding author and principal investigator, Luis Gabriel Cuervo, led the project and manuscript writing and conceptualised the study with support from Daniel Cuervo and Ciro Jaramillo. Substantive additional contributions and editing of the report were provided by (in alphabetical order): María Olga Bula, Daniel Cuervo, Janet Hatcher-Roberts, Ciro Jaramillo Molina, Eliana Martínez-Herrera, Luis Fernando Pinilla, Felipe Piquero, and Lyda Osorio. All members of the AMORE Project Collaboration listed in Table 4 provided comments, conceptual contributions, or consumer perspectives. Those listed approved the manuscript, declared they stood by this research report and approved being recognised as members of the AMORE Project Collaboration.

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Dynamic accessibility by car to tertiary care emergency services in Cali, Colombia, in 2020: cross-sectional equity analyses using travel-time big data from a Google API

Table 4 Contributions by Members of the AMORE Project Collaboration approving the manuscript

Surname	Given name	Draft writing	Revision & comments	Conceptual contributions	User perspectives	Stands by manuscript	Approved final version
Agredo Lemos	Freddy Enrique		●	●	●	●	●
Avila Rodriguez	German				●	●	●
Bula	María Olga	●	●	●	●	●	●
				●	●	●	●
Cuervo	Daniel	●	●	●		●	●
Cuervo	Luis Gabriel	●	●	●		●	●
Franco	Oscar			●		●	●
Garcia	Crhistian			●	●	●	●
Guerrero	Rodrigo		●	●	●	●	●
Hatcher-Roberts	Janet	●	●	●		●	●
Jaramillo	Ciro	●	●	●	●	●	●
Martínez Arámbula	Fernando Rafael			●		●	●
Martínez Herrera	Eliana	●	●	●	●	●	●
Merino Juarez	Maria Fernanda		●	●		●	●
Osorio	Lyda		●	●	●	●	●
Ospina	Maria B			●	●	●	●
Paredes	Gabriel	●		●		●	●
Paredes-Zapata	David		●	●	●	●	●
Pinilla	Luis Fernando	●	●	●	●	●	●
Piquero	Felipe	●	●		●	●	●
Rojas	Oscar		●		●	●	●
Rosero Hernández	Myriam			●		●	●
Tobar-Blandón	Maria Fernanda		●		●	●	●
Zapata Murillo	Pablo			●		●	●

Competing interests

All authors have completed the ICMJE uniform disclosure form and declare: no financial support from any organisation for the submitted work; IQuartil SAS provided technical support to develop the AMORE Platform and was subsidised by the PI (LGC) for consulting services; DC is a partner at IQuartil SAS and a sibling to LGC. LFP gave technical support at IQuartil SAS until March 2021.

LGC contributed to this work in his personal capacity and time. The views expressed in this article do not necessarily represent the decisions or policies of his employer, PAHO/WHO. Reproductions of this article should not include any suggestion that PAHO/WHO endorsed this research or is endorsing any specific organisation, services, or products.
COI Declaration by other members of the AMORE Project Collaborative Group signing off the manuscript: FRMA is an engineer on roads and transportation who participated in his personal capacity and time; his contributions do not necessarily reflect the policies or decisions of his employer, the Municipality of Santiago de Cali. MFMJ participated in her personal capacity and time, and her contributions do not necessarily reflect the policies or decisions of her employer. PZM is a consultant at IQuartil SAS.

Data availability statement

The data sources used in this study are in the public domain. The links to the sources are provided (see Study design), and the data constitutes a negligible risk to confidentiality; Colombia's census microdata was anonymised at the source. Neither Google Maps Distance Matrix API nor REPS include personal information (see Ethical considerations). Data from the AMORE Platform relevant to this publication will be made available after the publication of this manuscript at https://www.iquartil.net/proyectoAMORE/.

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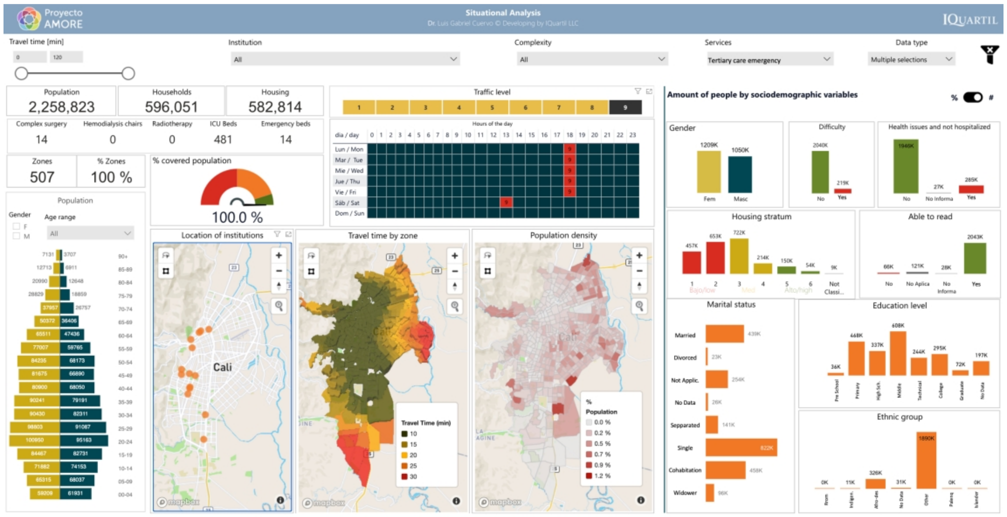


Proyecto AMORE

Situational Analysis

Dr. Luis Gabriel Cuervo © Developing by IQuartil LLC

IQUARTIL

Travel time [min]: 0 – 120

Institution: All

Complexity: All

Services: Tertiary care emergency

Data type: Multiple selections

Population: 2,258,823

Households: 596,051

Housing: 582,814

Complex surgery: 14

Hemodialysis chairs: 0

Radiotherapy: 0

ICU Beds: 481

Emergency beds: 14

Zones: 507

% Zones: 100 %

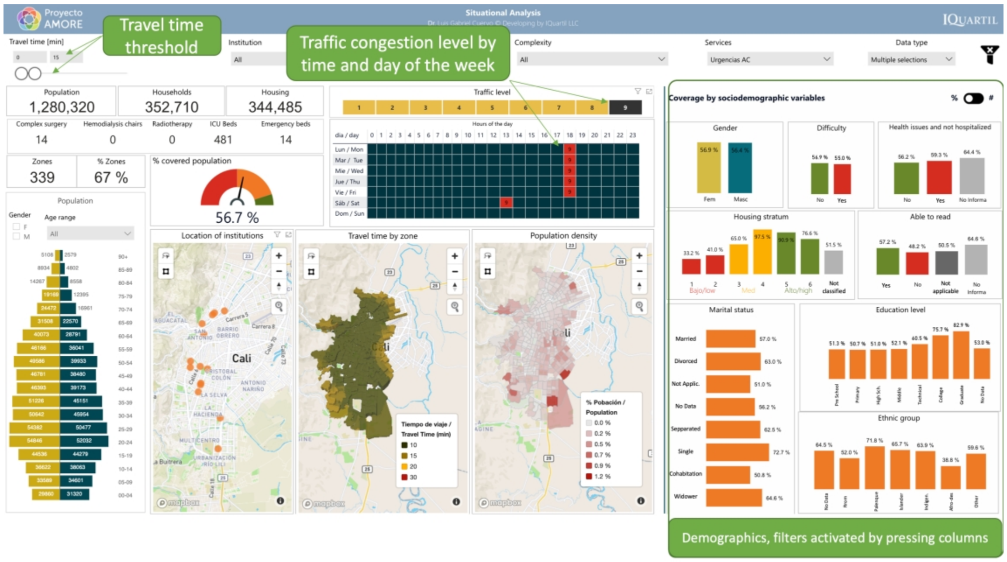
% covered population: 100.0 %

Gender: ☐ F ☐ M

Age range: All

Figure 1, AMORE Platform situational analysis

338x190mm (222 x 222 DPI)



Travel time threshold

Traffic congestion level by time and day of the week

Demographics, filters activated by pressing columns

Figure 2, Situational analysis, filters and visualizations, Nov 2020

338x190mm (222 x 222 DPI)

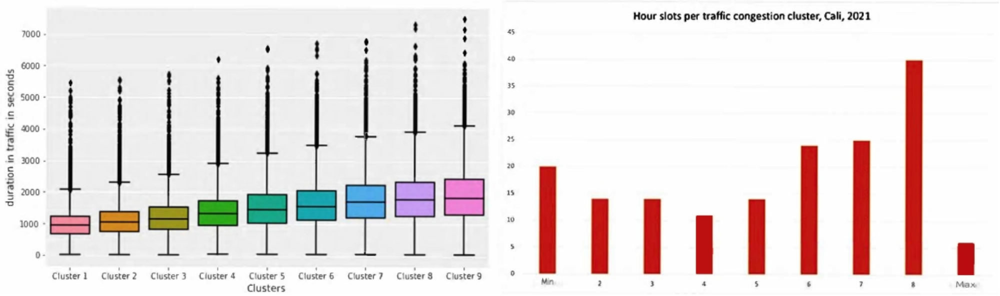


Figure 3, Travel-time clusters from free flow to peak traffic, by time and day

337x99mm (221 x 222 DPI)

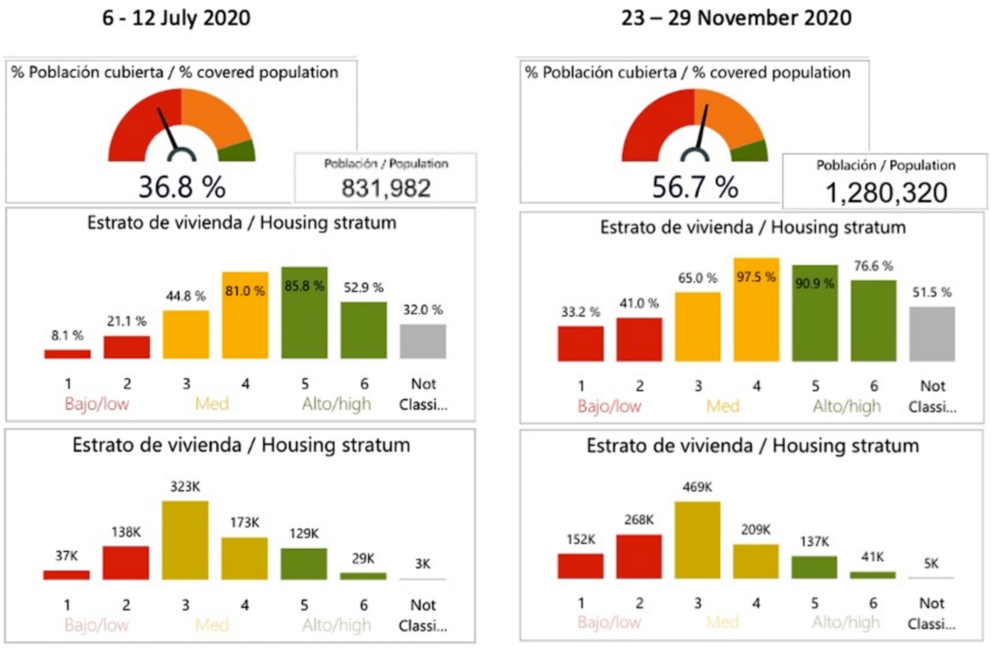


Figure 4, Accessibility by income to tertiary care comparing July and November 2020

284x186mm (222 x 222 DPI)

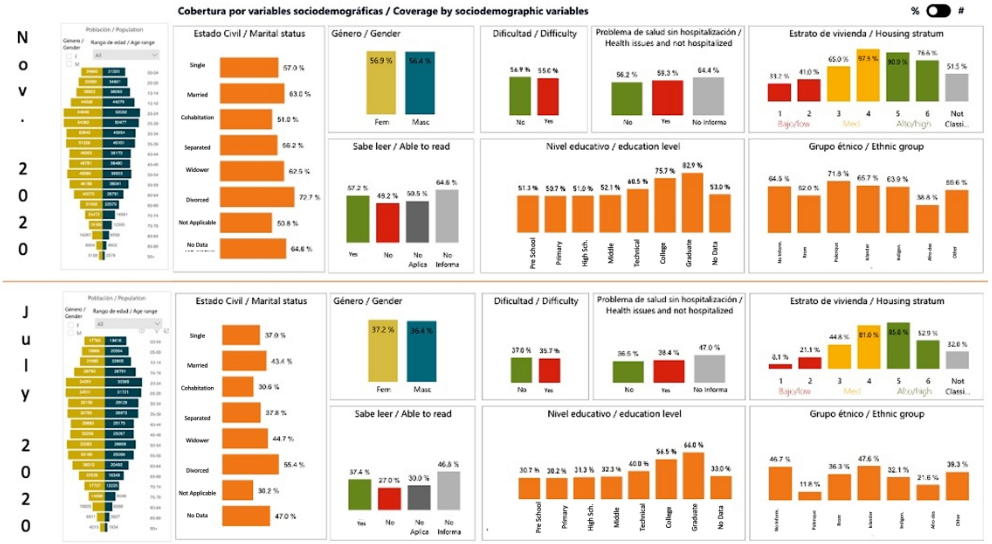


Figure 5, Accessibility by sociodemographic characteristics in July and November 2020

338x190mm (222 x 222 DPI)

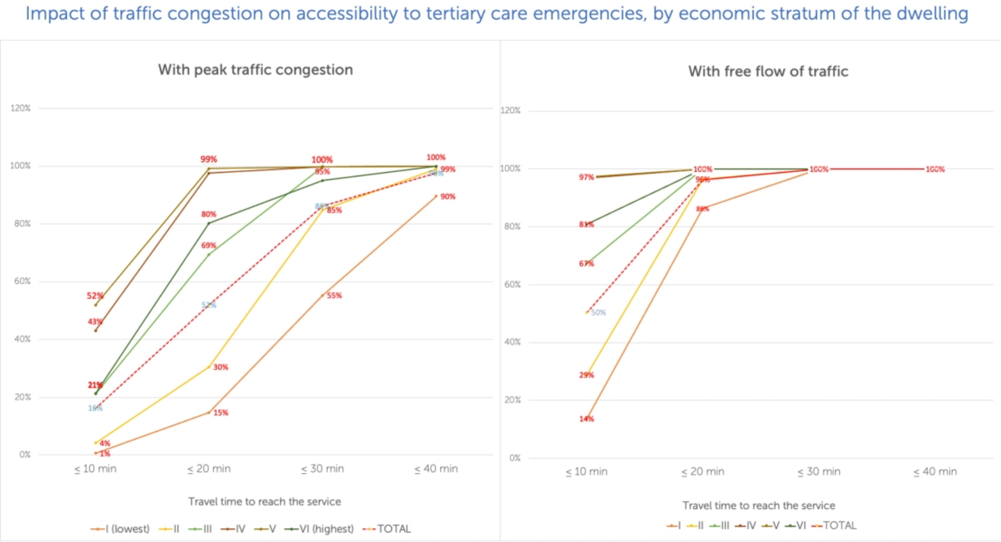


Figure 6 Impact of traffic congestion on accessibility, by economic stratum, July 2020

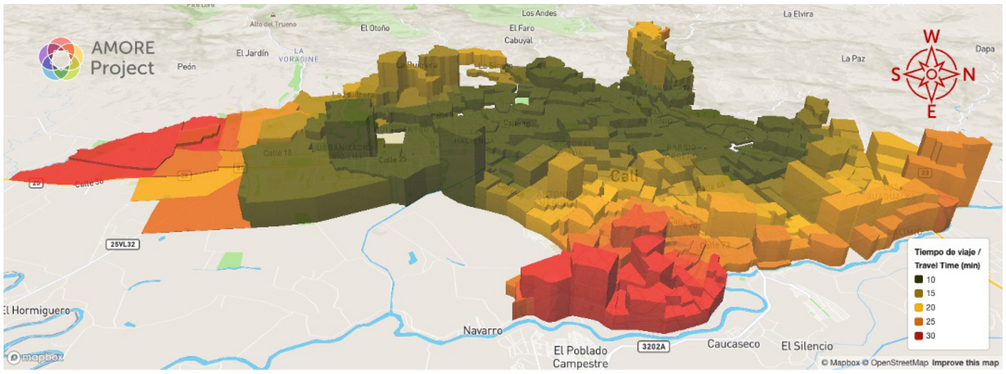
338x190mm (300 x 300 DPI)

Figure 7, Location of the Palenque people

188x314mm (72 x 72 DPI)

Institution
Centro Médico Imbanaco
Clínica Amiga
Clínica Colombia ES
Clínica Colsanitas S.A. Sebastián de Belalcazar
Clínica de Occidente
Cínica Esensa
Clínica Farallones S.A.
Clinica Nuestra
Clínica Nuestra Señora de los Remedios
Clínica Nueva de Cali SAS Sede La Quinta
Clínica Rey David
DIME Clínica Neurocardiovascular S.A.
Hospital Universitario del Valle Evaristo García E.S.E.
Fundación Valle de Lilí

228x168mm (81 x 81 DPI)



338x123mm (81 x 81 DPI)

879x320mm (72 x 72 DPI)

Cross-sectional equity analysis of accessibility by automobile to tertiary care emergency services in Cali, Colombia in 2020

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	4
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	3, 8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7, 10, 13
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6, 10
		(*b*) Describe any methods used to examine subgroups and interactions	6, 10
		(*c*) Explain how missing data were addressed	7, 10, 13
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed	13
		(b) Give reasons for non-participation at each stage	8
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders	13
		(b) Indicate number of participants with missing data for each variable of interest	13
Outcome data	15*	Report numbers of outcome events or summary measures	8-13

Cross-sectional equity analysis of accessibility by automobile to tertiary care emergency services in Cali, Colombia in 2020

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included	13
		(*b*) Report category boundaries when continuous variables were categorized	7, 13
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	10
Discussion			
Key results	18	Summarize key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14
Generalizability	21	Discuss the generalizability (external validity) of the study results	16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for exposed and unexposed groups.

Dynamic accessibility by car to tertiary care emergency services in Cali, Colombia, in 2020: cross-sectional equity analyses using travel-time big data from a Google API

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Complete List of Authors:	Cuervo, Luis Gabriel; Universitat Autònoma de Barcelona, Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine Martinez-Herrera, Eliana; Universidad de Antioquia, Facultad Nacional de Salud Pública Osorio, Lyda; Universidad del Valle Facultad de Salud, Escuela de Salud Pública Hatcher-Roberts, Janet; University of Ottawa Faculty of Medicine, School of Epidemiology and Public Health; Bruyere Research Institute Cuervo, Daniel; IQuartil SAS Bula, Maria Olga; Egis Consulting Pinilla, Luis Fernando; Universidad de La Sabana, Correct email is LuisFerPinilla@gmail.com (system does not allow fixing it) Piquero, Felipe; Consumer advocate; Author of "Opportunities Amidst Uncertainty: My life with one kidney and without it", Published in English and Spanish Jaramillo, Ciro; Universidad del Valle, School of Civil and Geomatic Engineering Collaborative Group, AMORE Project; AMORE Project Collaborative Group; Universitat Autonoma de Barcelona
Primary Subject Heading:	Health services research
Secondary Subject Heading:	Public health, Health services research, Health policy, Global health
Keywords:	Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, ACCIDENT & EMERGENCY MEDICINE, Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Organisation of health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PUBLIC HEALTH, HEALTH SERVICES ADMINISTRATION & MANAGEMENT

Dynamic accessibility by car to tertiary care emergency services in Cali, Colombia, in 2020: cross-sectional equity analyses using travel-time big data from a Google API

Luis Gabriel Cuervo,(1) Eliana Martinez Herrera,(2) Lyda Osorio,(3) Janet Hatcher Roberts,(4) Daniel Cuervo,(5) María Olga Bula,(6) Luis Fernando Pinilla,(7) Felipe Piquero,(8) Ciro Jaramillo,(9) on behalf of the AMORE Project Collaboration

(1) Luis Gabriel Cuervo, Universitat Autònoma de Barcelona, Spain
(2) National School of Public Health, Universidad de Antioquia, Medellín, Colombia
(3) Faculty, School of Public Health, Universidad del Valle, Colombia.
(4) Brùyere Research Institute and Adjunct School of Epidemiology and Public Health, University of Ottawa.
(5) Partner at IQuartil SAS. Industrial Engineer, MBA, Certified Data Analyst.
(6) MSc in urban planning, Egis Consulting.
(7) Universidad de la Sabana. Lecturer in the Operations Management Specialization.
(8) Attorney in administrative law and healthcare legislation. Consumer advocate and book author
(9) Associate Professor in the School of Civil and Geomatic Engineering, Universidad del Valle, Colombia; PhD thesis director, Universitat Autònoma de Barcelona.

Correspondence to: Luis Gabriel Cuervo, Universitat Autònoma de Barcelona, Spain
LuisGabriel.Cuervo@autonoma.cat

Abstract

Objectives: To test a new approach to characterise accessibility to tertiary care emergency health services in urban Cali and assess the links between accessibility and sociodemographic factors relevant to health equity.

Design: The impact of traffic congestion on accessibility to tertiary care emergency departments was studied with an equity perspective, using a web-based digital platform that integrated publicly available digital data, including sociodemographic characteristics of the population and places of residence with travel times.

Setting and participants: Cali, Colombia (population 2.258 million in 2020) using geographic and sociodemographic data. The study used predicted travel times downloaded for a week in July 2020 and a week in November 2020.

Primary and secondary outcomes: The share of the population within a 15-minute journey by car from the place of residence to the tertiary care emergency department with the shortest journey (i.e., 15-minute accessibility rate; 15mAR) at peak-traffic congestion hours. Sociodemographic characteristics were disaggregated for equity analyses. A time-series bivariate analysis explored accessibility rates versus housing stratification.

Results: Traffic congestion sharply reduces accessibility to tertiary emergency care (e.g., 15mAR was 36.8% during peak-traffic hours vs 84.4% during free-flow hours for the week of July 6 – 12, 2020). Traffic congestion sharply reduces accessibility to tertiary emergency care. The greatest impact fell on specific ethnic groups, people with less educational attainment, and those living in low-income households or on the periphery of Cali (15mAR: 8.1% peak traffic vs 51% free-flow traffic). These populations face longer average travel times to health services than the average population.

Conclusions: These findings suggest that health services and land use planning should prioritise travel times over travel distance and integrate them into urban planning. Existing technology and data can reveal inequities by integrating sociodemographic data with accurate travel times to health services estimates, providing the basis for valuable indicators.

Strengths and limitations of this study

- Our study investigated affordably measured dynamic accessibility to tertiary care emergency services for the entire population using massive amounts of measurements and provides an equity perspective.
- The platform was developed using a person-centred design; it communicates findings using basic descriptive statistics, graphics, and cartography.
- Travel times account for traffic congestion and are a proxy for travel costs (i.e., distance, cost, time).
- Sources used to measure travel times are empirically known to be accurate, but variations of their precision across sectors and populations, like the algorithms behind the measurements, are unknown.
- Models need to be retrained if conditions change ostensibly.

Introduction

Background and rationale

Every minute counts in life-threatening emergencies that do not leave time for referrals (e.g., insufficient tissue oxygenation, critical bleeding, significant tissue damage, poisoning). The well-being of patients depends on getting immediate attention in a tertiary care facility that offers essential subspecialised care by highly skilled personnel and sophisticated facilities, including specialised surgical theatres and intensive care units.

This study tests a new approach that allows stakeholders to explore different assumptions and scenarios. For example, different time-to-destination thresholds, traffic congestion levels, or accessibility for the whole or parts of the population.

The study delivers baselines for accessibility by car (automobile) to tertiary care emergency departments in Cali, Colombia. It assesses the impact of traffic congestion on accessibility and health equity, using a car (private or for-hire) as the means of transportation because it is how Cali residents typically reach tertiary care facilities in emergencies. This approach also makes it possible for future studies to analyse accessibility with other means of transportation or under different assumptions.

Accessibility is a dynamic spatial attribute measured as the travel time needed to reach a health service location (destination) from the origin of the demand (place of residence in this study).[1–8] Travel times fluctuate over time and with traffic congestion. Accessibility has been challenging to study and monitor, and poor accessibility can be detrimental to health equity.[4,8–10]

Traditional assessments of accessibility in urban planning seldom consider its dynamic nature; origin-destination studies and surveys usually lack a dynamic assessment showing the effects of infrastructure, population changes, or traffic on accessibility and health equity.[11,12]

Traditional assessments are onerous, done every five to ten years, using lengthy surveys that lack the specificity of health services and the geographical granularity of Traffic Analysis Zones, or TAZs (instead of more expansive neighbourhoods or communes). The conditions assessed may have changed when results become public, rendering any proposed solutions irrelevant.[8,13] This study explores an approach that addresses critical limitations of traditional accessibility assessments to expose the links between equity and accessibility to tertiary care emergency services.[10]

Innovative approaches using accessible web-based platforms are an opportunity for evidence-informed decision-making and planning to improve health coverage. These platforms allow stakeholders to test assumptions and reach conclusions and capitalise on features such as big data from smartphones that can provide accurate travel-time estimates. Therefore, dynamic, affordable, and updatable assessments that account for traffic congestion could be used, thus focusing on travel times instead of travel distances.[5,8,12,14–17] They might allow stakeholders to explore data, test assumptions better, and reach action-oriented conclusions.[18] This study integrates the equity-relevant data we used to perform equity analyses.

Objectives

This study aims to characterise accessibility to tertiary care emergency health services in urban Cali and the links between accessibility and sociodemographic factors relevant to health equity.

Methods

Study population and setting

This study is about emergencies requiring attention in tertiary care institutions. By early July 2020, COVID-19 pandemic-related quarantine and stay-at-home orders had been lifted, and traffic projections showed substantial congestion. By November 2020, some measures had been reinstated, car travel was restricted by license number, and traffic projections showed reduced travel times, especially in central city areas.[19–21]

This cross-sectional study was conducted with data downloads for the urban area of Cali, the third-largest city in Colombia and the largest urban centre in the southwest and Pacific regions, with an estimated 2.258 million residents in 2020. About half of the population lives in low-income housing, 42% in middle-income housing, and 8% in high-income housing. Housing stratification does not necessarily represent the income of individuals.[22,23]

About 84% of the population identifies as white, 14% as Afro-Colombian and a small proportion as indigenous or nomadic people like the Rrom. In December 2020, unemployment rates in Cali were 26.7% for women and 18.5% for men, a one-year increase of 12.5% and 8.8%, respectively.

The situation was worse among young people, and an estimated 52% of women and 47.2% of men relied on the informal economy. The COVID-19 pandemic punished the local economy. While 1 in 5 people was unemployed, the rates were higher among people in low-income households. From 2016 to 2020, Cali also absorbed 139,000 migrants from Venezuela; 25,000 in 2020.[24]

Poverty, inequity, and discrimination drove social unrest that led to violence after a 2021 national strike.[25,26]

The city government is dividing its 22 communes into six to eight districts, which might lead to negotiations over resources and issues such as access to essential services.[27,28]

Targeted sites and participants

The study targeted the 14 tertiary care institutions with emergency departments registered in the Ministry of Health Special Registry of Health Services Providers (REPS in Spanish). The registry listed the same institutions in July 2020 and January 2021; all provided surgery and intensive care services. Those institutions are listed in Supplemental File 1.[29]

Study design

This study includes two cross-sectional analyses integrating publicly available data using digital technologies and analytics. The study generated new knowledge of potential value when implementing evidence-informed approaches to improve accessibility and health equity. The study used updatable data to measure travel times and evaluate the effects of interventions and changes to infrastructure, service provision, traffic congestion, and population. The following study methods seek to address current challenges for assessments of accessibility to health services:[10]

- Dynamic assessments of travel times to account for traffic variations.

- Inputs from diverse stakeholders to create an interactive platform that displays intersectoral data on dashboards so stakeholders can interpret data quickly and accurately.
- Disaggregated data to enable straightforward equity analysis of accessibility.
- Situational analysis of the accessibility to specific services for urban areas.
- An approach suitable for monitoring health equity related to accessibility.

The data for the cross-sectional analyses were obtained from the internet-based AMORE Platform (https://www.iquartil.net/proyectoAMORE), hosted by iQuartil SAS, an analytics company, and developed under the leadership of the Principal Investigator (LGC).

The AMORE Platform integrates data from:

- 2018 National Census Data for Cali, obtained from the official public databases of the Colombian National Department of Statistics (DANE in Spanish).[22,23]
- The administrative divisions of Cali were obtained from the Colombian IDESC Geoportal; Traffic Analysis Zones (TAZ) were matched to the census blocks.[13,30] The origin for each journey is the population-weighted centroid for the TAZ of the place of residence. Similarly, the destination is the centroid for the TAZ hosting the tertiary care emergency department with the shortest travel time.
- Google Distance Matrix API. For this baseline assessment of the Cali urban area, predicted travel times were downloaded on 3 July 2020 for the week of 6 – 12 July 2020, and on 27 October 2020, for the week of 23 – 29 November 2020. Travel times varied substantially during the COVID-19 pandemic and while it is unclear how this influenced Google Distance Matrix algorithms,[31] empirical and anecdotal reports suggest they remained accurate.
- The 14 tertiary care institutions with an emergency department in Cali were identified using REPS.[29]

Databases were integrated and tested between August 2020 and October 2021 using: KNIME® open-source data analytics reporting and integration platform, Python™ programming language software (back end), and an interface (front end) developed with interactive data visualisation software Microsoft PowerBi™.

Patient and public involvement

The AMORE Project Collaborative Group is diverse, with over two-dozen contributors representing different stakeholders and sectors. Group members participated throughout the design, conduct, and reporting of this study and the dissemination of results. The contributors and some public servants participated in the co-creation of knowledge and are listed in the Acknowledgments. These collaborators offer different governance perspectives: authorities, service providers, service users, and organised civil society, including academics, advocates, and experts from various fields of knowledge.[32,33]

Data integration and output

The AMORE Platform dashboards and visualisations provide descriptive indicators using simple maps, dials, bars, and data. These indicators show travel times using the shortest journeys and descriptive statistics for each urban TAZ at a given traffic congestion level. The displays for July and November can be accessed on this project website. The AMORE Platform allows users to perform equity analyses by disaggregating sociodemographic characteristics.[34] The top section of the Platform (**Figure 1**) has nine traffic-congestion clusters and their representation in the week. A dial shows the share of the population within the set travel-time threshold.

The middle section displays a population pyramid and maps the 14 tertiary care emergency departments, travel times, and population density (**Figure 1**). Each section of the pyramid or map can be toggled to filter populations. The choropleth maps can be expanded and rotated for a 3D display, with TAZ height representing population density (**Supplemental File 2**). Selecting a TAZ displays its ID, population, and travel time.

Choropleth maps consist of TAZs established by MetroCali (Integrated Mass Transit System) in 2015 for the urban area and linked to the geotagged census block information, matching the population with these TAZs.[13] The geometric matching of blocks and TAZs yielded 507 inhabited TAZs within the urban perimeter. The origin-destination times were estimated from the population-adjusted geographic centroid of each TAZ to the respective centroid where each institution was located.

The Colombian census was completed through interviews with an adult for each household. Data was stored, linking it to a city block code to anonymise it. The AMORE Platform used the census microdata categorisations and, for a few variables, aggregate groups for simplification (e.g., education was simplified with guidance from an expert in the Colombian education system, Psychologist Myriam Lorena Rosero Hernández, ME).

In 2019, DANE recommended adjusting the 2018 population of Cali upward by 18% from the original census data due to under-registration.[23,35] DANE advised making further adjustments due to intercensal growth, migration and updates.[24,36] These adjustments amounted to 28.1%, and DANE did not disaggregate the adjustment data. Therefore, 495,219 records were randomly selected and duplicated, reaching a population of 2,258,823 inhabitants, keeping the distributions. These are displayed in the AMORE Platform by toggling the census adjustment (**Figure 1**, “Data type”).

The right section of the platform displays sociodemographic characteristics (**Figure 1**).

The AMORE Platform displays the absolute and relative figures for the georeferenced data of inhabitants, both for the city or selected TAZs within a travel schedule **Error! Reference source not found.**. The variables integrated into the platform are listed in Table 1.

Data sources and measurements

Table 1. Census data included in the AMORE Platform dashboards and maps

Geotagged variables	Platform display
Age in completed years grouped by quinquennium (census)	Population density per TAZ
Ethnicity, self-described	Health service: tertiary care emergency departments
Health status (Sick / Healthy)	Absolute and relative figures of modified aggregation
Highest education level attained	Travel-time thresholds (slider + choropleth heatmap)
Literacy	Travel times and population per TAZ
Marital status	Overall accessibility for filtered population
Population pyramid by gender and age	
Report of disability / physical condition	
School attendance	
Household inhabitants	
Housing inhabitants	
Housing socio-economic stratum	
Housing type	

We used the controls listed in Table 2 to conduct univariate and bivariate analyses.

Table 2. AMORE Platform displays resulting from integrating travel times, services, origin TAZ, and census data

Variables that change according to traffic, travel-time threshold, and other filters
Travel-time threshold filter for the analysis.
Drop-down list with institutions that can be toggled for inactivation.
Drop-down list to select people registered by the census, the 28.1% adjustment, or the adjusted census data.
Traffic levels identified with a K-means clustering algorithm.
Absolute and relative figures provided for each variable.
Maps are organized by TAZs.
Intensive care beds data for selected institutions taken from REPS.
People with accessibility for a selected time threshold and traffic level.
Blocks with accessibility for a selected time threshold.
TAZs within the time threshold by level of traffic.
Household inhabitants
Housing inhabitants
Housing by power bill economic stratum

Bias

Each source is susceptible to biases and imprecision, but these are unlikely to be of a magnitude that would change conclusions. Some of the data sources and the timing of their updates can introduce bias. For example, the census is updated every five years. Since the last census in 2018, there has been a significant flow of migrants to Cali and job losses rose during the COVID-19 pandemic.[24,37] These developments likely make our results appear more favourable than they are. The census had under-registration from failed or incomplete visits, underreporting of people living in households, or people absent in each of the three times registrars visited. The estimates for migrants and intercensal growth are broad and likely unevenly distributed among the population and no precise measurement errors are available.[23,24]

Traffic patterns may have changed with the imposition and lifting of pandemic-related restrictions, thus altering traffic predictions. Stay-at-home orders and traffic restrictions may have changed traffic congestion, causing unusual and uneven patterns of accessibility. Google Distance Matrix API may have more accurate travel times for areas where more people travel with mobile phones and in cars.

Income categorisation is determined by the individual household electricity bill, which is graded from 1 to 6, with 6 representing the highest-income households. Some homes may have been misclassified (e.g., due to error or corruption) and that low-income people are living in higher-income households. This is possible for relatives and domestic workers residing in high-income housing and earning minimum wages or having no income. This kind of misclassification would introduce some bias that would overrepresent high-income populations.

The Colombian census recognises ethnicity, but some people likely found it difficult to choose their ethnicity. The census lacks an option for residents of white or mestizo descent, two large groups not explicitly listed on the census. Similarly, people with multi-ethnic parents may find it challenging to choose one ethnic category.

Traffic restrictions linked to car license numbers affect households and neighbourhoods differently; more affluent families are more likely to own more cars and be less affected by these measures.[38]

To reduce data downloads, we performed a cluster analysis (using a K-means method) of the travel times on a sample of the total weekly hours. This allowed us to identify the hours of the week with similar traffic congestion levels by measuring the incremental changes against the minimum travel time. We determined that nine clusters allowed us to discriminate traffic congestion based on sensitivity analysis to represent the 168 hours of the week.

For each day and hour time band, we estimated the percentage difference between the minimum time of that trip and the travel for the time band. We calculated the average of this metric for all the journeys of the sample to obtain clusters. For example, the traffic from 6 to 7 p.m. on weekdays and from noon to 2 p.m. on Saturdays behaves similarly for this cluster, representing the highest traffic congestion. Creating these clusters again reduces information requirements and costs.

Using hourly assessments is arbitrary; travel times could be measured every minute or second. However, more frequent checks would increase costs (i.e., from data downloads, computing time, people time) by orders of magnitude without substantive changes in the conclusions.

More frequent checks would thus be impractical and of little value. Details of the effects of these optimisations will be the subject of a future manuscript.

Using congestion clusters and TAZs for the 14 institutions made it possible to obtain the city estimates with a sample of 1,159,536 measurements downloaded from Google Distance Matrix API. The geometric matching of blocks and TAZs yielded 507 inhabited TAZs in the urban perimeter.

Populations are not evenly distributed across TAZs. We therefore adjusted TAZ geographic centroids by weighing population distribution. Because centroids had irregular shapes, population-weighted centroids could end outside the boundaries of a TAZ. This required relocating the adjusted centroid to the nearest border, potentially generating some seconds of imprecision in estimates. Similarly, using the TAZ of a hospital instead of the location of the emergency department entrance also generates imprecisions.

Traffic patterns are not homogeneous within the city or its TAZs; traffic flow patterns vary in time and direction. We therefore sorted traffic times so that cluster nine always represented the maximum traffic congestion, cluster one the minimum traffic congestion, and intermediate clusters were sorted accordingly. **Error! Reference source not found.** illustrates the clusters and variations.

The definition of an acceptable travel-time threshold to reach a tertiary care emergency department is arbitrary, and we found no international standard. For this analysis, we chose a threshold of fifteen minutes at peak-traffic congestion times that was the most frequently considered by interviewed local public servants and members of the AMORE Project Collaborative; it is within the thresholds found in the literature.[39–41]

Notably, the distribution of traffic levels is skewed towards heavy congestion from Monday to Saturday between 6:00 and 22:00, with the mode being cluster 8 (40/168 hours, or 24% of the week); Cali is a congested city.

Results

Participants

The study included the adjusted population of 2,258,823 people, representing 596,051 households living in 582,814 housing units. The size and representation of populations are disaggregated in Table 3.

Most of the population is mestizo or white (83.7 %) or Afro-descendants (14.5%). Islanders and Rrom people represent less than 1% of the population. Absolute and relative figures disaggregated by sociodemographic characteristics are presented in Table 3.

Descriptive data

The analysis found that most of the low-income population could not reach the nearest tertiary care emergency department within 15 minutes during peak-traffic times, whether in November 2020 (81.4%) or July 2020 (96.3%; **Supplemental File 2** and **Supplemental File 3**, respectively).

The analysis also shows that accessibility is a substantial barrier to low-income households with high population density and those living in peripheral TAZs, amplifying inequities.

Main results

The effects of traffic disaggregated by household income level, ethnicity, gender and age, education level, and civil status are presented in **Error! Reference source not found.**, **Error! Reference source not found.**, and Table 3. **Error! Reference source not found.** shows differential accessibilities by housing stratum during peak and free-flow traffic hours, with the differential being more detrimental to the poorest and more affected by peak-traffic congestion.

Traffic variations and their effect (July vs November 2020)

6 – 12 July vs 23 – 29 November 2020

The July travel-time predictions pointed to 831,982 people (36.8%) living within 15 minutes of travel time from tertiary care emergency services, but this increased to 1.28 million (56.7%) in November. The distribution of accessibility when disaggregating data by income level indicated lower accessibility for the poor and those living in peripheral TAZs (**Error! Reference source not found.**, **Error! Reference source not found.**, and evident in **Supplemental File 2** and **Supplemental File 3** to those familiar with the demographic distribution of Cali). These populations also have a higher representation of minority ethnic groups and people with lower educational attainment.

Table 3 shows the data obtained from the AMORE Platform for the July 2020 and November 2020 assessments, which lets users explore equity considerations.

Other analyses

Error! Reference source not found. shows that people living in low-income households face longer travel times and are more severely impacted by traffic congestion; they thus invest more resources in accessing services.

Myriads of analyses can be done by modifying traffic congestion clusters, travel-time thresholds, or toggling population groups or institutions. For pragmatic reasons, this article focused on sticking to the 15-minute threshold and exploring accessibility at peak hours in more detail, which is a good scenario when planning for emergencies.

Palenque, Islanders, Rrom, and indigenous people represent 0.5% of the population of Cali. Minority ethnic groups benefitted the most from the reduction in traffic congestion. The noticeable improvement among the Palenque resulted from most living in the south-eastern neighbourhoods of El Morichal, El Retiro, El Vallado, and Ciudad Córdoba, which fell within the 15-minute threshold when traffic eased in November (see **Error! Reference source not found.**).

Table 3. Accessibility by auto within fifteen minutes to tertiary care in July and November, Cali 2020

15 min accessibility to the nearest tertiary care emergency service	Jul 2020 (%)	Nov 2020 (%)	Change	Jul 2020 (#)	Nov 2020 (#)	Change (#)	Total Population	%	Accessibility July	Accessibility November	Subgroup change
	36.8%	56.7%	19.8%	831,982	1,280,320	448,338	2,258,823		36.8%	56.7%	
Socio-economic stratum											
Low	7.7%	18.6%	10.8%	174,869	419,448	244,579	1,109,549	49.1%	15.8%	37.8%	22.0%
Middle	22.0%	30.0%	8.0%	496,558	677,967	181,409	935,699	41.4%	53.1%	72.5%	19.4%
High	7.0%	7.9%	0.9%	157,682	178,277	20,595	204,589	9.1%	77.1%	87.1%	10.1%
N.D.	0.1%	0.2%	0.1%	2,873	4,628	1,755	8,986	0.4%	32.0%	51.5%	19.5%
Ethnicity											
Afro descendent	3.1%	5.6%	2.5%	70,394	126,298	55,904	325,865	14.4%	21.6%	38.8%	17.2%
Rrom (nomadic)	0.0%	0.0%	0.0%	37	53	16	102	0.0%	36.3%	52.0%	15.7%
Indigenous	0.2%	0.3%	0.2%	3,571	7,103	3,532	11,112	0.5%	32.1%	63.9%	31.8%
Islander/Raizal	0.0%	0.0%	0.0%	182	251	69	382	0.0%	47.6%	65.7%	18.1%
Other (Caucasian, Mestizo)	32.9%	49.9%	17.0%	743,469	1,126,671	383,202	1,890,491	83.7%	39.3%	59.6%	20.3%
Palenque	0.0%	0.0%	0.0%	29	176	147	245	0.0%	11.8%	71.8%	60.0%
N.D.	0.6%	0.9%	0.2%	14,300	19,768	5,468	30,626	1.4%	46.7%	64.5%	17.9%
Educational level											
Graduate degree	2.1%	2.7%	0.5%	47,785	60,019	12,234	72,441	3.2%	66.0%	82.9%	16.9%
Bachelor's degree	7.4%	9.9%	2.5%	166,816	223,602	56,786	295,319	13.1%	56.5%	75.7%	19.2%
Technical	4.3%	6.5%	2.2%	97,733	147,634	49,901	244,160	10.8%	40.0%	60.5%	20.4%
Middle	8.7%	14.0%	5.3%	196,674	316,810	120,136	608,429	26.9%	32.3%	52.1%	19.7%
High School	4.7%	7.6%	2.9%	105,509	171,843	66,334	337,065	14.9%	31.3%	51.0%	19.7%
Primary	6.3%	10.5%	4.3%	141,309	237,344	96,035	468,206	20.7%	30.2%	50.7%	20.5%
Pre-school	0.5%	0.8%	0.3%	11,158	18,636	7,478	36,294	1.6%	30.7%	51.3%	20.6%
No data	2.9%	4.6%	1.7%	64,998	104,432	39,434	196,909	8.7%	33.0%	53.0%	20.0%
Literacy											
Literate	33.8%	51.7%	17.9%	764,426	1,168,883	404,457	2,043,041	90.4%	37.4%	57.2%	19.8%
No literacy	0.8%	1.4%	0.6%	17,927	32,006	14,079	66,383	2.9%	27.0%	48.2%	21.2%
N.A.	1.6%	2.7%	1.1%	36,401	61,180	24,779	121,140	5.4%	30.0%	50.5%	20.5%
N.D.	0.6%	0.8%	0.2%	13,228	18,251	5,023	28,259	1.3%	46.8%	64.6%	17.8%
Gender/Sex											
Female	19.9%	30.5%	10.6%	449,188	688,160	238,972	1,208,617	53.5%	37.2%	56.9%	19.8%
Male	16.9%	26.2%	9.3%	382,794	592,160	209,366	1,050,206	46.5%	36.4%	56.4%	19.9%
Civil status											
Single	13.4%	20.7%	7.3%	303,645	468,447	164,802	821,536	36.4%	37.0%	57.0%	20.1%
Married or cohabitation	14.6%	22.6%	7.9%	330,460	509,814	179,354	896,958	39.7%	36.8%	56.8%	20.0%
Divorced or separated	2.9%	4.2%	1.3%	65,978	95,928	29,950	163,980	7.3%	40.2%	58.5%	18.3%
Widow	1.9%	2.6%	0.8%	42,743	59,804	17,061	95,611	4.2%	44.7%	62.5%	17.8%
N.A.	3.4%	5.7%	2.3%	76,821	129,370	52,549	254,492	11.3%	30.2%	50.8%	20.6%
N.D.	0.5%	0.8%	0.2%	12,335	16,957	4,622	26,246	1.2%	47.0%	64.6%	17.6%
Age											
0-4	1.6%	50.5%	48.9%	36,401	61,180	24,779	121,140	5.4%	30.0%	50.5%	20.5%
0-14	5.4%	50.9%	45.6%	121,111	204,055	82,944	400,527	17.7%	30.2%	50.9%	20.7%
5-14	3.8%	51.1%	47.4%	84,710	142,875	58,165	279,387	12.4%	30.3%	51.1%	20.8%
15-24	5.3%	53.9%	48.6%	120,001	195,693	75,692	363,311	16.1%	33.0%	53.9%	20.8%
15-59	23.8%	56.4%	32.7%	536,754	836,078	299,324	1,482,069	65.6%	36.2%	56.4%	20.2%
15-64	25.9%	56.7%	30.8%	585,558	904,942	319,384	1,595,016	70.6%	36.7%	56.7%	20.0%
60+	7.7%	63.8%	56.1%	174,117	240,187	66,070	376,227	16.7%	46.3%	63.8%	17.6%
65+	5.5%	65.1%	59.5%	125,313	171,323	46,010	263,280	11.7%	47.6%	65.1%	17.5%
80+	1.5%	69.0%	67.6%	33,380	44,248	10,868	64,100	2.8%	52.1%	69.0%	17.0%
	36.8%	56.7%	19.8%	831,982	1,280,320	448,338	2,258,823				

Discussion

Main findings

The analysis shows substantial variations in access to tertiary care emergency services due to traffic congestion and the links between geographical accessibility and other social determinants of health. The two points of estimate were for early July and late November 2020, and their substantial variations stress the importance of having updatable sources.

The unusually light traffic congestion of November 2020 might have been due to the mobility restrictions associated with the COVID-19 pandemic. Lighter traffic congestion improved accessibility for an additional 448,338 people, most living in low-income households. These people were also within the 15-minute threshold (**Error! Reference source not found.**), and their location can be visualised by comparing **Supplemental File 2** and **Supplemental File 3**. Table 3 shows accessibility at peak-traffic hours disaggregated by sociodemographic characteristics relevant to equity.[42–44]

The longest journeys were 46 minutes in July and November. These journeys started from densely populated, impoverished eastern neighbourhoods along the Cauca River (Aguablanca district) and sparsely populated wealthy villas in the southern edge of the city, bordering Jamundí.

Easing traffic congestion brought an additional 22% (244,579) of people in the low-income household and 19.4% (181,409) more people living in middle-income households within the 15-minute threshold.

Improvements were not notably disparate among the different groups (sex, educational attainment and literacy, age, and civil status). In terms of education, people with higher educational attainment (a bachelor’s degree or higher) were less impacted by traffic changes (69,020 people) and those with lower educational attainment were more highly impacted (e.g., 282,505 people with primary, middle, high, or technical school education). The variations seemed unimpressive in relative terms but are notable in absolute numbers, considering that an additional 332,406 people with primary, middle, high, or technical school education were included as congestion eased. Variations in congestion resulted in substantial accessibility improvement, with nearly half a million more people within a 15-minute accessibility threshold, almost 20% of the population.

Comparing age groups, children and the young and working-age populations gained more accessibility with the changes in traffic, as the elderly tend to live closer to health services.

Variations in traffic congestion can lead to notable accessibility measurement changes among populations that concentrate around the borders of assessed travel time thresholds, as seen among the Palenque people.

Supplemental File 2 and **Supplemental File 3** show that tertiary care health services are far from where most of the population lives. Geospatial analysis, big data, and predictive and prescriptive analytics could inform service planning in ways that maximise accessibility if new services address these limitations.

Limitations

The AMORE Platform used data modelling and clustering to estimate travel times between the origin and destination TAZ, lowering the cost of using big data and still delivering accessibility. Operational costs are thus low, and platform updates for monitoring and evaluation are affordable. The trade-off for affordability is imprecisions in estimates. These imprecisions are more likely to affect populations living near the 15-minute threshold and those further away from TAZ centroids with heavy traffic congestion. However, these imprecisions are unlikely to change the overall urban assessment.

Predicted travel times from the Google Distance Matrix API are accurate and are fed by big data from smartphones. Other databases, such as Waze Transport SDK API, can be used to generate estimates, but these providers do not release prediction algorithms. It is thus impossible to know the magnitude and variations introduced by unforeseen events, like pandemic-related restrictions, and to estimate the impact of resulting errors or biases on estimates.

Colombian law requires hospitals to treat patients in emergencies. Modelling for this study assumed that people would resort to the hospital with the shortest travel time. But people may go to a different hospital if they know it better, their insurer recommends it or it has a good reputation. Our estimates are thus likely optimistic.

While choropleth maps allow users to explore the travel times from a specific TAZ, panels do not reflect that a origin of a journey will not always be the place of residence. This limitation will spread differently at different times and for diverse populations.

The relevance of our findings could change if the registered tertiary care facilities changed in REPS (i.e., a new institution opens, or an existing institution is reclassified as tertiary, changing the results). The interactive platform allows for prompt updates and reanalysis in response to these contingencies.

Interpretation

The AMORE Platform reveals accessibility and its health equity implications, providing new dynamic data that accounts for the effects of traffic. It does so more precisely and at a fraction of the costs of household surveys and origin-destination studies, providing a new tool to inform service plans, programs, and policies.

Integrating publicly available data from public sources might be a breakthrough that improves evidence-informed decisions regarding the location and provision of health services. Visualisations might help stakeholders interpret the data and agree on a common objective and metric: painting the city green by covering its entire population and offering equitable accessibility to all people.

Updating the AMORE Platform is cheaper and faster than updating other origin-destination studies; its assessments are granular and sensitive to variations and can be used to monitor and evaluate changes. In emergencies such as earthquakes, a modified platform could provide a prompt situation analysis by feeding real-time data downloads rather than predictions.

These findings suggest that with congested traffic in peak hours, most Cali residents (63%) are beyond the 15-minute travel-time threshold by car to the nearest tertiary care emergency department. However, this figure fell to 43% when traffic congestion eased.

Reduced accessibility is unevenly distributed and reflects the inverse care law: people who live in low-income households or have less education face longer journeys to tertiary care emergency departments. Incidentally, heavy traffic also affects people on the periphery of Cali, including some high-income households, as congestion clogs roads they use to reach tertiary emergency care facilities.

Accessibility is one of many potential access barriers to health services and a critical one. Other factors that affect access to health care (e.g., rights, quality, or supplies) are meaningless if patients cannot reach tertiary emergency care in a crisis. Additional barriers to accessing health services (such as non-compliance with Colombian law, quality, and institutional and reputation) are beyond the scope of this study and merit consideration.

Researchers and planners can use data mining to optimise new tertiary care emergency services locations that maximise accessibility. Data mining could inform which existing institutions should be prioritised for an upgrade to improve accessibility or point at the optimal location for new ones, thus informing sound choices. These data are unique and provide an opportunity to enhance health services planning. Stakeholders and health equity advocates should encourage the integration of accessibility considerations in urban planning processes.

Planners and service providers wishing to combat social injustices must examine this new evidence that distance and congestion combine to exclude the most vulnerable and socioeconomically disadvantaged from critical health services. Planners and service providers must then consider bringing services closer to these populations. This new evidence and approach raise opportunities to address inequities, improve indicators, and engage stakeholders in urban planning. Future studies will examine the impact of this approach. This evidence supports planning using travel time and monitoring accessibility and equity when assessing the quality of health services.[45–47]

This situational analysis is insufficient to drive change. Integrating evidence about accessibility and equity into stakeholder and intersectoral dialogues, decision-making processes and other strategies that seek the social appropriation of knowledge by stakeholders and sectors might be catalysts for implementation.[33,48]

This report is part of the broader AMORE Project. Future reports will explore the potential of optimising the location of up to two new emergency departments. Future studies will assess the use and appropriation of data, and the advocacy of stakeholders, including those in the AMORE Project Collaborative Group.[10,49]

Interactive platforms can help decision-makers explore different assumptions and myriads of other results of combining different thresholds and traffic levels, allowing data to speak for itself.[50,51]

Looking ahead, identifying and proposing public policy plans and partnerships could improve health equity and bring hope to residents of Cali. These measures could also reduce social injustices, including the burden of the inverse care law that vulnerable populations pay more to access essential health services.[4,52,53]

Generalisability and applicability

This study is reproducible in other settings with dynamic travel-time data (e.g., Waze or Google Maps) and georeferenced service and population data that make situational analyses accessible. Information accuracy depends on the accuracy of sources, the modelling used to conduct searches and maintaining data that is affordable and easy to interpret.

Travel times, infrastructure and populations change. Travel times and census data may thus need to be updated, and traffic clusters may need to be adjusted.

The proposed approach highlights the dynamic nature of travel times and uses TAZs to offer a granular assessment of the city. The scale of these assessments is suitable for informing short or long-term policies and plans and can be periodically revised as conditions change.

Conclusions and future directions

These results test an approach to provide a situational analysis. Defining potential improvements by adding services and using data by decision-makers and other stakeholders are part of the broader AMORE Project and the subject of future reports. Travel time is a continuous variable and could be the subject of myriad analyses beyond the purpose of this study. Our aim is to demonstrate the possibility of conducting an affordable situational analysis with existing data providing information that decision-makers and other stakeholders might use; something to be assessed in future studies.

The web-based platform allows users to change assumptions or variables, explore different scenarios or perform sensitivity analyses. The possibilities are numerous and include expanding the study with more bivariate and multivariate analyses that go beyond the objectives of this report.

Ethical considerations

This observational study on quality improvement for health services planning does not research human subjects. It integrates anonymised coded secondary data sources obtained from publicly available open records.[54,55] The Research Ethics Committee for the School of Engineering of the Universidad del Valle determined that the project is “without risk” per Colombian legislation and cleared the project (REF: CEIFI 010-2022). No identifiable private information was used in the study. Oversight of the project has been provided by the Doctoral Programme on Methodology of Biomedical Research and Public Health at the Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine at the Universitat Autònoma de Barcelona. Contributors to this study are members of the AMORE Project Collaborative Group and public servants in their official capacity; they are listed in the acknowledgements.

Contributors

The corresponding author and principal investigator, Luis Gabriel Cuervo, led the project and manuscript writing and conceptualised the study with support from Daniel Cuervo and Ciro Jaramillo. Substantive additional contributions and editing of the report were provided by (in alphabetical order): María Olga Bula, Daniel Cuervo, Janet Hatcher-Roberts, Ciro Jaramillo Molina, Eliana Martínez-Herrera, Luis Fernando Pinilla, Felipe Piquero, and Lyda Osorio. All members of the AMORE Project Collaboration listed in **Table 4** provided comments, conceptual contributions, or consumer perspectives. Those listed approved the manuscript, declared they stood by this research report and approved being recognised as members of the AMORE Project Collaboration.

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Vanegas for improvements to the AMORE Platform and the AMORE Project website. The development of the AMORE Platform used for this study was led by Luis Gabriel Cuervo, Daniel Cuervo, Luis Fernando Pinilla, and Pablo Zapata. An early prototype of the AMORE Platform was developed under the guidance of the principal investigator (LGC) by Team 33 of the 2020 cohort of the Data Science for All – Correlation Once certificate training program. Members of Team 33 included Daniel Cuervo, Catherine Cabrera, Dario Mogollón, Juan G. Betancourt, Stephanie Rojas, Rafael Ropero, and Santiago Tobar. This work has been carried out within the framework of the doctorate in Methodology of Biomedical Research and Public Health of the Universitat Autonoma de Barcelona.

Table 4. Contributions by Members of the AMORE Project Collaboration approving the manuscript

Surname	Given name	Draft writing	Revision & comments	Conceptual contributions	User perspectives	Stands by manuscript	Approved final version
Agredo Lemos	Freddy Enrique		●	●	●	●	●
Avila Rodriguez	German				●	●	●
Bula	María Olga	●	●	●	●	●	●
				●	●	●	●
Cuervo	Daniel	●	●	●		●	●
Cuervo	Luis Gabriel	●	●	●		●	●
Franco	Oscar			●		●	●
Garcia	Crhistian			●	●	●	●
Guerrero	Rodrigo		●	●	●	●	●
Hatcher-Roberts	Janet	●	●	●		●	●
Jaramillo	Ciro	●	●	●	●	●	●
Martínez Arámbula	Fernando Rafael			●		●	●
Martínez Herrera	Eliana	●	●	●	●	●	●
Merino Juarez	Maria Fernanda		●	●		●	●
Osorio	Lyda		●	●	●	●	●
Ospina	Maria B			●	●	●	●
Paredes	Gabriel	●		●		●	●
Paredes-Zapata	David		●	●	●	●	●

Pinilla	Luis Fernando	●	●	●	●	●	●
Piquero	Felipe	●	●		●	●	●
Rojas	Oscar		●		●	●	●
Rosero Hernández	Myriam			●		●	●
Tobar-Blandón	Maria Fernanda		●		●	●	●
Zapata Murillo	Pablo			●		●	●

Competing interests

All authors have completed the ICMJE uniform disclosure form and declare no financial support from any organisation for the submitted work. IQuartil SAS provided technical support to develop the AMORE Platform and was subsidised by the PI (LGC) for consulting services. DC is a partner at IQuartil SAS and a sibling to LGC. LFP gave technical support at IQuartil SAS until March 2021. LGC contributed to this work in his personal capacity and time. The views expressed in this article do not necessarily represent the decisions or policies of his employer, PAHO/WHO. Reproductions of this article should not include any suggestion that PAHO/WHO endorsed this research or is endorsing any specific organisation, services, or products. COI Declaration by other members of the AMORE Project Collaborative Group signing off the manuscript: FRMA is an engineer on roads and transportation who participated in his personal capacity and time; his contributions do not necessarily reflect the policies or decisions of his employer, the Municipality of Santiago de Cali. MFMJ participated in her personal capacity and time, and her contributions do not necessarily reflect the policies or decisions of her employer. PZM is a consultant at IQuartil SAS.

Data availability statement

The data sources used in this study are in the public domain. The links to the sources are provided (see Study design), and the data constitutes a negligible risk to confidentiality; Colombia's census microdata was anonymised at the source. Neither Google Maps Distance Matrix API nor REPS include personal information (see Ethical considerations). Data from the AMORE Platform relevant to this publication will be made available after the publication of this manuscript at https://www.iquartil.net/proyectoAMORE/.

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Figure 1. AMORE Platform situational analysis

Figure 2. Situational analysis, filters and visualisations, Nov 2020

Figure 3. Travel-time clusters from free-flow to peak traffic, by time and day.

Figure 4. Accessibility by income to tertiary care comparing July and November 2020

Figure 5. Accessibility by sociodemographic characteristics in July and November 2020

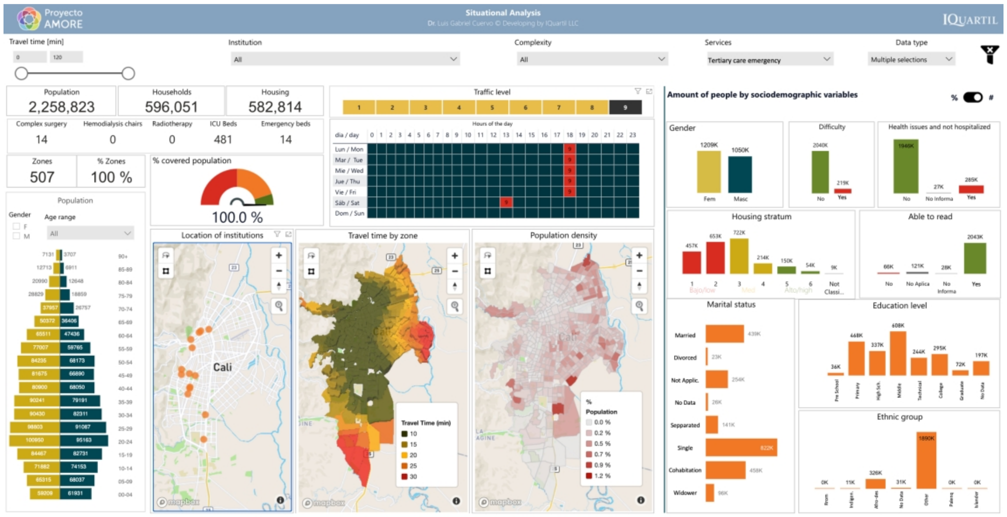
Figure 6. Impact of traffic congestion on accessibility, by economic stratum, July 2020

Figure 7. Location of the Palenque people

Supplemental File 1. Tertiary care emergency departments in institutions with intensive care and surgery, ordered as displayed in REPS[29]

Supplemental File 2. Travel times and population density, tertiary care institutions, peak traffic, November 2020

Supplemental File 3. Travel times by auto to the nearest emergency, with peak traffic, July 2020



Situational Analysis

Dr. Luis Gabriel Cuervo © Developing by IQuartil LLC

Travel time [min]: 0 – 120

Institution: All

Complexity: All

Services: Tertiary care emergency

Data type: Multiple selections

Population: 2,258,823

Households: 596,051

Housing: 582,814

Complex surgery: 14

Hemodialysis chairs: 0

Radiotherapy: 0

ICU Beds: 481

Emergency beds: 14

Zones: 507

% Zones: 100 %

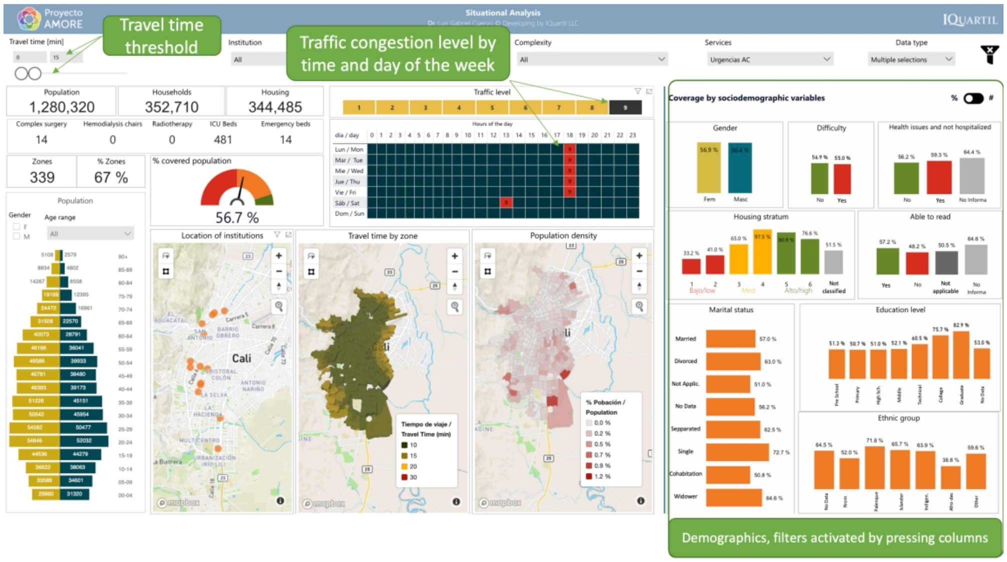
% covered population: 100.0 %

Gender: ☐ F ☐ M

Age range: All

Figure 1, AMORE Platform situational analysis

338x190mm (222 x 222 DPI)



Travel time [min]: 0 – 15

Institution: All

Complexity: All

Services: Urgencias AC

Data type: Multiple selections

Gender: ☐ F ☐ M

Age range: All

Figure 2, Situational analysis, filters and visualizations, Nov 2020

338x190mm (222 x 222 DPI)

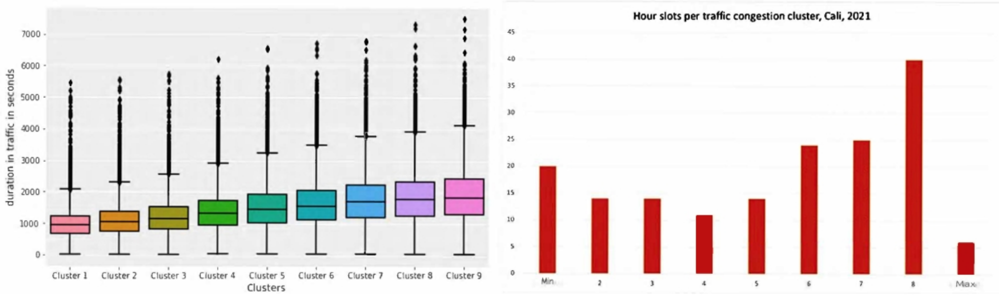


Figure 3, Travel-time clusters from free flow to peak traffic, by time and day

337x99mm (221 x 222 DPI)

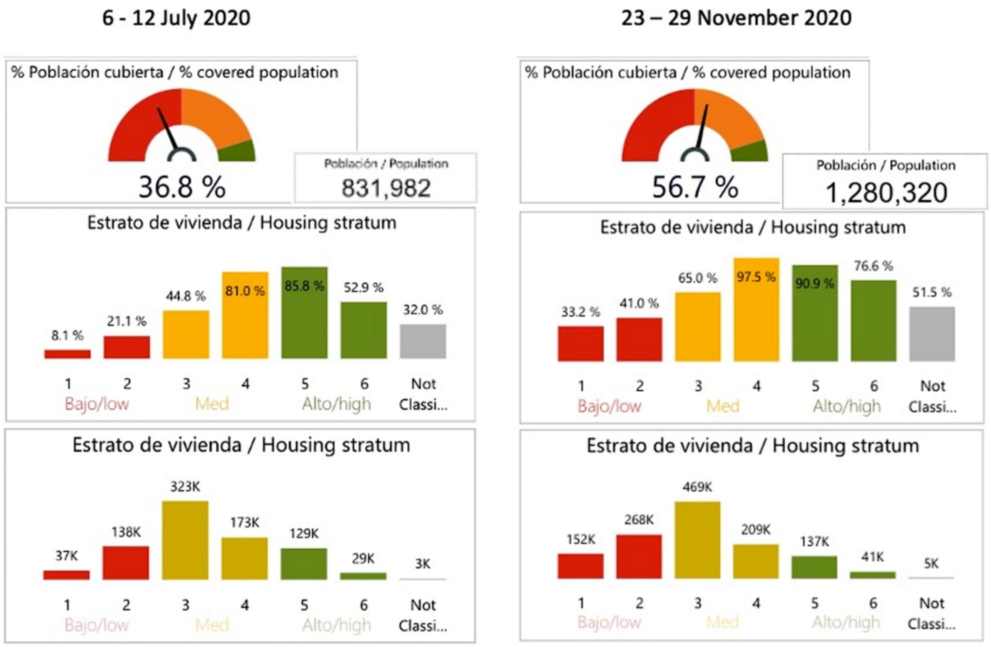


Figure 4, Accessibility by income to tertiary care comparing July and November 2020

284x186mm (222 x 222 DPI)

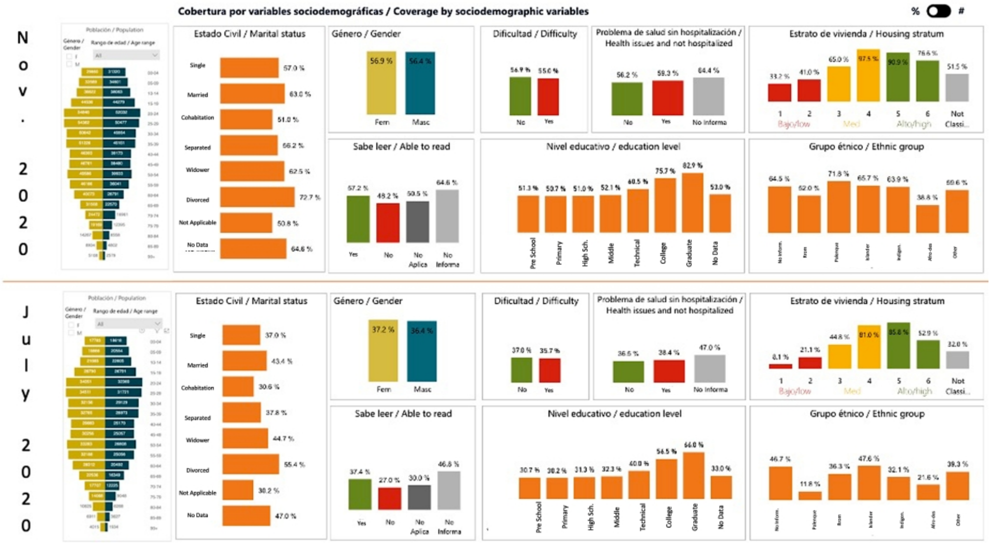


Figure 5, Accessibility by sociodemographic characteristics in July and November 2020

338x190mm (222 x 222 DPI)

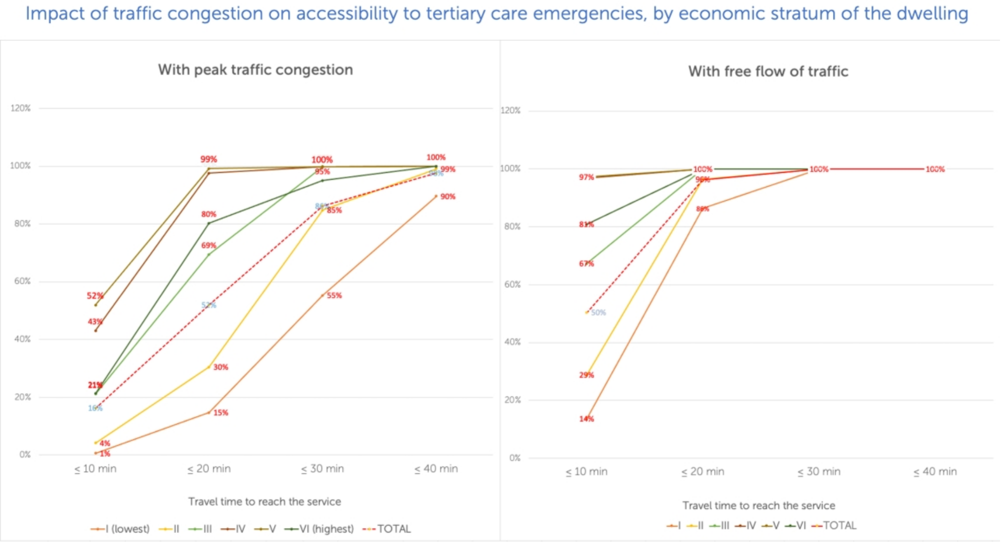
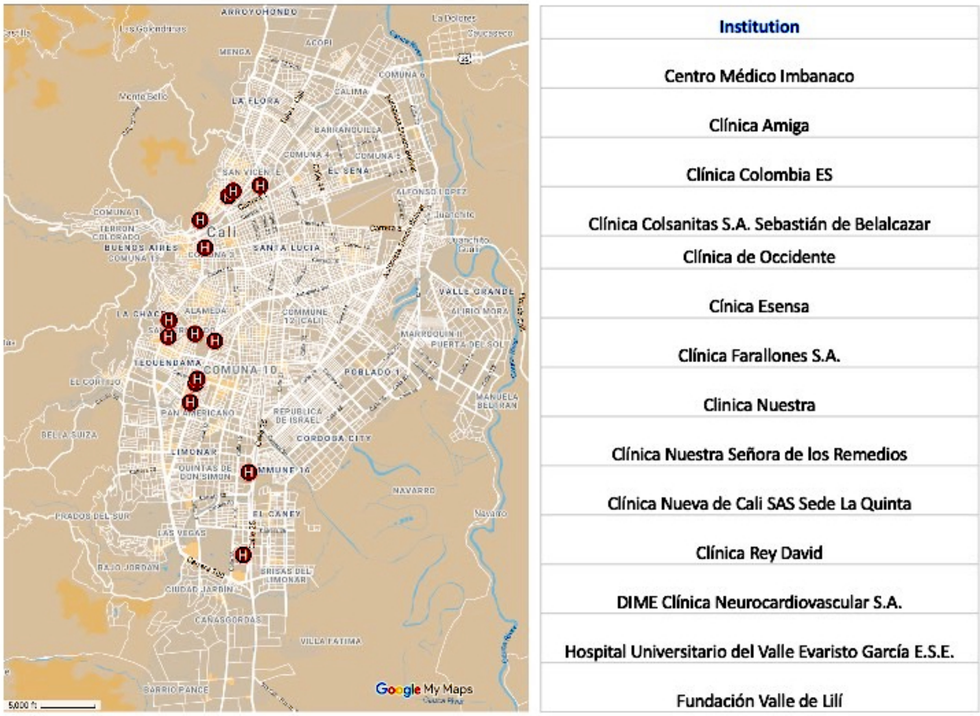


Figure 6 Impact of traffic congestion on accessibility, by economic stratum, July 2020

338x190mm (600 x 600 DPI)

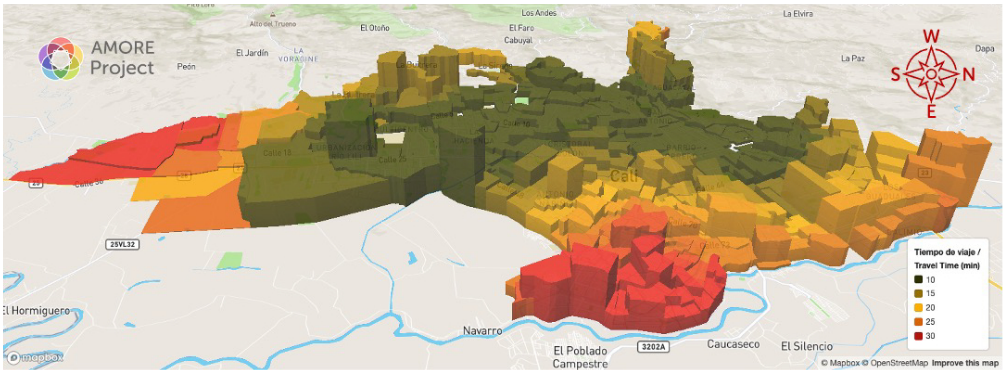
Figure 7, Location of the Palenque people

188x314mm (72 x 72 DPI)



Institution
Centro Médico Imbanaco
Clínica Amiga
Clínica Colombia ES
Clínica Colsanitas S.A. Sebastián de Belalcazar
Clínica de Occidente
Cínica Esensa
Clínica Farallones S.A.
Clinica Nuestra
Clínica Nuestra Señora de los Remedios
Clínica Nueva de Cali SAS Sede La Quinta
Clínica Rey David
DIME Clínica Neurocardiovascular S.A.
Hospital Universitario del Valle Evaristo García E.S.E.
Fundación Valle de Lilí

228x168mm (81 x 81 DPI)



338x123mm (81 x 81 DPI)

879x320mm (72 x 72 DPI)

Cross-sectional equity analysis of accessibility by automobile to tertiary care emergency services in Cali, Colombia in 2020

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5
Bias	9	Describe any efforts to address potential sources of bias	7
Study size	10	Explain how the study size was arrived at	3,9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9- 12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5, 10
		(*b*) Describe any methods used to examine subgroups and interactions	5, 10
		(*c*) Explain how missing data were addressed	7, 10, 11
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed	11
		(b) Give reasons for non-participation at each stage	6-7
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders	9-11
		(b) Indicate number of participants with missing data for each variable of interest	11
Outcome data	15*	Report numbers of outcome events or summary measures	8-11

Cross-sectional equity analysis of accessibility by automobile to tertiary care emergency services in Cali, Colombia in 2020

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11
		(*b*) Report category boundaries when continuous variables were categorized	7, 11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	10
Discussion			
Key results	18	Summarize key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalizability	21	Discuss the generalizability (external validity) of the study results	15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for exposed and unexposed groups.