



Geospatial analysis of unmet pediatric surgical need in Uganda^{☆,☆☆}

Emily R. Smith ^{a,l,*}, Joao Ricardo Nickenig Vissoci ^{a,b}, Thiago Augusto Hernandes Rocha ^c, Tu M. Tran ¹, Anthony T. Fuller ^{k,l}, Elissa K. Butler ^e, Luciano de Andrade ^{m,n}, Fredrick Makumbi ^f, Samuel Luboga ^g, Christine Muhumuza ^f, Didacus B. Namanya ^h, Jeffrey G. Chipman ⁱ, Moses Galukande ^j, Michael M. Haglund ^{a,d,k,l}

^a Duke University Global Health Institute, Durham, NC, USA

^b Division of Emergency Medicine, Department of Surgery, Duke University Medical Center, Durham, NC, USA

^c Federal University of Minas Gerais, Business Administration Research Center, Belo Horizonte, MG, BRA

^d Duke University School of Medicine, Durham, NC, USA

^e Department of Surgery, University of Washington, Seattle, WA, USA

^f Makerere University School of Public Health, Kampala, Uganda

^g Department of Anatomy, Makerere University School of Medicine, Kampala, Uganda

^h Ministry of Health, Government of Uganda, Kampala, Uganda

ⁱ Department of Surgery, University of Minnesota, Minneapolis, MN, USA

^j Department of Surgery, Makerere University College of Health Sciences, Kampala, Uganda

^k Department of Neurosurgery, Duke University Medical Center, Durham, NC, USA

^l Duke University Division of Global Neurosurgery and Neurology, Durham, NC, USA

^m State University of West of Parana, Unioeste, Foz do Iguaçu, Brazil

ⁿ Public Health Research Group, Unioeste, Toledo, Brazil

ARTICLE INFO

Article history:

Received 16 January 2017

Received in revised form 21 February 2017

Accepted 15 March 2017

Key words:

Disease burden

SOSAS

Global surgery

Community survey

Low- and middle-income countries

Sub-Saharan Africa

Geospatial

ABSTRACT

Background: In low- and middle-income countries (LMICs), an estimated 85% of children do not have access to surgical care. The objective of the current study was to determine the geographic distribution of surgical conditions among children throughout Uganda.

Methods: Using the Surgeons OverSeas Assessment of Surgical Need (SOSAS) survey, we enumerated 2176 children in 2315 households throughout Uganda. At the district level, we determined the spatial autocorrelation of surgical need with geographic access to surgical centers variable.

Findings: The highest average distance to a surgical center was found in the northern region at 14.97 km (95% CI: 11.29 km–16.89 km). Younger children less than five years old had a higher prevalence of unmet surgical need in all four regions than their older counterparts. The spatial regression model showed that distance to surgical center and care availability were the main spatial predictors of unmet surgical need.

Interpretation: We found differences in unmet surgical need by region and age group of the children, which could serve as priority areas for focused interventions to alleviate the burden. Future studies could be conducted in the northern regions to develop targeted interventions aimed at increasing pediatric surgical care in the areas of most need.

Level of Evidence: Level III.

© 2017 Elsevier Inc. All rights reserved.

In low-income and middle-income countries (LMICs), an estimated 5 billion people do not have access to surgical care when needed, with the highest unmet need in eastern sub-Saharan Africa [1]. Within these areas, nine out of 10 people are unable to access basic surgical

services. In the recent landmark study, Lancet Global Surgery 2030 [1], researchers outlined a goal of providing safe, affordable surgical and anesthesia care in LMICs. Increasing access to surgical care and volume of surgeries was set forth as metrics to meet these goals.

Among children, the burden of surgical conditions is even more striking, with approximately 85% of children in LMICs having a surgically-treatable condition by the age of 15 [2]. Many pediatric surgical conditions carry the risk of lifelong disability, disproportionately increasing the number of disability-adjusted life years (DALYs) lost [3]. Thus, children represent a population with unique preoperative, operative, and postoperative capacity needs.

To assess the burden of surgically treatable conditions in LMICs, the Surgeons OverSeas Assessment of Surgical Need (SOSAS) Survey was

* Grant Support: Duke Global Health Institute Seed Grant, Duke Division of Neurosurgery, Duke–Mulago Hospital Neurosurgery Training Program, Johnson & Johnson Family of Companies, Doris Duke International Clinical Research Fellowship, and University of Minnesota Department of Surgery.

☆☆ Conflicts of Interest: The authors have no conflicts of interest.

* Corresponding author at: Duke Global Health Institute, Division of Global Neurosurgery and Neuroscience, Duke University, 310 Trent Drive, Durham, NC 27710, United States. Tel.: +1 919 684 6508.

E-mail address: emily.smith1@duke.edu (E.R. Smith).

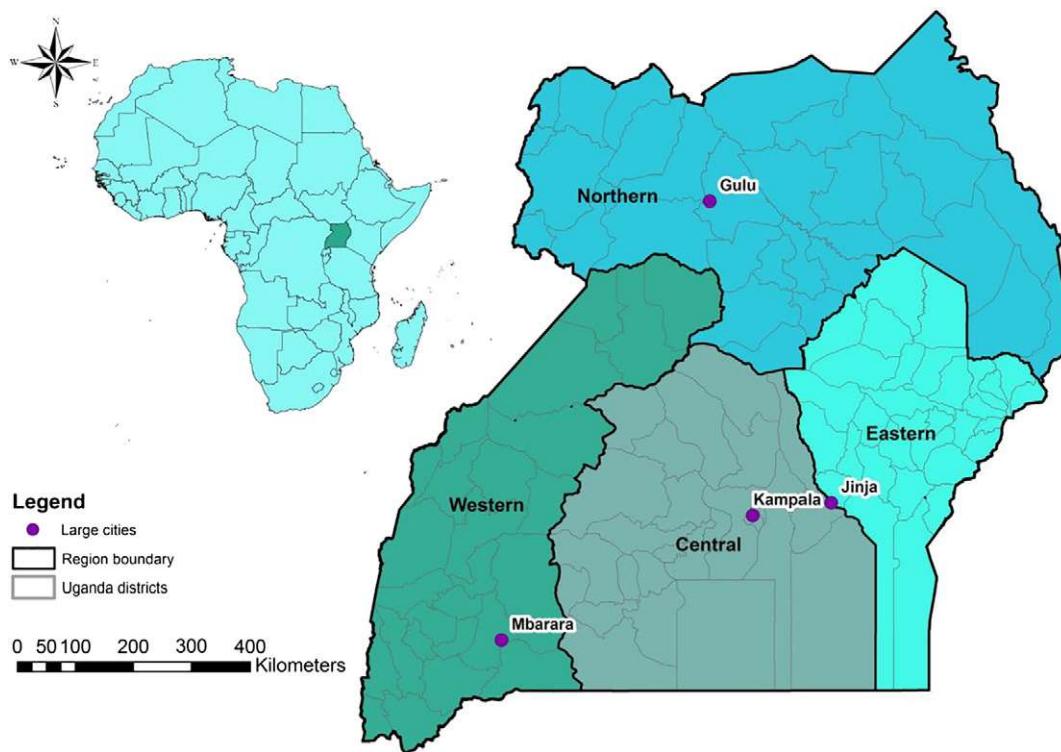


Fig. 1. Geographic visualization of Uganda.

developed [4]. This population-based assessment provides a unique examination of surgical conditions throughout countries that are not limited to conditions within existing healthcare facilities. Rather, the countrywide assessment provides an overview of the distribution of surgical conditions throughout the country. To date, SOSAS has been used in Sierra Leone, Rwanda, Nepal, and Uganda [5–7].

In Uganda, the site for the current study, 14% of pediatric respondents to the SOSAS survey reported having a surgical condition at

some point in their life, of which over 50% were untreated [8]. The predominant cause of surgical conditions was trauma, followed by wounds, acquired deformities, and burns, although causes varied by age of the child. Among children less than 6 years of age, burns were most common, but among children older than 6 years, wounds and acquired deformities were more common. Although this information is highly valuable in quantifying the current need of surgical conditions among children, a better understanding of where the need for surgery is

Table 1

Demographic characteristics and presence of unmet surgical conditions in children interviewed in SOSAS, stratified by Uganda regions.

	Total (n = 2176)	Uganda regions				p-value
		Central (n = 496)	Eastern (n = 564)	Northern (n = 622)	Western (n = 494)	
Demographic characteristics	n (%)	n (%)	n (%)	n (%)	n (%)	0.12
Age (years)						
0–5	808 (43.9)	187 (45.0)	211 (43.1)	217 (41.6)	193 (45.9)	
6–9	472 (20.1)	102 (18.8)	141 (22.7)	122 (17.9)	107 (20.4)	
10–14	531 (23.3)	117 (22.8)	119 (20.8)	180 (27.6)	115 (22.8)	
15–18	365 (12.7)	90 (13.5)	93 (13.4)	103 (12.9)	79 (10.9)	
Gender						0.45
Male	1083 (49.7)	239 (48.1)	300 (53.0)	303 (49.9)	241 (48.2)	
Female	1093 (50.2)	257 (51.9)	264 (47.0)	319 (50.1)	253 (51.8)	
Village type						0.53
Rural	1780 (81.8)	419 (83.4)	446 (79.9)	503 (80.9)	412 (82.3)	
Urban	396 (18.2)	77 (16.6)	118 (20.1)	119 (19.1)	82 (17.7)	
Presence of unmet surgical need	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	
0–5 years old	10.6 (8.9, 12.4)	11.0 (8.6, 13.9)	5.4 ^a (3.7, 7.8)	13.8 (9.9, 18.8)	13.3 (9.1, 19.1)	
>5 years old	7.9 (5.3, 11.6)	7.4 (3.1, 11.7)	4.3 (2.1, 6.5)	10.1 (5.1, 13.8)	9.9 (5.7, 14.2)	
Geographical access indicators	Md (Q1, Q3)	Md (Q1, Q3)	Md (Q1, Q3)	Md (Q1, Q3)	Md (Q1, Q3)	
Distance to health center (km)	11.82 (11.39, 15.08)	10.80 (7.18, 15.95)	10.76 (8.79, 12.42)	14.97 (11.29, 16.89)	6.30 (4.02, 12.60)	0.05
Travel time to tertiary care (min)	159.50 (75.94, 205.40)	78.91 (47.97, 109.86)	171.61 (124.19, 219.02)	193.58 (162.61, 224.56)	129.32 (80.15, 178.50)	0.001
Coverage area (km ²)	598.50 (475.00, 1427)	765 (474, 1172)	525 (273, 1172)	1999 (533, 2835)	562 (323, 1338)	0.001
Care availability*	50.09 (40.54, 64.38)	49.99 (34.05, 57.17)	46.44 (40.14, 49.79)	69.29 (50.85, 111.80)	52.35 (41.04, 64.73)	0.01

MD-Median; Q1–25% quartile; Q3–75% quartile.

* % hospital beds/population for each hospital in a district.

geographically located is also needed for strategic interventions aimed at improving pediatric surgical care.

In an effort to improve access to care, geospatial analyses of surgical needs may demonstrate clustering in areas within existing healthcare systems that require additional services targeted at children. Likewise, clusters of surgical needs for children found in rural areas highlight needs for expanded services to the rural communities. A component of the Ugandan's health system critical strategic plan is to strengthen the health system, as specified by the Ugandan Health Sector Strategic and Investment Plan 2015/16–2019/20 [9] which makes this study timely for developing plans to strengthen the health system for children with surgical needs. The objective of the current study was to determine the geographic distribution of unmet and met surgical conditions among children throughout Uganda.

1. Methods

1.1. Country overview

Uganda is a low-income country with 34.9 million inhabitants and is divided administratively into four regions (central, eastern, northern, and western), 111 districts and the Kampala Capital City Authority (Fig. 1). The Ugandan National Health System comprised public and private facilities. The public sector is structured into level 1 national referral hospitals (NRHs), level 2 regional referral hospitals (RRHs), and level 3 general hospitals and health centers (GHs and HCIVs) [10]. Procedures increase in complexity and infrastructure/resource needs from level 3 to level 1, with level 1 hospitals performing the same procedures as level 2 with the addition of comprehensive pediatric and neonatal surgery.

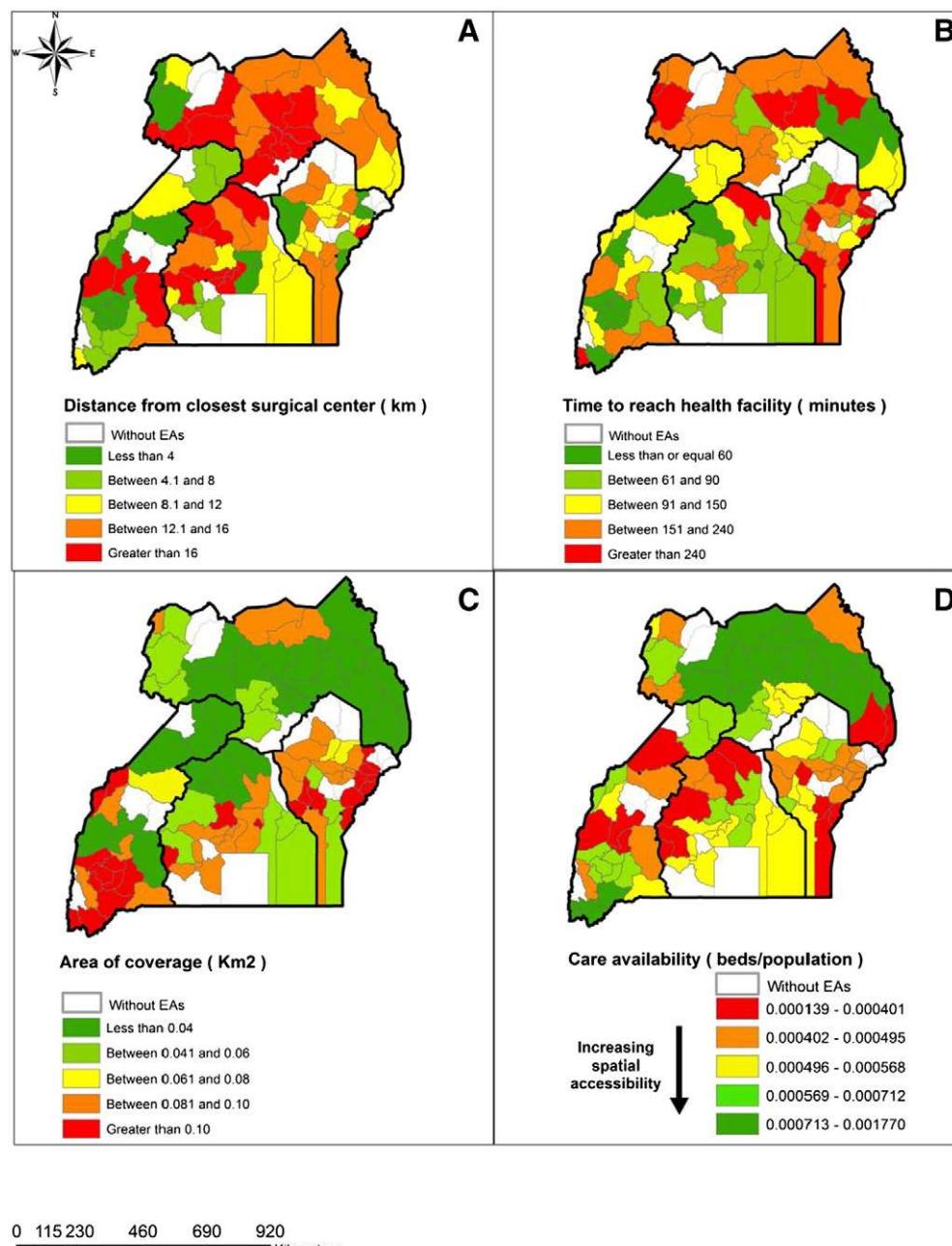


Fig. 2. Geographical access to care distributions by districts: (A) Distance from closest surgical center in Km, (B) travel time to reach tertiary care in minutes, (C) area of coverage in km², (D) care availability as proportion of hospital beds by population size.

Administration of health services has been decentralized to the district level with 139 general hospitals capable of emergency surgeries and at least one physician with training in general surgical practice.

1.2. SOSAS data collection

In 2014, we administered the SOSAS questionnaire to 4248 individuals in 2315 households across 105 enumeration areas (EAs) using a two-stage cluster-randomized sampling design, described elsewhere [11]. Children were defined as survey respondents between the ages of 0 and 18 years. Each identified surgical condition was rated by two or more surgeons and medical/surgical trainees as surgically-treatable and non-surgically treatable conditions. Among the surgically-treatable conditions, each case was coded as treated or untreated based on whether the patient received appropriate surgical care.

1.3. Geospatial analyses

Geographic locations of all healthcare centers were provided by the government of Uganda's Ministry of Health. We defined geographic access to a surgical center as access to a health facility with surgical capacity. Utilizing these data, spatial autocorrelation was determined for four study outcome variables: (1) distance between the EA and the nearest surgical facility, in kilometers (km); (2) area of coverage, defined as the geographic catchment area of each center (km^2); (3) tertiary facility transport time, defined as the self-reported time to reach a tertiary healthcare facility (e.g. regional referral hospital) in the SOSAS survey (minutes); and (4) care availability estimated by the ratio of surgical center beds to the official catchment population.

1.4. Distance

The distance to the nearest surgical facility with minimum surgical capacity based on government designations included distances to all government HCIVs, general hospitals, district hospitals, and regional referral hospitals. The geometric center of each EA survey location was used as the centroid to measure the closest surgical center through a straight-line, Euclidean distance. Distances (km) for each district were calculated by averaging the distance of each individual EA within the same district.

1.5. Area of coverage

A Voronoi diagram map was created by mapping all surgical centers with minimum surgical capacity, resulting in a polygon with minimized distances between the center coordinates. Thus, the specific geographic coverage areas were assessed by district regarding the lack of coverage [12,13]. The surgical coverage areas of each district were determined by averaging the Voronoi diagram area of coverage for each surgical center within the same district.

Table 2

Spatial weighted regression of access to surgical center.

R-adjusted	0–5 years old		>5 years old	
	Estimate	Significance	Estimate	Significance
Variables				
Constant	0.003	0.795	0.013	0.504
Time	4.095	0.954	0.001	0.052*
Distance	1.066	0.344	0.084	0.627
Area	0.093	0.435	-0.119	0.518
Availability	94.161	0.000*	28.475	0.451

* Statistically significant ($p < 0.05$).

1.6. Time to tertiary care center

In the SOSAS survey, study respondents provided the average time needed to reach a primary care facility (GH or HCIV), secondary care facility (RRH), and tertiary care facility (NRH) in minutes. For the purpose of evaluating unmet surgical needs (USN) and access to surgical centers, we added the self-reported times needed to access a tertiary care facility in the analysis. Time (minutes) for each district was calculated by averaging the self-reported time of each EA belonging to the same district.

1.7. Surgical care availability

Surgical care availability was estimated with the spatial accessibility index calculated by the two-step floating catchment area (2SFCA) method [14]. The 2SFCA method is conducted in two steps and the size of the catchment area with surgical care availability is determined by a choice of travel time or distance. It was assumed that all services within that catchment area are accessible and equally proximate to the population within the catchment area, while all locations outside the catchment area are not accessible. Thus, the method utilized floating catchment areas with cross static boundaries, defined as the district areas, that overlap and enable the model to measure the surgical facility access by geographic area proximity and availability.

1.8. Geospatial analysis

We analyzed spatial data grouped by geographic locations (districts) to evaluate whether the presence of spatial aggregation of USN was associated with geographic access to surgical center variables [15,16]. We applied exploratory spatial data analysis (ESDA) through the software ArcGIS, QGIS and GeoDa™ version 0.9.5-i (Spatial Analysis Laboratory, University of Illinois, Urbana Champaign, IL, USA) [17] to determine measures of global spatial autocorrelation, local spatial autocorrelation [18], and spatial regression. Kriging interpolation [19] was applied to extrapolate variables by geospatial predicted values for districts without EAs for data collection.

1.9. Spatial autocorrelation

To evaluate the existence of spatial autocorrelation, we defined a spatial weight matrix (W). We used a queen-type matrix that allows for the measurement of non-random association between the value of a variable observed in a given geographical unit and the value of variables observed in neighboring units [18]. We calculated spatial autocorrelation evaluating prevalence proportion of USN and geographical indicators of access to surgical centers for each district. Using the (I) Global Moran index, we calculated univariable association for USN prevalence and bivariable associations for USN with (a) distance; (b) coverage area; (c) time to tertiary care facility; and (d) care availability [18,20]. This index identifies if the value of the proportion of USN tends to be clustered (positive Moran I) or dispersed (negative Moran I) among districts [15,18,20].

1.10. Spatial regression

To identify which geographical access-to-care variable had a higher geospatial impact on the distribution of USN, we conducted a multivariable spatial regression analysis [21–23]. Using a spatial autoregressive lag (SAR) model, we regressed our independent variables (distance, coverage area, time to tertiary care, and care availability) against the proportion of USN. SAR modeling is a strong approach to understand high spatial autocorrelated data. Interactions are modeled as a weighted average of the neighboring observations through a spatially-lagged dependent variable. The model is weighted based on the neighborhood interaction matrix to analyze spatial dependency [24]. Finally, we added

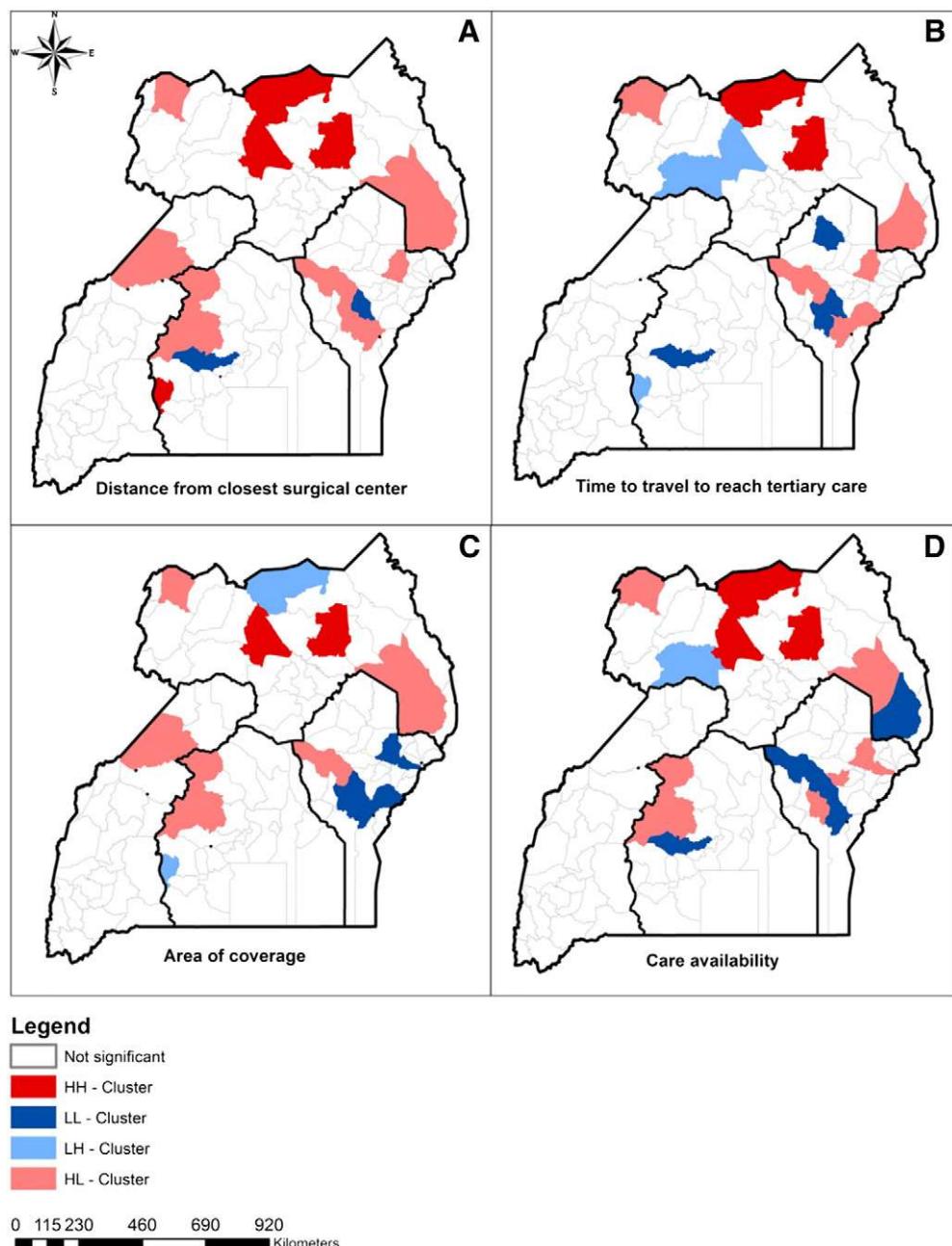


Fig. 3. Local indicators of spatial association maps by district for children with ages 0–5 years. (A–D) Bivariate analysis showing the association between the prevalence of USN and the second variable of interest within districts: (A) Distance from closest surgical center, (B) travel time to reach tertiary care, (C) area of coverage, (D) care availability. Clusters describe associations between districts. HH, high/high clusters; HI, high/low clusters; LH, low/high clusters; LL, low/low clusters; NS, non-significant.

the population size and the proportion of urban population per district to the model to control for the density of urban areas versus rural areas.

1.11. Ethical considerations

Makerere University School of Medicine Research and Ethics Committee, Duke University Health System Institutional Review Board, and University of Minnesota Institutional Review Board approved this study prior to implementation. Enumerators obtained informed consent from each head of household and each individual participating in the survey, prior to initiation of the survey. For children less than 18, a parent or guardian provided informed consent, and children 8 to 18 provided assent. When necessary, parents or guardians assisted children in answering survey questions.

2. Results

Of the 4428 SOSAS respondents, 2176 (49.1%) were 18 years of age or less (Table 1). Nearly half of the children were younger than 5 (43.9%), half were male (49.7%), and most lived in a rural area (81.8%). No differences by demographic characteristics were seen by region. The national proportion of pediatric USN was 6.9% (95% CI: 5.3%, 8.4%). By region, the eastern region has a significantly lower proportion of USN (5.4 [95% CI: 3.7, 7.8]) in relation to the other regions while the highest proportion of USN occurred in the northern and western regions. Stratified by children younger than 5 and children older than 5, the highest USN for both groups occurred in the northern and western regions. In each region, the proportion of USN was higher for children younger than 5 compared with older children.

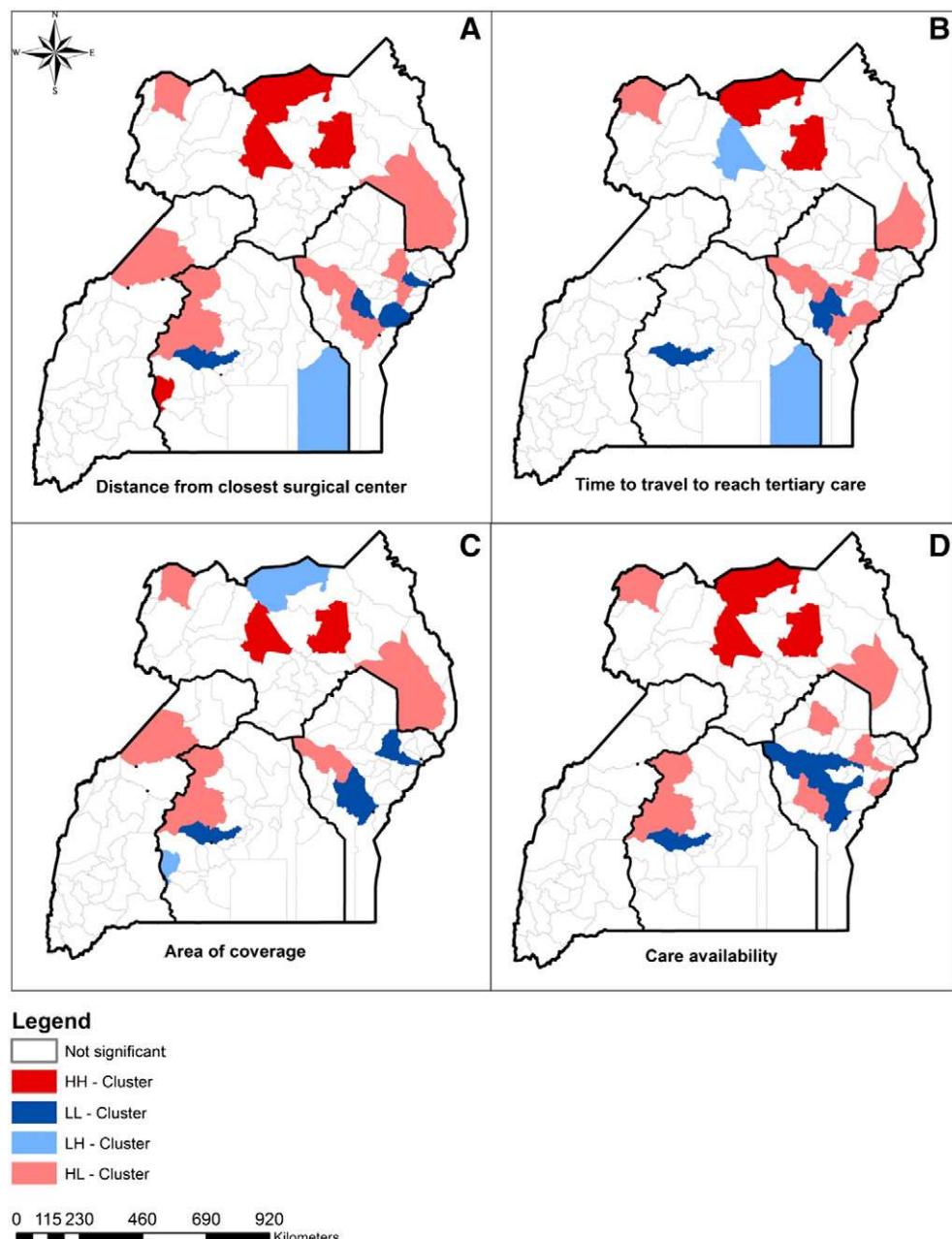


Fig. 4. Local indicators of spatial association maps by district for children with ages above 5 years. (A–D) Bivariate analysis showing the association between the prevalence of USN and the second variable of interest within districts: (A) Distance from closest surgical center, (B) travel time to reach tertiary care, (C) area of coverage, (D) care availability. Clusters describe associations between districts. HH, high/high clusters; HL, high/low clusters; LH, low/high clusters; LL, low/low clusters; NS, non-significant.

The highest average distance to a surgical center was found in the northern region at 14.97 km (95% CI: 11.29 km–16.89 km); differing significantly from the western region (Table 1). The average distances to the nearest surgical center in each district are depicted in Fig. 2A. The higher values of distance by district are seen in the northern districts. The northern region also had the highest average area of coverage by surgical center, differing significantly only from the eastern region. Fig. 2B depicts the Voronoi area analysis, showing areas of coverage for each surgical center, representing the triangulated geographic range for which each center provides care. For example, hospitals located in major cities with multiple centers have smaller areas of coverage. Centers with larger areas of coverage are marked in red. Overall, the largest areas of coverage for surgical centers are seen in the northern

region (median 3966 km²) and the central region (median 3068 km²). The eastern region had the smallest area of coverage with a median of 1566 km² (Table 1). The eastern region differed significantly from the central and northern regions ($p < 0.05$).

The central region had the lowest average reported travel time to tertiary care facility, differing significantly from the eastern and northern regions (Table 1). Similar to the other geographical access to care variables, the districts in northern region had the highest reported travel time with a median of more than 3 h to reach the nearest surgical center (Fig. 2C).

Care availability followed an inverse pattern in relation to geographical access to care. Care availability is expressed as the ratio of hospital beds available to the overall population in a defined administrative

area (i.e. district) surrounding the surgical center (i.e. HCIV). As such, this metric is dependent upon hospital capacity. Although the northern region has the worst results for distance to surgical center, area of coverage for each surgical center, and time to reach the tertiary care facility, care availability is higher in this region. The districts in the northern region marked in green (Fig. 2D) had higher ratios of beds per hospital in the designated area in relation to the other districts, differing statistically from the aggregated values of the eastern and central regions. This result is important to differentiate areas that are highly populated like the central region around Kampala, surrounded by red-marked districts (Fig. 2D), where surgical centers are not far away but are crowded. Although care seems to be more available in the northern region, individuals struggle with geographical access as measured by distance and time to reach surgical care.

2.1. Spatial association and regression

Univariate analysis of the proportion of USN indicated the existence of a positive spatial autocorrelation ($I = 0.17$, $p = 0.001$), demonstrating that EAs with high proportions of USN tend to be adjacent to EAs with similarly high proportions (Table 2). Investigating spatial correlation, all of the analyzed variables were associated with proportion of USN ($p < 0.05$). The correlation was weak and positive for distance to surgical center ($I = 0.09$, $p = 0.03$), area of coverage ($I = 0.11$, $p = 0.02$), facility travel time ($I = 0.06$, $p = 0.03$), and care availability ($I = 0.17$, $p = 0.01$) (Table 2). Analyzing all four variables in the spatial regression model showed that distance to surgical center and care availability were the main spatial predictors of USN (Table 2). Also, these three measures of access to care in Uganda explained 35% of the variance of the spatial dependence of USN. Regression diagnostics showed that the model residual spatial correlation was weak and not significant, indicating no spatial dependency of residuals.

The results in Table 2 highlight that although USN was influenced by distance, area of coverage, travel time to the surgical center, and care availability, the spatial pattern of influence of these variables was not homogeneous throughout Uganda. There appeared to be areas in Uganda where these indicators were more relevant to determine the access to care for Ugandans. As such, we evaluated the existence of spatial clusters with the LISA analysis to determine the impact of these variables on USN throughout the country. The bivariate LISA analysis, stratified by age group, (Figs. 3A–D and 4A–D) shows the pattern of district clustering pertaining to distance from surgical center, coverage area of each center, respondent-reported travel time and care availability for each district. These graphs demonstrate the clusters of districts which have a high association between USN and the other variable of interest. The areas of high/high (HH) type clustering (signifying a district with a high association between two variables surrounded by other districts with high associations between two variables) in bivariate analysis matched in all models. These data indicate that mostly the districts in the north region represent areas of highest surgical need with higher geographical access issues. Low/Low (LL) clusters indicate districts with a low prevalence (Fig. 4A) or low association (Fig. 4B–D) surrounded by other low districts.

3. Discussion

Among children in LMICs, USN poses a large problem not only to children but also places a burden on struggling health systems that cannot meet those needs. In Uganda, that need is great with an estimated 50% of children with surgical needs not receiving the care they need [8]. The main objective of our study was to geographically assess the distribution of USN among children throughout the country. We found differences in USN by region and age group of the children, which could serve as priority areas for focused interventions to alleviate the burden. We also found statistically significant associations between pediatric USN and geographic variables examined.

In our results, districts with a high prevalence of unmet pediatric surgical need correlated with low availability of care for children younger than 5 and with high respondent-reported travel time to nearest surgical facility for older children. These findings demonstrate that surgical care for children may differ by the child's age and complexity of surgery. Although we were not able to examine differences in the specific reasons for the children's surgery, younger children are more likely to have procedures related to congenital anomalies and older children are more likely to have procedures related to injuries and traumas [25,26]. Likewise, younger children are at a higher risk of mortality if left untreated for a surgical condition [27,28]. In order to provide surgical care for complex procedures affecting young children, such as gastroschisis and intestinal atresia, specialized training and resources are needed. In LMICs, there is a dearth of these specialized services for children. In Uganda, there is one national referral hospital capable of performing complex pediatric surgeries and it is located in the capital city of Kampala in the central region. Our data also suggest that the highest need for children younger than 5 occurs in the northern region. Thus, children from the northern region must travel long distances to reach Kampala if these services are needed. Clearly, care availability to very young children is needed in the northern region of Uganda.

Our data consistently demonstrate that the highest need for expansion of surgical services occurs in the northern region. Road infrastructure is relatively poor in this area and poverty within this area is nearly double the national average [29]. Regarding health infrastructure, the northern region has fewer facilities, fewer numbers of operating theaters, and longer travel times to the nearest referral hospital [29]. Despite the ongoing conflicts, our data suggest that providing adequate pediatric surgical resources in northern Uganda is greatly needed.

Investing in pediatric surgical services in LMICs is not only cost-effective but can also prevent lifelong disability or premature death [30]. In contrast to the popular belief that surgery is expensive, several procedures have very low costs associated with societal economic gains and averted disability-adjusted life years (DALY). For example, procedures to treat inguinal hernias had a median cost effective ratio of \$15/DALY and neurosurgical procedures had a median societal benefit, or economic benefit gained from surgical care, of \$58,977 in LMICs. Likewise, investing in surgery significantly increases the rate of return by strengthening the entire health system with positive repercussions to many aspects of healthcare capacity and delivery [1,31,32]. Bolstering surgical care in LMICs also offers financial risk protection against medical impoverishment for individuals and economically strained countries [1].

Although this study was the first to demonstrate targeted areas of need among children requiring surgery, there are limitations regarding data collection and analysis. Although our sampling frame used a systematic sampling of the entire population throughout Uganda using proportional-to-size sampling, our numbers of pediatric cases in need of surgery were small in some districts or were non-existent in others. Similarly, the use of various EA for cluster definitions did not encompass every district throughout Uganda. Thus, some districts were not represented. An additional limitation is the use of self-reported surgical needs and travel times to healthcare facilities. Inherent in self-reported measures is the risk of bias, particularly for underreporting of surgical needs among children. Some needs may be overlooked by caregivers as developmental issues or may not be noticed until the child is older.

Our data demonstrated regions in need of addressing pediatric surgical needs and found differences in barriers to care depending on the child's age. Future studies could be conducted in the northern regions to develop targeted interventions aimed at increasing pediatric surgical care in the areas of most need. Given the large numbers of children in Uganda and other LMICs in need of surgical care, critical expansion of resources is needed for this vulnerable population. Furthermore, the study results are relevant to the Ugandan health system with direct implications for local policy makers.

References

- [1] Meara JG, Leather AJ, Hagander L, et al. Global surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet* (London, England) 2015;386(9993):569–624.
- [2] Bickler SW, Rode H. Surgical services for children in developing countries. *Bull World Health Organ* 2002;80(10):829–35.
- [3] Ozgediz D, Poenaru D. The burden of pediatric surgical conditions in low and middle income countries: a call to action. *J Pediatr Surg* 2012;47(12):2305–11.
- [4] Groen RS, Samai M, Petroze RT, et al. Pilot testing of a population-based surgical survey tool in Sierra Leone. *World J Surg* 2012;36(4):771–4.
- [5] Groen RS, Samai M, Petroze RT, et al. Household survey in Sierra Leone reveals high prevalence of surgical conditions in children. *World J Surg* 2013;37(6):1220–6.
- [6] Petroze RT, Calland JF, Niyonkuru F, et al. Estimating pediatric surgical need in developing countries: a household survey in Rwanda. *J Pediatr Surg* 2014;49(7):1092–8.
- [7] Nagarajan N, Gupta S, Shresthra S, et al. Unmet surgical needs in children: a household survey in Nepal. *Pediatr Surg Int* 2015;31(4):389–95.
- [8] Butler EK, Tran TM, Fuller AT, et al. Quantifying the pediatric surgical need in Uganda: results of a nationwide cross-sectional, household survey. *Pediatr Surg Int* 2016;32(11):1075–85.
- [9] Health sector strategic & investment plan 2010/11–2014/15. Kampala, Uganda: Uganda Ministry of Health; 2010.
- [10] Health Mo, editor. Health sector strategic & investment plan 2010/11–2014/15; 2010 [Kampala, Uganda].
- [11] Fuller AT, Butler EK, Tran TM, et al. Surgeons Over Seas Assessment of Surgical Need (SOSAS) Uganda: update for household survey. *World J Surg* 2015;39(12):2900–7.
- [12] Okabe A, Boots B, Sugihara K, et al. *Spatial tessellations: Concepts and applications of Voronoi diagrams*. 2nd ed. London: Wiley; 2000.
- [13] Moura A. Geoprocessamento na gestão e planejamento urbano. Interciencia: Belo Horizonte; 2003.
- [14] Druck S, Carvalho M, Câmara G, et al. *Análise Espacial de Dados Geográficos*. EMBRAPA: Brasília; 2004.
- [15] Krempel A. Exploring spatial statistics tools for an accessibility analysis in the city of Bauru[Dissertation - Engineering School of São Carlos, University of São Paulo]; 2004.
- [16] Anselin L, Syabri I, Kho Y. *GeoDa: an introduction to spatial data analysis: Geographical analysis*; 2005.
- [17] Anselin L. *Geographical information systems: principles, techniques, management and applications*. Geographical information systems. New York: Wiley; 1998. p. 253–65.
- [18] Perobelli FS, Haddad EA. Padrões de comércio interestadual no Brasil, 1985 e, Vol 102006; 1997.
- [19] Bivand R, Gebhardt A. Implementing functions for spatial statistical analysis using the R language. *J Geogr Syst* 2004;2:307–17.
- [20] Bivand RS, Portnov BA. Exploring spatial data analysis techniques using R: the case of observations with no neighbors. In: Anselin L, Florax R, Rey S, editors. *Advances in spatial econometrics: Methodology, tools and applications*. Berlin: Springer-Verlag; 2004. p. 121–42.
- [21] Zhang L, Gove JH, Heath LS. Spatial residual analysis of six modeling techniques. *Ecol Model* 2005;186:154–77.
- [22] Lambert DM, Brown JP, Florax RJ. A two-step estimator for a spatial lag model of counts: theory, small sample performance and an application. *Reg Sci Urban Econ* 2010;40(4):241–52.
- [23] Ministry of Health (MOH) [Uganda] and Macro International Inc. Uganda Service Provision Assessment Survey. Kampala, Uganda: Ministry of Health and Macro International Inc; 2007 2008.
- [24] Makasa EM. Letter to global health agency leaders on the importance of surgical indicators. *Lancet* (London, England) 2014;384(9956):1748.
- [25] Bickler SW, Sanno-Duanda B. Epidemiology of paediatric surgical admissions to a government referral hospital in the Gambia. *Bull World Health Organ* 2000;78(11):1330–6.
- [26] Fuller AT, Haglund MM, Lim S, et al. Pediatric neurosurgical outcomes following a neurosurgery health system intervention at Mulago Hospital in Uganda. *World Neurosurg* 2016;95:309–14.
- [27] Kouame BD, N'Guette-Brou IA, Kouame GS, et al. Epidemiology of congenital abnormalities in West Africa: results of a descriptive study in teaching hospitals in Abidjan: Côte d'Ivoire. *Afr J Paediatr Surg* 2015;12(1):51–5.
- [28] Ameh E, Bickler S, Lakhoo K, et al. *Paediatric surgery: A comprehensive text for Africa*. Seattle, Washington: Global HELP Organization; 2010.
- [29] Linden AF, Sekinde FS, Galukande M, et al. Challenges of surgery in developing countries: survey of surgical and anesthesia capacity in Uganda's public hospitals. *World J Surg* 2012;36(5):1056–65.
- [30] Saxton AT, Poenaru D, Ozgediz D, et al. Economic analysis of children's surgical care in low- and middle-income countries: a systematic review and analysis. *PLoS One* 2016;11(10):e0165480.
- [31] Jamison DT, Summers LH, Alleyne G, et al. Global health 2035: a world converging within a generation. *Lancet* (London, England) 2013;382(9908):1898–955.
- [32] Mock C, Cherian M, Juillard C, et al. Developing priorities for addressing surgical conditions globally: furthering the link between surgery and public health policy. *World J Surg* 2010;34(3):381–5.