Use of geospatial analysis for priority setting in surgical system investment in Guatemala

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Summary

Background Two-hour and 30 min travel times to a hospital capable of performing emergency general surgery and cesarean section are benchmarks for timely surgical access. This study aimed to estimate the population of Guatemala with timely access to surgical care and identify existing hospitals where the expansion of surgical services would increase access.

Methods The World Federation of Societies of Anaesthesiologists (WFSA) Anesthesia Facility Assessment Tool (AFAT) previously identified 37 public Guatemalan hospitals that provide surgical care. Nine additional public non-surgical hospitals were also identified. Geospatial analysis was performed to estimate walking and driving geographic access to all 46 hospitals. We calculated the potential increase in access that would accompany the expansion of surgical services at each of the nine non-surgical hospitals.

Findings The percentage of the population with walking access to a surgical hospital within 30 min, 1 h, and 2 h are 5·1%, 12·9%, and 27·3%, respectively. The percentage of people within 30 min, 1 h, and 2 h driving times are 27·3%, 41·1%, and 53·1%, respectively. The median percentage of the population within each of Guatemala's 22 administrative departments with 2 h walking access was 19·0% [IQR 14·1–30·7] and 2 h driving access was 52·4% [IQR 30·5–62·8]. Expansion of surgical care at existing public Guatemalan hospitals in Guatemala would result in a minimal increase in overall geographic access compared to current availability.

Interpretation While Guatemala provides universal health coverage, geographic access to surgical care remains inadequate. Geospatial mapping and survey data work synergistically to assess surgical system strength and identify gaps in geographic access to essential surgical care.

Funding None.

Keywords: Global surgery; Surgical indicators; Surgical health systems; Geospatial analysis; Guatemala

Introduction

According to the Lancet Commission on Global Surgery (LCoGS) published in 2015, an estimated five billion people lack access to safe, affordable, and timely surgery worldwide.[1] Six core indicators were recommended to be used to assess a surgical system's progress in increasing surgical capacity with minimum targets to be achieved by 2030.[1] The LCoGS indicator targets were developed to provide information to assess whether surgical systems and services are effectively delivering access to timely, safe, and affordable surgery worldwide.[1]

One of the six core indicators is geographical access, defined as the proportion of the population who can access, within 2 h, a facility that can provide the

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Research in context

Evidence before this study

Evidence before this study: According to the Lancet Commission on Global Surgery (LCoGS), an estimated five billion people lack access to safe, affordable, and timely surgery worldwide. Two-hour and 30 min-minute times to a hospital capable of performing emergency general surgery and cesarean-section have been established as benchmarks for timely surgical access by the LCoGS and the American College of Obstetricians & Gynecologists (ACOG), respectively. In Guatemala, the majority of the population is covered under the publicly funded health system, but not all public hospitals provide surgical care. Several barriers exist to accessing surgical care through Guatemala's public health systems. These include cost of services, regional language differences, and lack of geographic access especially for indigenous populations in more rural areas.

Added value of this study

Our research expands on previous geospatial analyses done in Guatemala. Our analyses estimate the population of Guatemala that has timely access to surgical care and obstetric care. We show that neither expanding existing surgical and obstetric services at public hospitals nor adding new surgical services at public hospitals currently without surgical services, will adequately increase timely access to surgical care in Guatemala. We demonstrate how geospatial methods and Anesthesia Facility Assessment Tool (AFAT) survey results can work together synergistically to assess surgical system strength and geographic access in a particular country.

Implications of all the available evidence

Measuring geographic access and understanding gaps in access accordingly, using the LCoGS surgical indicator, allows governments an evidence-based assessment to guide investments in surgical infrastructure, facilities, and workforce based on where the population resides. Our findings suggest that while Guatemala provides universal health coverage, geographic access to hospitals that provide surgery remains inadequate and varies regionally. Geospatial data analysis should be guided by concrete surgical assessment tools for accurate primary data about practices and resources in different surgical facilities.

Bellwether procedures (i.e., essential surgical care that includes laparotomy, caesarean section, or open-fracture treatment).[1] The "Three Delays Framework" explains barriers to medical care including delay in the decision to seek care, delay in reaching care, and delay in receiving care. Geographic access is best summarized by the second important barrier-delay in reaching care.[2,3] A minimum of 80% coverage for 2 h access of essential surgical and anaesthesia services per country by 2030 has been recommended by LCoGS.[1] The American College of Obstetricians & Gynecologists (ACOG), American Academy of Pediatrics, and Royal College of Obstetricians & Gynecologists have proposed 30 min access to a hospital capable of performing emergency cesarean section as the standard.[4,5] Regarding access to obstetric surgical care, the Emergency Obstetric and Newborn Care (EmONC) framework developed by WHO, UNFPA, and UNICEF in 2009 has incorporated geospatial access to optimize physical access to healthcare facilities.[6,7] Ebener et al. has proposed three geographic indicators to collect data and assess access to EmONC services to strengthen surgical system capacity and improve policymaking.[6] Both LCoGS and ACOG recommendations are considered benchmarks for adequate delivery in surgical, anaesthesia, and obstetric (SAO) care.

Guatemala is located in Central America, between Mexico and El Salvador, and borders the Pacific Ocean.[8] At approximately 17 million inhabitants, Guatemala is one of the most populated countries in Central America.[8] The vast majority of Guatemala's population are located in the southern, mountainous part of the country, and more than 50% of the population lives in rural areas.[8,9] The large populations in rural areas coupled with the geographic diversity present unique challenges to surgical care delivery. Guatemala's health system consists of public and private sector options.[9–11] The public sector includes the Ministry of Public Health and Social Assistance (Ministerio de Salud Pública y Asistencia Social, MSPAS), the Guatemalan Social Security Institute (Instituto Guatemalteco del Seguro Social, IGSS), and the Military Health System, which combined provides healthcare to approximately 67–90% of the population.[9–11] The private sector including nongovernmental organizations provides healthcare for approximately 12% of the population and is financed by out-of-pocket payments or private insurance.[9–11] Several barriers exist in accessing surgical care through Guatemala's public health systems including the cost of services, regional language differences, and lack of geographic access especially for indigenous populations in more rural areas.[11,12] Other obstacles to access healthcare include transportation challenges and a concentration of surgical care and services in the capital.[11,12] Guatemala is ranked 127 out of 189 countries based on the United Nations Human Development Index and has a gross national income per capita of $8,494.[11,13] In Guatemala, from 1·2 to 6·3% of gross domestic product is spent on healthcare.[11] According to data from 2018, Guatemala had 3·6 physicians per 10,000 people, however, some departments had only as few as 1·5 physicians per 10,000 reflecting the regional differences in healthcare access that exist.[14,15] According to Zha et al., the SAO workforce density in Guatemala is 3·3 per 100,000 population which is far below the target of 20 per 100,000 population recommended by the Lancet Commission on Global Surgery.[1,11]

In Guatemala, while the majority of the population is covered under Guatemala's publicly funded health system, access to surgical care remains poorly defined.

Previous research by Knowlton et al. estimated that 79·7% of the population had geographic access within a 2 h driving time to 12 surgical hospitals in Guatemala.[16] Another analysis of access to pediatric surgical care in Guatemala found that age at the time of surgery was positively correlated with distance from a hospital, signifying that distance to a hospital may be a barrier to accessing timely surgical care.[17] In this study, we build on these previous findings, by estimating the population of Guatemala that has timely access to essential SAO care. We identify hospitals in specific locations that do not currently provide essential surgical care, but if equipped, could help to expand timely access to essential surgical care for the community. In addition, we assess timely access to the surgical care of women of reproductive age in Guatemala to better capture access to obstetric care in the country. Our findings can potentially provide local policymakers with further insights to guide surgical system strengthening and increasing geographical access to SAO care in the population.

Methods

Health facility data

The World Federation of Societies of Anaesthesiologists (WFSA) developed the Anesthesia Facility Assessment Tool (AFAT) to accompany the updated 2018 WHO-WFSA International Standards for a Safe Practice of Anaesthesia. It was developed to help regional and national healthcare leadership gather facility-level data about the anaesthesia and surgical workforce, equipment, medications, and surgical care delivery. In 2018, the Guatemalan MSPAS in partnership with the WFSA, distributed the AFAT, translated into Spanish, to the 46 MSPAS hospitals believed to provide surgical care. Hospital directors were contacted by MSPAS via email and asked to participate in the survey. The AFAT was completed by all 46 hospitals. A detailed methodology and findings of this study are described elsewhere.[11,18] While 46 hospitals were believed to provide surgical care, the survey results revealed that only 37 hospitals provide surgical care at the time of the survey (Supplemental Table 1). Nine hospitals were identified by MSPAS as not performing surgery at the time or were found to not provide surgical care by the AFAT survey (Fig. 1). The Global Positioning System (GPS) coordinates of all hospitals identified were mapped in ArcGIS Pro (Version 2·6·0).

Spatial Data Sources

A spatial dataset of roads was obtained from OpenStreetMap with raw data downloaded from Geofabrik for the walking analysis.[19] A polyline layer of the rivers of Guatemala was downloaded from OpenStreetMap for the walking analysis.[19] Digital elevation data was downloaded from the National Aeronautics and Space Administration's Shuttle Radar Topography Mission (SRTM) at a 90 m resolution.[20] A land cover map was obtained from Copernicus Global Land Service at a 100 m resolution for Guatemala to identify the classification of land use over the area.[21] A raster of population distribution from 2018 at a resolution of 100 by 100 m was downloaded from the WorldPop project (www.worldpop.org).[22] The methodology for generating the gridded population model is described elsewhere; combining remotely sensed data from satellites as well as census data using machine learning algorithms.[23]

Geospatial access to timely surgical care

Timely access to surgical care was estimated as a measure of 2 h access to a hospital providing surgical care as outlined by the Lancet Commission on Global Surgery.[1] Thirty-minute access was also measured to evaluate access to essential obstetric care as outlined by ACOG, which suggests a 30 min benchmark for access to emergent cesarean section.[4,5]

To estimate walking time, the Path Distance tool was used to identify the area around each surgical facility indicating 30 min, 1 h, and 2 h geographic walking access. The surface was modeled using a raster data model, which maps out a grid of equally sized pixels that each contain a relative cost to travel across that pixel towards the nearest surgical facility. For this model, the surgical hospital locations were the destinations, and rivers, lakes, dense forests, and permanently flooded wetland were considered barriers. Roads, bridges, and land cover were used to define the horizontal travel cost, and the degree slope was the vertical travel cost. To estimate time across each pixel, the model assumed a walking speed of five km/h (3·1 mph) on flat ground, which is considered the average walking speed of a healthy adult. The model uses a vertical factor table based on Tobler's Hiking Function and equation {(V=6*exp(−3·5abs[Tan (slope in degrees/57·296)+0·05])}.[24] The vertical factor acts as a multiplier to estimate the impact of slope on the speed of walking. A slight decline increases the speed of travel, while an increase in slope leads to slower travel. To estimate the horizontal cost of travel, a cost surface was developed based on methods used by Fogliati et al. that applies coefficients based on land cover data (Supplemental Table 2).[25] A coefficient of one signifies that land cover does not affect travel speed, whereas a coefficient of zero acts as a barrier over which no travel can occur. To create the cost raster, layers were merged, and functional bridges were included. The population estimate raster was overlaid with the walking time analysis areas to calculate the total population within each travel time. These data were summarised using zonal statistics.

To estimate driving times, we used ArcGIS Pro Network Analyst with the StreetMap Premium Latin America road network dataset to identify the area around each surgical facility indicating 30 min, 1 h, and 2 h geographic driving access.[26] This ArcGIS Pro dataset uses

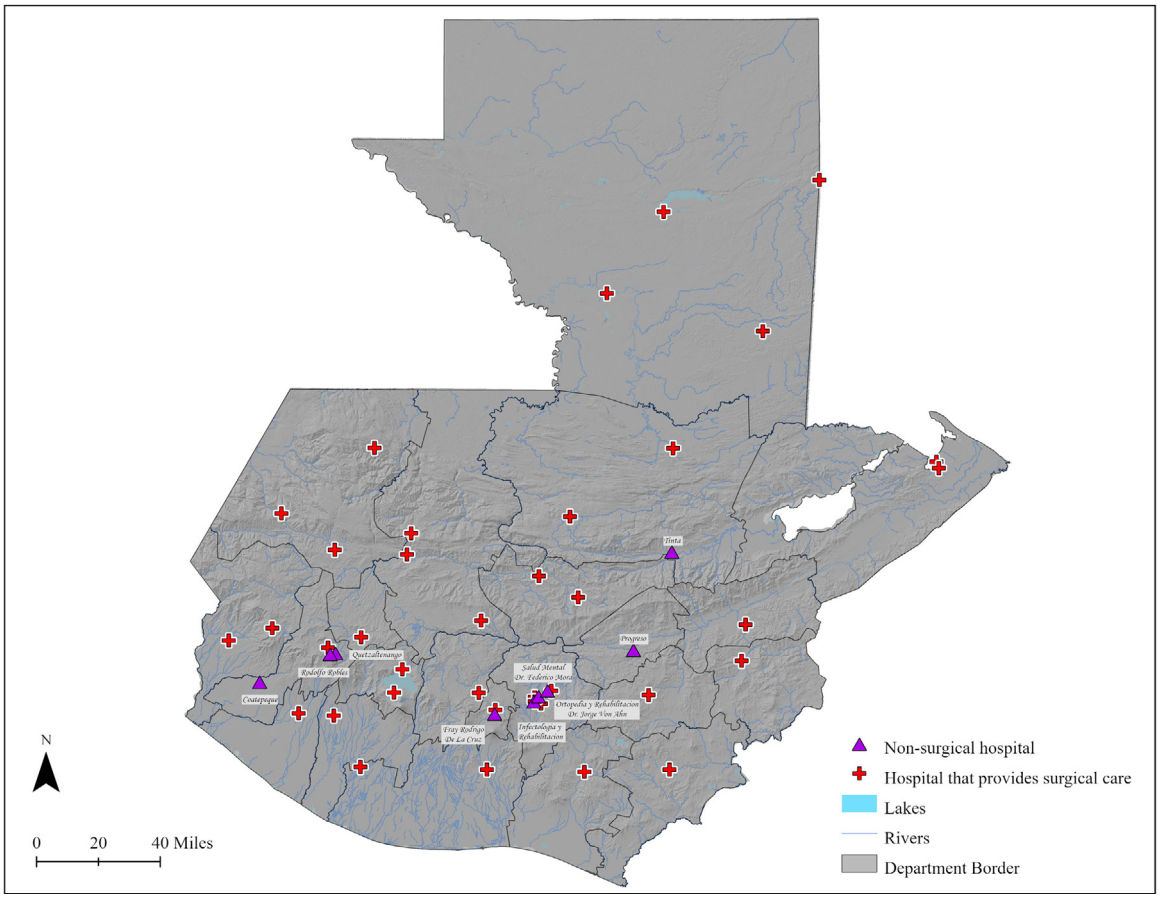

Fig. 1. Location of non-surgical hospitals. This figure depicts the location of the 37 hospitals (red) that provide surgical care, identified by the AFAT. The figure shows the location of the nine hospitals (purple) that do not provide surgical care. These non-surgical hospitals are clustered in the Guatemala and Quetzaltenango departments.

transportation network data from the HERE network, which includes historical road data for the preceding two years and speed limits for all major roads.[26] The speed limits are embedded within the road network dataset. The analysis assumes that all patients are driving the speed limit at all times. First, a service area analysis layer was created by importing the StreetMap Premium Latin America dataset for Guatemala. The driving time parameters and the hospital locations were selected and the solving tool was run to perform the analysis. The population estimate raster was overlaid with the driving time analysis areas to calculate the total population within each travel time. These data were summarised using zonal statistics.

Timely access to obstetric surgical care

The World Health Organization uses the number of women between 15 and 49 years of age as an indicator to estimate the women of reproductive age in a population.[27] To estimate timely access to obstetric surgical care, we calculated the population of women between 15 and 49 years, who had access to each of the hospitals capable of providing surgery. We estimated geographic access of this population to obstetric care given the importance of timely access to emergency cesarean sections. Population rasters from 2018 for women of reproductive age (15–49 years) at a resolution of 100 by 100 m were downloaded from WorldPop.[22] The population of women of reproductive age raster was overlaid with the walking and driving time analysis areas to calculate the specific population within each travel time and then summarized using zonal statistics.

Impact of additional surgical services at existing Guatemalan hospitals

To estimate the potential impact that offering surgical care at existing non-surgical hospitals would have in Guatemala, we calculated the potential increase in timely access that would accompany each of the nine individual hospitals being equipped for essential surgical care (Fig. 1). The same methods described above were completed in an iterative process on the 37 surgical

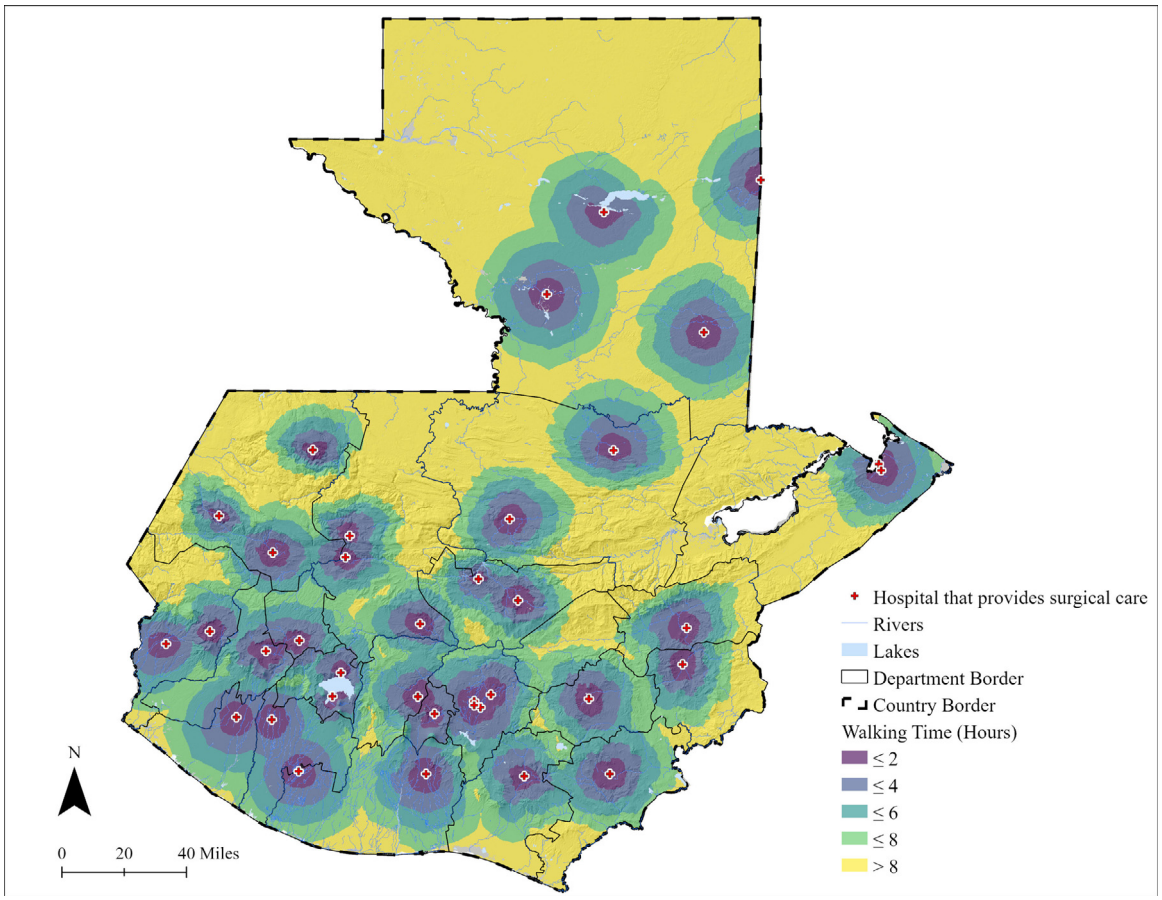

Fig. 2. Geographic walking access to surgical hospitals in Guatemala. This figure demonstrates geographic walking access to the 37 surgical hospitals identified by the AFAT. This estimate assumes a walking speed of 5 km/h and incorporates land cover, elevation, and barriers (rivers/lakes). The population of Guatemala that resides within the dark purple area would be able to walk to the nearest surgical hospital within 2 h.

hospitals plus each of the nine hospitals that were previously identified as not performing surgical care. We calculated the increase in 30 min, 1 h, and 2 h access time nationally that outfitting each of these hospitals would provide to determine if expanding surgical services at existing non-surgical hospitals would increase overall geographic access to care. The marginal increase offered by each hospital was calculated and negligible changes were rounded to zero.

Ethical implications

We did not seek IRB approval as all the data for this study were publicly accessible and did not involve human subjects.

Role of the Funding Source

All authors had full access to the data and accepted the responsibility to submit it for publication. There was no sponsor or funding for this research.

Results

The percentage of the population of Guatemala within 30 min, 1 h, and 2 h walking times from the 37 hospitals that provide surgical care are 5·1%, 12·9%, and 27·3%, respectively (Fig. 2). The percentage of the population of Guatemala within 30 min, 1 h, and 2 h driving times from the hospitals are 27·3%, 41·1%, and 53·1%, respectively (Fig. 3). The median percentage of the population within each of Guatemala's 22 administrative departments with 2 h walking access was 19·0% [IQR 14·1 −30·7] and 2 h driving access was 52·4% [IQR 30·5 −62·8] (Table 1).

The percentage of the total population that are women of reproductive age in Guatemala within 30 min, 1 h and 2 h walking times from the 37 hospitals that provide surgical care are 1·4%, 3·5%, and 7·4%, respectively. The percentage of the total population that are women of reproductive age in Guatemala within 30 min, 1 h, and 2 h driving times from the hospitals are 7·6%, 11·2%, and 14·8%, respectively. The median

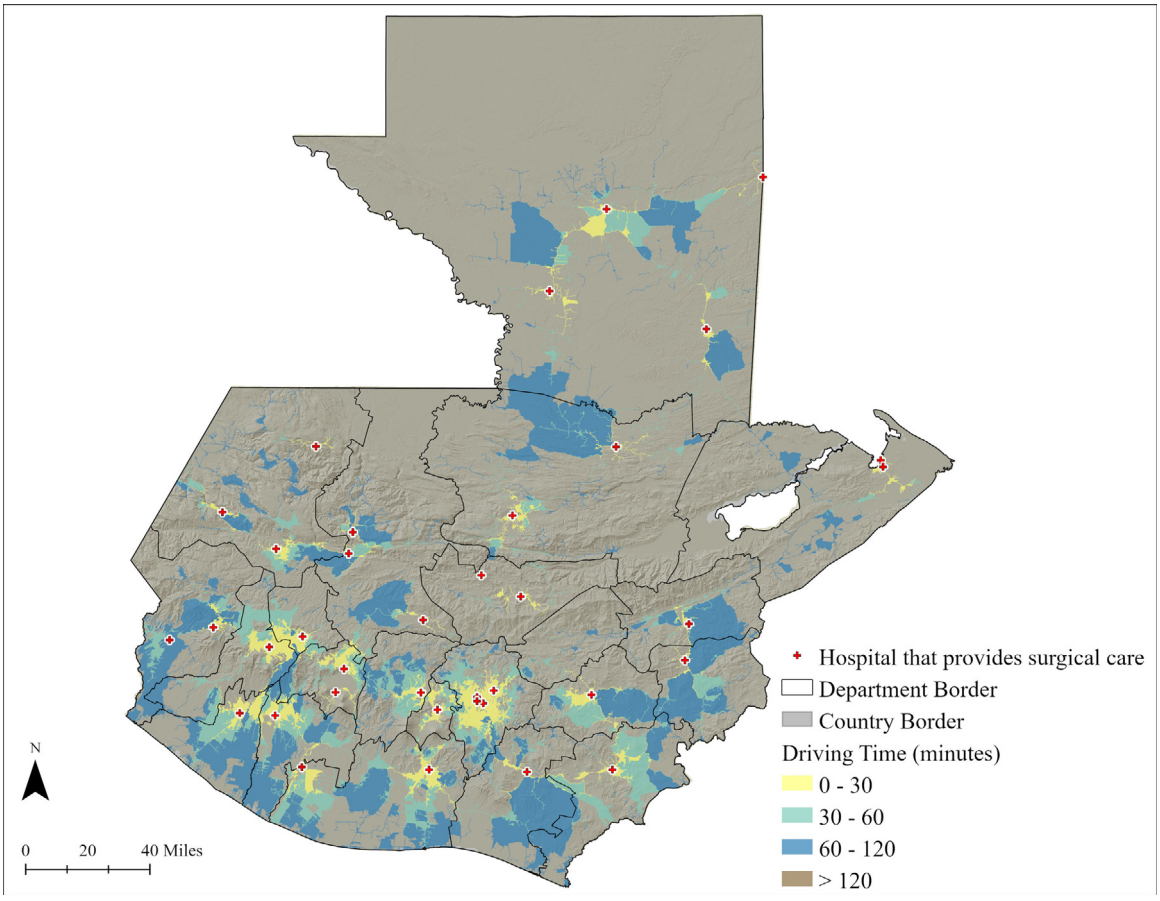

Fig. 3. Geographic driving access to surgical hospitals in Guatemala. This figure demonstrates geographic driving access to the 37 surgical hospitals identified by the AFAT. This model incorporates speed limits and historical road data for Guatemala from the HERE network road dataset. The population of Guatemala that resides within the yellow area would be able to drive to the nearest surgical hospital within 30 min.

percentage of the total population that are women of reproductive age within each of Guatemala's 22 administrative departments with 2 h walking access was 5·0% [IQR 3·5–7·9] and 2 h driving access was 13·4% [IQR 7·5–16·8] (Table 2).

Adding surgical care to existing public hospitals in Guatemala would result in a minimal increase in overall geographic access compared to what is currently available (Fig. 1, Table 3). For example, if the government expanded healthcare to provide surgical care at one of the nine non-surgical hospitals, the highest increase in 2 h walking and driving access would be seen by adding surgical services at the Coatepeque Hospital in the Quetzaltenango Department. Expansion of surgical care at this hospital would increase the 2 h walking access by only 0·7% (from 27·3% to 28·0%) nationally or increase access for 123,868 people from what is currently available. Similarly, if surgeries were performed at Coatepeque Hospital, 2 h driving access to surgical care would increase by only 0·4% (from 53·1% to 53·5%) nationally or increase access for 65,392 people from what is currently available. Simulations for all other hospitals projected an even smaller impact in walking and driving geographic access to surgical care in the expansion analysis (Table 3).

Discussion

Geographic access plays a vital role to ensure a population has timely access to surgical care. Considering the "Three Delays Framework", which outlines different barriers to medical care, geographic access is captured by the second one: delay in the decision to seek care, delay in reaching care, and delay in receiving care.[2,3] Timely access to surgical care remains a core surgical indicator and is critical to ensure optimal outcomes for emergent surgical and obstetric care are met. While several studies have measured 2 h access to surgical care, our study expands on previous findings and proposes using geospatial methods to inform surgical system expansion in Guatemala through evaluating the impact of investments in expanding timely surgical access. Our

Department	2018 Population	Number of hospitals providing surgery (*N* = 37)	Population with 30 min walking time (%)	Population with 2 h walking time (%)	Population with 30 min driving time (%)	Population with 2 h driving time (%)
Alta Verapaz	1,385,498	2	3·0	15·8	10·6	24·2
Baja Verapaz	334,607	2	2·6	13·5	6·5	12·5
Chimaltenango	735,990	1	7·7	30·9	24·9	68·4
Chiquimula	430,908	1	7·6	18·3	9·3	52·4
Escuintla	776,941	2	4·5	18·9	19·1	61·4
Guatemala	3,511,934	4	8·4	54·8	67·9	86·4
Huehuetenango	1,310,661	3	1·4	9·7	6·3	25·6
Izabal	458,867	2	5·4	13·2	8·3	20·5
Jalapa	384,880	1	10·3	22·4	20·1	53·0
Jutiapa	497,241	1	4·5	17·9	14·9	50·2
Petén	791,864	4	7·6	20·4	15·2	30·5
El Progreso	185,922	0	0·0	0·0	0·2	24·1
Quiché	1,216,470	3	1·5	7·8	3·6	30·7
Quetzaltenango	931,216	1	4·6	33·5	37·7	63·0
Retalhuleu	357,783	1	7·2	39·4	38·5	73·4
Sacatepéquez	348,315	1	6·4	44·8	42·0	64·9
San Marcos	1,184,028	2	2·4	19·0	6·4	47·1
Sololá	528,324	2	2·9	24·4	36·1	62·0
Santa Rosa	399,435	1	2·5	13·2	8·6	49·7
Suchitepéquez	613,802	1	9·7	38·9	38·7	78·2
Totonicapán	573,386	1	2·7	29·8	33·1	53·8
Zacapa	245,443	1	7·8	24·6	11·3	50·1

***Table 1*: Geographic access of total population in guatemala to surgical care by department.**
Note: This table shows the geographic access of the population of Guatemala to surgical care by the administrative department. The percentage of population coverage in each department accounts for the population that can reach a hospital in a neighboring department within the travel time threshold

results suggest that access to timely surgical and obstetric care in Guatemala remains limited and that a large proportion of the population does not meet the 30 min and 2 h recommendations set by the ACOG and the LCoGS for adequate delivery in SAO care. Furthermore, geographic access to surgical care by the general population as well as among women of reproductive age varies greatly by the administrative department throughout Guatemala. Importantly, we show that neither expanding existing services of surgical and obstetric services at existing public hospitals nor adding new surgical services to hospitals that currently do not offer it will adequately increase timely access, which reflects a need to build new infrastructure in underserved regions currently without hospital access. Measuring geographic access and understanding gaps in access accordingly, using the LCoGS surgical indicator, allows governments an evidence-based assessment for where to invest surgical infrastructure, facilities, and staff based on where the population resides.

Geographical access to SAO care must be defined as it can lead to expanding access to surgical care and strategies to increase geographic access for the population. SAO care encompasses a broad range of procedures, and obstetric care is a large foundation that specifically impacts women of reproductive age. Numerous studies have been performed to assess geographical access in many different countries using geographic information system (GIS) software.[2,28–34] Any efforts to scale up access to surgical care requires a careful evaluation of the distribution of facilities providing surgical care. A geospatial analysis performed in sub-Saharan Africa in 2018 has been used as a foundation to begin to determine 2 h surgical access.[28] Subsequently, several studies that measure geographic access to surgical care have been performed across Latin America, including in Bolivia, Colombia, Brazil, and Mexico.[3,32,35] In addition, as a follow-up to the initial geospatial analysis, a more granular geospatial evaluation was performed in Nigeria.[36] The data collected in this study were incorporated into the country's national surgical, obstetrics, anaesthesia, and nursing plan (NSOANP).[36] This provides further support that the results of the geospatial analysis could be used to guide national surgical planning and policy development to promote access to safe, affordable, and timely surgical care.

Timely access to obstetric surgical care is important to consider from a geographic perspective. Our results found that geographic access to the surgical care of the

Department	Number of hospitals providing surgery (*N* = 37)	2018 Total Population	Number of Women Age 15–49 in 2018	Population with 30 min walking time (%)	Population with 2 h walking time (%)	Population with 30 min driving time (%)	Population with 2 h driving time (%)
Alta Verapaz	2	1,385,498	336,292	0·7	3·8	2·6	5·9
Baja Verapaz	2	334,607	82,525	0·6	3·3	1·6	3·1
Chimaltenango	1	735,990	188,751	2·0	7·9	6·4	17·5
Chiquimula	1	430,908	113,140	2·0	4·8	2·4	13·8
Escuintla	2	776,941	205,051	1·2	5·0	5·0	16·2
Guatemala	4	3,511,934	1,032,234	2·5	16·1	20·0	25·4
Huehuetenango	3	1,310,661	331,476	0·3	2·5	1·6	6·5
Izabal	2	458,867	119,630	1·4	3·4	2·2	5·3
Jalapa	1	384,880	97,031	2·6	5·6	5·0	13·3
Jutiapa	1	497,241	127,426	1·2	4·6	3·8	12·9
Petén	4	791,864	194,182	1·9	5·0	3·7	7·5
El Progreso	0	185,922	49,191	0·0	0·0	0·1	6·4
Quiché	3	1,216,470	298,028	0·4	1·9	0·9	7·5
Quetzaltenango	1	931,216	250,564	1·2	9·0	10·1	17·0
Retalhuleu	1	357,783	92,155	1·9	10·2	9·9	18·9
Sacatepéquez	1	348,315	95,490	1·8	12·3	11·5	17·8
San Marcos	2	1,184,028	296,661	0·6	4·8	1·6	11·8
Sololá	2	528,324	136,458	0·8	6·3	9·3	16·0
Santa Rosa	1	399,435	102,667	0·6	3·4	2·2	12·8
Suchitepéquez	1	613,802	157,028	2·5	10·0	9·9	20·0
Totonicapán	1	573,386	149,483	0·7	7·8	8·6	14·0
Zacapa	1	245,443	66,095	2·1	6·6	3·0	13·5

***Table 2*: Geographic access of women of reproductive age in guatemala to surgical care by department.**
Note: This table shows the geographic access of women of childbearing age in Guatemala to surgical care by the administrative department. The percentage of population coverage in each department accounts for the population that can reach a hospital in a neighboring department within the travel time threshold.

general population aligned well with geographic access of women of reproductive age, with similar department variation. Expansion of surgical care at hospitals not currently providing surgery would not be sufficient to achieve the LCoGS recommendation which identifies a target of 80% of the population able to reach a hospital in 2 h. This may be because existing non-surgical hospitals are located near surgical hospitals. Of the nine non-surgical hospitals identified in this study, three were concentrated in the Guatemala department, and another three were located in the Quetzaltenango department, where there are already other surgical hospitals (Fig. 1). This may explain why expanding surgical care using existing infrastructure is not the ideal solution for Guatemala. To increase overall geographic access to surgical care, efforts should be focused on identifying optimal locations to build new hospitals and investing in strengthening the surgical system, including workforce and training, where there is currently limited access. Other solutions to potentially expand surgical care include publicly subsidizing care within private facilities by forming public-private partnerships or augmenting the MSPAS surgical expansion efforts.[1,37] Similar to the collaboration between Liga Nacional Contra el Cáncer, a nonprofit organization, and Instituto Nacional de Cancerología, multi-sectoral health care planning strategies could help address these systemic gaps.[38]

The findings from our study complement previous geospatial analysis performed in Guatemala by including estimated geographic access to obstetric surgical care and modeling the impact of the expansion of surgical services in public access to care. Our results show that 53·1% of the population of Guatemala has 2 h driving access to surgical care, which is lower than a previous estimate of 79·7%.[16] Knowlton et al. used a different analysis software and a different road network, OpenStreetMaps, which likely accounts for the observed discrepancy. Additionally, including more geospatial data such as topography, aquatic elements, etc. in our geographic analysis allows for a more realistic and comprehensive estimate of geospatial access. An important point to note is that timely access to a healthcare facility may not adequately capture urban access, as surgical conditions account for approximately half of all urban interfacility ambulance transfers.[39] Additionally, our study utilized facility-level data from the AFAT survey in Guatemala that captures whether surgery was performed as opposed to previous studies of which many have assumed surgical care at all hospitals.

	Department	Population within 30 min walking time (% change)	Population within 1 h walking time (% change)	Population within 2 h walking time (% change)	Population within 30 min driving time (% change)	Population within 1 h driving time (% change)	Population within 2 h driving time (% change)
Existing Geographic Access MSPAS hospitals with surgical services	-	891,091	2,244,530	4,745,397	4,759,379	7,144,350	9,240,389
MPSAS Hospital currently without surgical services							
Coatepeque Hospital	Quetzaltenango	916,522 (3%)	2,299,688 (2%)	4,869,265 (3%)	4,826,391 (1%)	7,223,694 (1%)	9,305,781 (1%)
Fray Rodrigo De La Cruz Hospital	Sacatepequez	889,019 (0%)	2,248,202 (0%)	4,753,531(0%)	4,769,984 (0%)	7,143,892(0%)	9,239,797 (0%)
Infectología y Rehabilitación Hospital	Guatemala	881,867 (0%)	2,240,513 (0%)	4,740,819 (0%)	4,779,706 (0%)	7,147,109(0%)	9,239,735 (0%)
Ortopedia y Rehabilitación Dr. Jorge Von Ahn Hospital	Guatemala	962,073 (8%)	2,244,700 (0%)	4,739,702 (0%)	4,763,937 (0%)	7,144,972(0%)	9,239,799 (0%)
Progreso Hospital	El Progreso	886,214 (0%)	2,241,953 (0%)	4,770,045 (1%)	4,769,761 (0%)	7,165,440 (0%)	9,239,816 (0%)
Quetzaltenango Hospital	Quetzaltenango	910,905 (2%)	2,274,107 (1%)	4,785,845 (1%)	4,759,711 (0%)	7,143,871 (0%)	9,239,798 (0%)
Rodolfo Robles Hospital	Quetzaltenango	908,436 (2%)	2,258,438 (1%)	4,761,861 (0%)	4,762,311 (0%)	7,143,878 (0%)	9,239,805 (0%)
Salud Mental Dr. Federico Mora Hospital	Guatemala	939,269 (5%)	2,266,865 (1%)	4,748,861 (0%)	4,766,233 (0%)	7,144,041 (0%)	9,239,778(0%)
Tinta Hospital	Alta Verapaz	882,817 (0%)	2,238,296 (0%)	4,758,379 (0%)	4,767,543 (0%)	7,171,854 (0%)	9,264,993 (0%)

***Table 3*: Impact of adding surgical services at existing MSPAS non-surgical guatemalan hospitals.**

Note: This table shows the potential impact of expanding surgical services at existing non-surgical MSPAS funded Guatemalan hospitals. The first line shows the baseline geographic access of the population of Guatemala to the 37 hospitals that provide surgical care. Each additional row in the table shows the number of people that would have access and the percent change of the total population that would have geographic access if the hospital were able to provide surgical care.

Our results demonstrate that geospatial methods and AFAT work synergistically to assess surgical system strength and geographic access in a particular country. Geospatial data analysis should be guided by concrete surgical assessment tools for accurate primary data about practices and resources in different surgical facilities. Several studies have used AFAT and other survey tools including the World Health Organization's Tool for Situational Analysis (WHO SAT) to critically assess SAO care globally in a standardized way.[11,40,41] When these methodological tools are combined, as performed herein, the power of geospatial analysis coupled with survey data has the potential to guide NSOANPs and close gaps in geographic access to surgical care across the globe.

Limitations

Our study has multiple limitations. Our study only analyzed geographic access to MSPAS facilities in the public sector, and access to private hospitals, IGSS services, and non-governmental organizations, although important, were not captured by this analysis. Because approximately 70-90% of the population receives care in the public health sector (MSPAS, IGSS, and the Military Health System), we believe our study solely of the MSPAS hospitals is valuable. While the health care delivery system in Guatemala is complex and multifaceted, incorporating several different stakeholders including the public sector, private sector, and nonprofit organizations, our study seeks to use previously collected data using the WFSA AFAT tool to estimate the geographic access to MSPAS public sector surgical facilities.[9–11]

Since real travel times vary by a multitude of factors, our walking and driving estimates may be biased because actual travel patterns, weather conditions, access to vehicles, road conditions, and financial, social and cultural factors that influence travel are not examined. It is possible that the road network dataset is inaccurate in describing travel conditions in Guatemala or that the unconstrained population dataset underestimates the population in certain areas and overestimates in others leading to distorted results. To accurately measure geographic access to health care from rural areas, the availability of geospatial data must expand to include all road networks including non-named roads and smaller dirt paths and reliable, granular population-level data. We used StreetMap Premium Latin America which is the most up-to-date road map data of Guatemala currently available and incorporates both speed limits and historical data for the country.[26] This analysis measures purely geographic access, as the availability of providers or equipment, once an individual arrives at the hospital is unknown. Furthermore, timely access to care depends upon additional delays, as reaching a surgically capable hospital does not mean that surgical care has occurred. In addition, our analysis did not account for timely access to surgery that could be provided for individuals that live across the border in another country and assumes that patients always travel to the nearest facility. Previous research in this area suggests that in Guatemala only 2% of patients were found to travel to a hospital that is further away to access more resources.[42,43]

Conclusions

While Guatemala provides universal health coverage, geographic access to hospitals that provide surgery remains inadequate and varies regionally. Geospatial mapping combined with survey information, such as the AFAT tool, may help identify gaps in timely access to essential surgical care and where to make the most effective investments. Since the expansion of surgical care at existing public hospitals in Guatemala would result in minimal increases in geographic access, efforts should be focused on building new hospitals where there is limited access to increase timely access to surgical care nationally.

Contributors

AMB, PT, EI, SI, and FE designed and coordinated the study. AMB prepared the figures and completed the analysis. AMB, PT, and MS wrote the first draft report. AMB, PT, EI, SI, SA, MS, KP, GP, SJ, and FE contributed to the interpretation. AMB, PT, EI, SI, SA, MS, KP, GP, SJ, and FE edited the manuscript. All authors critically reviewed the paper and approved the final version.

Editor note

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Data sharing

The spatial data used in this analysis are all publicly available for download from different sources cited in the methods. Data from the AFAT survey is available upon request from the corresponding author.

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Declaration of Interests
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Supplementary materials

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