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ORIGINAL SCIENTIFIC REPORT

Geospatial Analysis of Unmet Surgical Need in Uganda: An Analysis of SOSAS Survey Data

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Abstract

Background Globally, a staggering five billion people lack access to adequate surgical care. Sub-Saharan Africa represents one of the regions of greatest need. We sought to understand how geographic factors related to unmet surgical need (USN) in Uganda.

Methods We performed a geographic information system analysis of a nationwide survey on surgical conditions performed in 105 enumeration areas (EAs) representing the national population. At the district level, we determined the spatial autocorrelation of the following study variables: prevalence of USN, hub distance (distance from EA to the nearest surgical center), area of coverage (geographic catchment area of each center), tertiary facility transport time (average respondent-reported travel time), and care availability (rate of hospital beds by population and by district). We then used local indicators of spatial association (LISA) and spatial regression to identify any significant clustering of these study variables among the districts.

Results The survey enumerated 4248 individuals. The prevalence of USN varied from 2.0–45 %. The USN prevalence was highest in the Northern and Western Regions. Moran's I bivariate analysis indicated a positive correlation between USN and hub distance ($p = 0.03$), area of coverage ($p = 0.02$), and facility transport time ($p = 0.03$). These associations were consistent nationally. The LISA analysis showed a high degree of clustering among sets of districts in the Northern Sub-Region.

Conclusions This study demonstrates a statistically significant association between USN and the geographic variables examined. We have identified the Northern Sub-Region as the highest priority areas for financial investment to reduce this unmet surgical disease burden.

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Introduction

While surgery remains an integral aspect of addressing the global burden of disease [1], more than five billion people lack access to safe and affordable surgical care around the world [2]. Poor countries are disproportionately affected; these countries account for one-third of the world's population, yet have been estimated to receive just 6 % of all surgical procedures [2]. The Lancet Commission on Global Surgery has identified several factors that lead to delays in delivery of surgical care, including seeking, reaching, and receiving adequate services in low- and middle-income countries (LMICs). Ultimately, access to surgical services and surgical volume must be greatly increased in LMICs to meet the Commission's goals for 2030. Eastern sub-Saharan Africa was identified as one of the regions of greatest unmet need [2]. Uganda is a low-income country in East Africa that lacks adequate surgical capacity to meet the needs of its growing population [3–6]. Surgical services are offered at few facilities, including national and regional referral hospitals, general hospitals, and Health Centre IVs (mini-hospitals). Currently, there is a gap in our understanding of the relationship between geographic factors and the prevalence of unmet surgical need (USN) in Uganda.

The Surgeons OverSeas Assessment of Surgical Need (SOSAS) Survey was developed to evaluate the burden of surgically treatable conditions in LMICs [7]. SOSAS has been used in Sierra Leone, Rwanda, and Nepal [8–12], and in 2014, our group deployed SOSAS for the first time in Uganda [13, 14]. We applied geographic information system (GIS) analysis, a methodology combining geographical and epidemiological data that can be used to evaluate the geospatial distribution of disease [15]. For example, in Tanzania, distance to healthcare facility was shown to directly correlate with pregnancy-related mortality, increasing mortality almost fourfold [16]. Previous work has used this methodology to analyze the geographic access to all healthcare facilities throughout Uganda [17], but no work has assessed access to surgical centers specifically.

In the current study, we sought to determine the geographic distribution of unmet surgical disease burden throughout Uganda utilizing the SOSAS methodology. We then compared the areas of highest surgical disease burden with the available surgical centers to determine any associated geographic variables for these areas of high burden. This analysis helps to identify areas throughout Uganda in need of expanded surgical services, and thus establishes an instructive framework for meeting the goals of the Lancet Commission by 2030 in Uganda.

Methods

Country overview

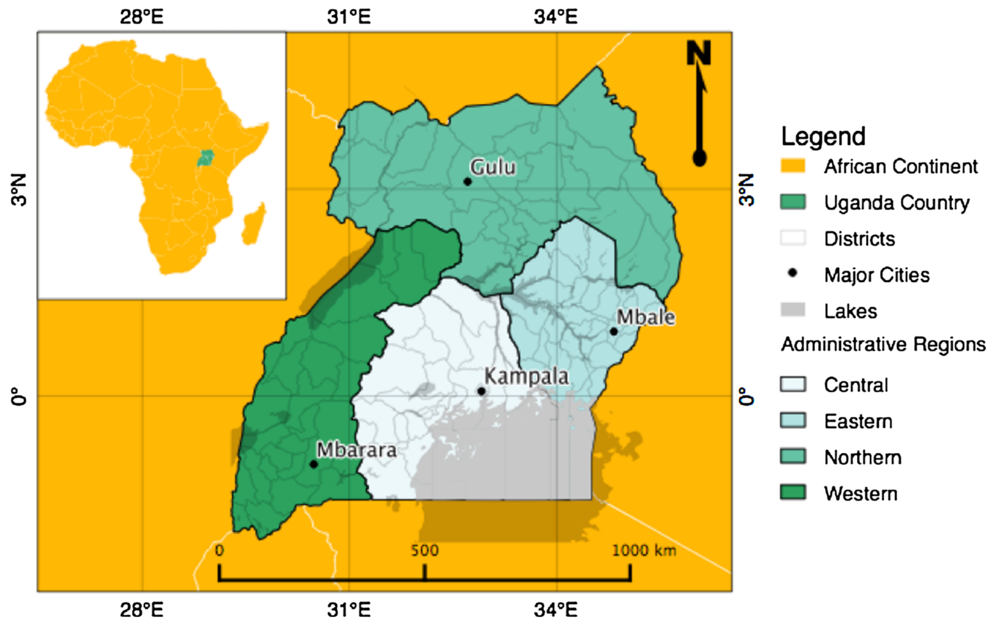
Uganda is a low-income country with 34.9 million inhabitants [18] whose government spends 9 % of the public budget on health, a number that is projected to decrease to 7 % for the 2015–2016 fiscal year [19]. The country is divided administratively into four regions (Central, Eastern, Northern, and Western), 111 districts, and the Kampala Capital City Authority (KCCA) (Fig. 1). Since the mid-1990s, the administration of health services and programs has been decentralized to the districts [20]; therefore, our analysis focused on the district level. There are 139 general hospitals capable of emergency surgeries with at least one physician provider with exposure to general surgical practice. Some general hospitals are classified as district hospitals. Below, general hospitals are 206 "mini-hospitals" (Health Centre IV, HCIV) capable of basic emergency procedures; many HCIVs employ experienced nurses as clinical heads [21]. At the top of the referral pyramid are 16 major referral hospitals, which are the regional referral hospitals and national referral hospitals.

Population data collection and analysis

Using the same two-stage cluster-randomized sampling design as the Uganda Demographic and Health Survey (DHS) [22], we enumerated 4248 individuals in 2315 households spread across 105 enumeration areas (EAs), representing the individual clusters. Sample size was calculated based on results of a pilot survey [13], and the methodologies for the nationwide survey have been published by our group [14]. Sampling error was approximated by Taylor Series Linearization method described in the DHS [22]. For the deployment of SOSAS in Uganda, the instrument's major revision was the separation of anatomical regions into their own sections when appropriate; for example, Buttocks, Groin, Genitalia were separated into Buttocks and Groin/Genitalia (Male/Female); moreover, open-ended responses were required for each problem reported by study participants. USN was coded by surgeons and medical/surgical trainees who rated each condition, delineating surgically indicated and non-surgically indicated conditions. Weighted proportion of USN was calculated for each EA and aggregated by district by averaging EAs proportions located in the same districts.

Uganda demographic and geographical characteristics were represented by region. Data were described through frequencies, distributions, and medians (interquartile range), while region characteristics comparisons were conducted with nonparametric tests due to data distribution

Fig. 1 Geographic visualization of Uganda and its regions



characteristics. Kruskal–Wallis tests were applied to evaluate regional differences with Mann–Whitney par-to-par comparisons with adjustment to significance values for multiple comparisons (significance level $p < 0.05$).

Geographic access to surgical center

Geographic access to a surgical center (a health facility with surgical capacity) was measured through (a) Distance between the EA and the nearest health facility (km); (b) Estimated size of area covered by the district's health facilities (km^2); (c) Self-reported time to reach a tertiary healthcare facility (e.g., Regional Referral Hospital) in the SOSAS survey (minutes); and (d) surgical capacity availability estimated by the ratio of surgical center beds to the official catchment population. Geographical locations of healthcare centers were provided by the government of Uganda's Ministry of Health.

Distance

The distance between centroids (geometric coordinate that determine the geometric center) of the EA survey locations and the closest surgical center was calculated through Euclidean distance (straight-line). Distance was calculated to nearest surgical centers with minimum surgical capacity based on government designations; thus, all government HCIVs, general hospitals, district hospitals, and regional referral hospitals were all included. Distances (km) for each district were calculated by averaging the distance of each individual EA within the same district.

Area of coverage

A Voronoi diagram map was created from all surgical centers with minimum surgical capacity data points. The result was a polygon with minimized distances between the surgical center coordinate. This allowed us to verify the specific geographic areas covered by a specific surgical center in order to assess which districts have the largest areas of coverage and potentially greatest need for more surgical centers [23, 24]. Coverage areas (km^2) for each district were calculated by averaging the Voronoi diagram area of coverage for each surgical center within the same district.

Time to tertiary care center

Participants were queried about the average time needed to reach a primary, secondary, and tertiary care facility in minutes. For the purpose of evaluating USN and access to surgical centers, we only 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.

Surgical care availability

Surgical care availability was estimated with the spatial accessibility index calculated by the two-step floating catchment area (2SFCA) method [25]. The 2SFCA method was proposed as a way to deal with the issues of existing measures of spatial accessibility which failed to include cross-border movement and distance decay within boundaries. This method uses floating catchment areas (coverage areas) which cross static boundaries (e.g., district areas) and overlap enabling the modeling and measurement of healthcare access by geographical area proximity and availability. The method is conducted in two steps and for each part a catchment area is defined. The size of the catchment is determined by a choice of travel time or distance, where all services (or populations) within that catchment are considered accessible and equally proximate to that particular population (or service), while all locations outside of the catchment are not accessible.

The process follows two steps: (1) determine the population size located within the catchment of each surgical center (health facility with surgical capacity), and the volume (number of beds), thus defining the provider-to-population (e.g., beds to population) ratio within a service catchment; (2) allocate these service ratios to the population by determining which services are located within the catchment of each population (district centroids) and aggregating the ratio scores in step 1 to calculate a location's access index by district. In Step 1, catchment area was defined as coverage area for each facility based on their catchment population (National Referral, Regional Referral, General Hospital, or HCIV) defined by the Ugandan Ministry of Health. Catchment area for Step 2 was a buffer of the district centroid with 60 km of diameter. We did not use roads as reference for distance or time because the updated current roadmap for Uganda is not openly available.

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 centers variables [26, 27]. 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) [28] to determine measures of global spatial autocorrelation, local spatial autocorrelation [29], and spatial regression. Kriging interpolation [30] was applied to extrapolate variables by geospatial predicted values for districts without EAs for data collection.

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 [29]. 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 [29, 31]. 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 [26, 29, 31].

To graphically depict spatial autocorrelation, we applied the local indicators of spatial association (LISA) clustering method. The LISA maps identify significant spatial clusters throughout Uganda, with high or low association values for the analyzed variables (proportion of USN, distance, area of coverage, time to tertiary care, and care availability) [26, 29, 31]. Clustered areas are categorized according to the pattern of characteristics in adjacent districts. High/high (HH) areas are a set of districts with high proportion of USN surrounded by other districts with high USN in univariate analysis. In bivariate analysis, HH areas comprise districts with high association between USN and another variable of interest (e.g., distance, area of coverage, time to tertiary care, or care availability) surrounded by similar districts. This means that two districts next to each other which both have a high proportion of USN correlated with a high distance to surgical center define a HH set of districts. The same sense is applied to low/low (LL) set of districts, where districts with low characteristics are surrounded by districts with low values for analyzed variables. When the inverse occurs, districts with low proportion of USN and low distance to surgical center are surrounded by districts with high USN and high distance, LISA maps categorize them as low/high (L/H) or high/low (H/L) for the opposite pattern.

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 [32–34]. 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 [35]. Finally, we added 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.

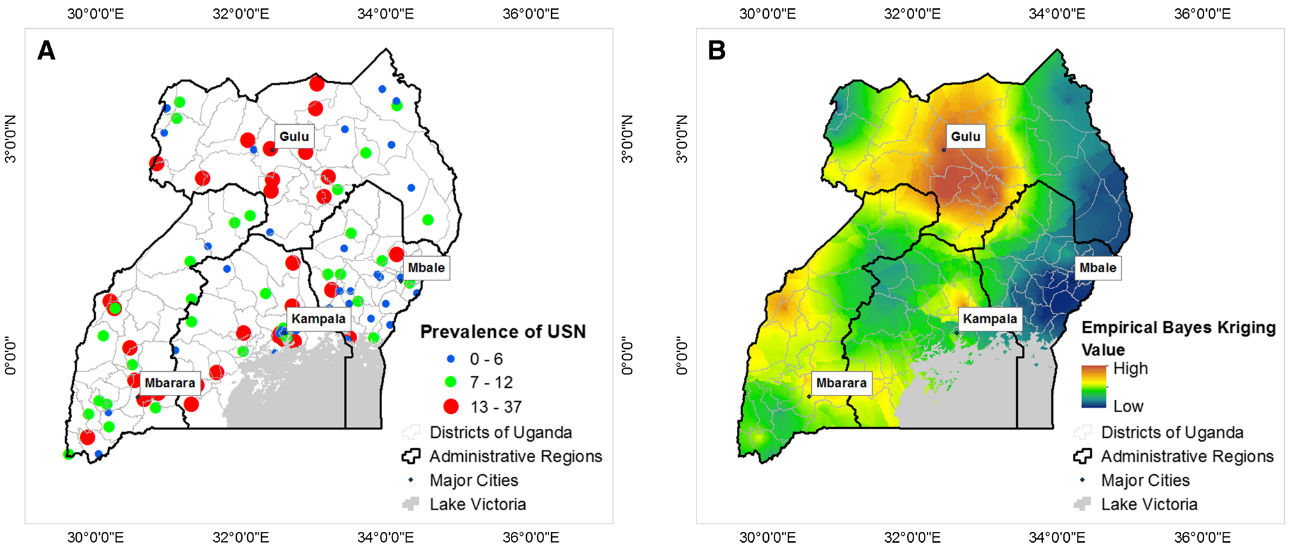


Fig. 2 Prevalence proportion of unmet surgical need (USN) (**a**) by enumeration area (EA) and (**b**) by for the whole country by Kriging interpolation

Results

The national proportion of USN was 10.6 % (8.9–12.4 %). Among the 105 EAs, the proportion of USN varied from 2.0–45 %, with 12 EAs showing no presence of USN (Fig. 2a). High USN-proportion EAs were located mainly in the Northern, Western, and Central Regions of Uganda (Table 1) as depicted in the Kriging interpolation heat map (Fig. 2b). EAs with the highest proportion (>25 %) throughout Uganda were located in the districts of Kiruhura, Gulu, Mbarara, Kitgum, Sheema, Otuke, Oyam, Wakiso, Lira, Kabarole, and Luwero. The Eastern Region had a significantly ($p < 0.05$) lower proportion of USN in relation to the other regions (Table 1). Characterizing the Ugandan regions, the Central Region is the most densely populated with the largest urban population (Table 1). The Northern Region is the least populated.

The highest average distance to surgical center was found in the Northern Region at 14.97 km (95 % CI: 11.29–16.89 km); differing significantly from the Western Region (Table 1). The average distances to the nearest surgical center in each district are depicted in Fig. 3a. The higher values of distance by district are seen in the Northern districts. Figure 3b 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 1999 km^2) and the Central Region (median 765 km^2). The Eastern Region had the smallest area of coverage with a median of 525 km^2 (Table 1). The Eastern Region differed significantly from the 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. 3c).

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., County) 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 red (Fig. 3d) 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 blue marked districts (Fig. 3d), where surgical centers are not far away but are crowded. Although care seems to be

Table 1 Characteristics of Ugandan regions

	Uganda regions			
	Central	Eastern	Northern	Western
Individuals enumerated	1037 (24.4 %)	1043 (24.6 %)	1152 (27.1 %)	1016 (23.9 %)
Base population [19] (% of national)	9,579,119 (27.5 %)	9,005,031 (25.8 %)	7,230,661 (20.8 %)	8,939,355 (25.7 %)
Urban	3,130,170	957,125	868,025	1,491,940
Rural	6,448,949	8,197,835	6,362,636	7,447,415
Districts sampled	24	32	30	26
Unmet surgical need rates (%) (95 % CI)	11.00 (8.61; 13.94)	5.43[a] (3.73; 7.82)	13.76 (9.92;18.78)	13.29 (9.07; 19.07)
Facility composition				
National referral	1	0	0	0
Regional referral	1	3	3	4
General hospital	7	8	7	6
Health centre IV	6	9	10	7
Public	14	17	16	14
Private	1	3	4	3
Hub distance (km) (95 % CI)	10.80 (7.18; 15.95)	10.76 (8.79; 12.42)	14.97 (11.29; 16.89)	6.30 (4.02; 12.60)[a]
Average travel time to primary facility (min) (95 % CI)	25.53 (17.52; 33.54)	76.03 (54.90; 98.16)	72.16 (57.85; 86.46)	47.07 (36.84; 57.31)
Average travel time to secondary facility (min) (95 % CI)	42.65 (28.28; 57.02)	99.96 (70.66; 129.26)	137.63 (110.70; 164.56)	75.64 (51.37; 99.92)
Average travel time to tertiary facility (min) (95 % CI)	78.91[b] (47.97; 109.86)	171.61 (124.19; 219.02)	193.58 (162.61; 224.56)	129.32 (80.15; 178.50)
Coverage area (km^2) (95 % CI)	765 (474;1172)	525 (273;1172)[c]	1999 (533;2835)	562 (323;1338)
Care availability (% hospital beds/ population/district)	49.99 (34.05; 57.17)	46.44 (40.14; 49.79)	69.29 (50.85; 111.80)	52.35 (41.04; 64.73)[d]

[a] The Western Region differed significantly from the Northern region ($p < 0.05$)

[b] The Central Region differed significantly from the Eastern ($p < 0.03$) and Northern ($p < 0.01$) Regions

[c] The Eastern Region differed significantly from Northern Region ($p < 0.01$)

[d] The Northern Region differed significantly from the Eastern and Central Regions ($p < 0.02$)

more available in the Northern Region, patients struggle with geographical access as measured by distance and time to reach surgical care.

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 tend to be adjacent to EAs with similarly high proportions (Table 2). Investigating spatial correlation, 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 ($I = 0.11, p = 0.02$) and facility travel time ($I = 0.06$, $p = 0.03$) (Table 2), and care availability ($I = 0.17$, $p = 0.01$). 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 residuals 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 (Fig. 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. As such, 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

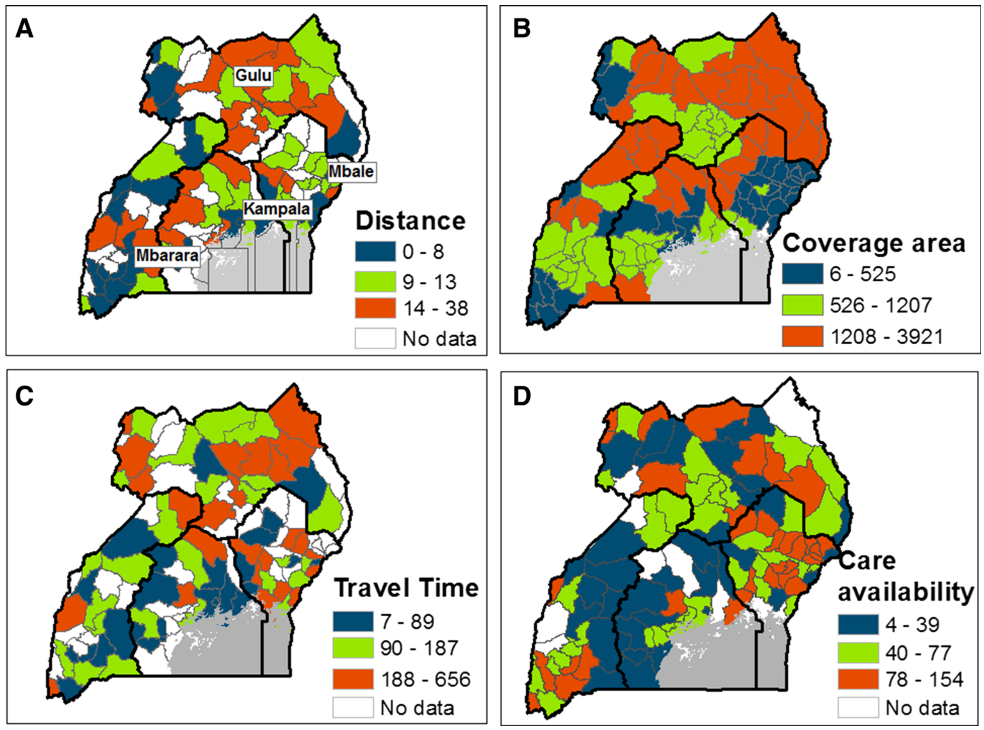


Fig. 3 Geographical access to care distributions by districts: **a** Distance from closest surgical center in km. **b** Area of coverage in Km^2. **c** Travel time to reach tertiary care in minutes. **d** Care availability as proportion of hospital beds by population size

Table 2 Spatial autocorrelation and regression of access to surgical center

Analysis	Moran's I	Regression estimate (*p* value)
Univariate		
Unmet surgical need	0.17*	–
Bivariate		
Hub distance (km)	0.09*	0.032 (0.01*)
Area of coverage (km^2)	0.11*	16.692 (0.17)
Average travel time to tertiary facility (min)	0.06*	0.005 (0.47)
Care availability (%)	0.17	0.145 (0.02*)
R-squared/model *p* value		0.35 (0.01)
Residual spatial correlation	0.02	

* Statistically significant ($p < 0.05$)

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. Districts in the northern section of the Northern Region (e.g., districts Lawmo, Gulu, Pader, and Lira), with a small presence in the Central Region (Nakasongola) for coverage area. 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.

Discussion

Low- and middle-income countries throughout the world lack adequate access to surgical services [2]. Uganda, a low-income East African country, currently cannot meet the healthcare needs of its growing population [3–6]. SOSAS Uganda is the first population-based survey on surgical conditions at a national level and to our knowledge, and this report is the first application of GIS analysis to measure access to surgical centers throughout Uganda. The main goal of this study was to determine the geographic distribution of the burden of USN throughout the

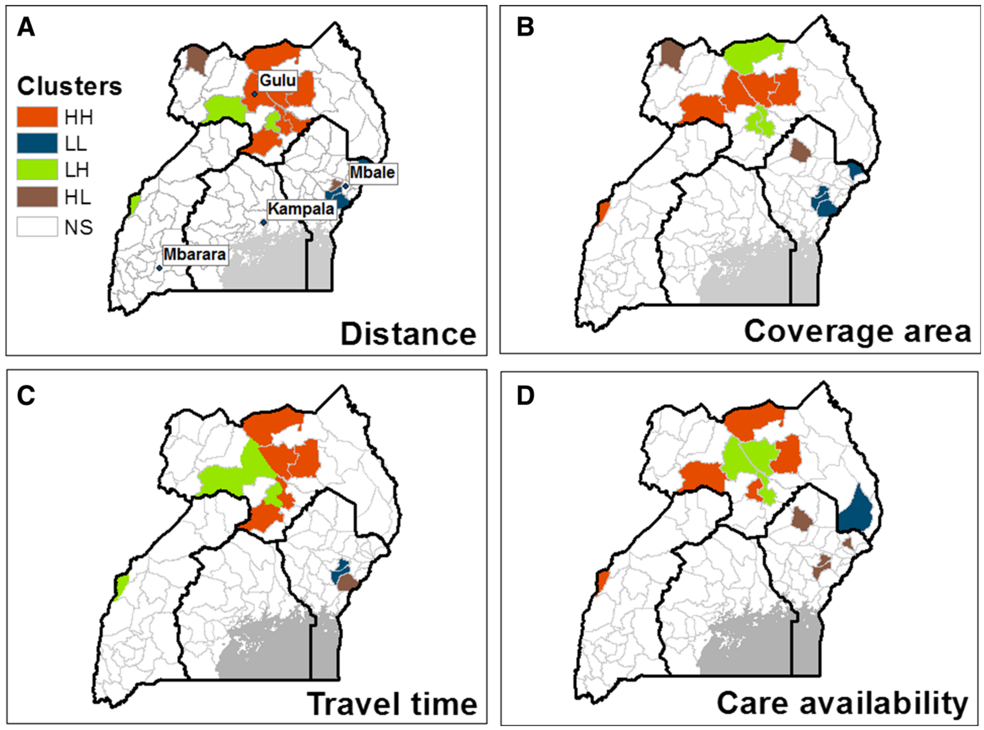


Fig. 4 Local indicators of spatial association maps by district. **a–d** Bivariate analysis showing the association between the prevalence of USN and the second variable of interest within districts: **a** Distance from closest surgical center. **b** Area of coverage. **c** Travel time to reach tertiary care. **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* nonsignificant

country. We then compared the areas of highest surgical disease burden with the available surgical centers to determine geographic factors related to these areas of high need. This study is vital to identify the specific regions most in need of expanded surgical services.

Using the LISA analysis, we identified a cluster of districts in the North Sub-Region where there are statistically higher proportions of USN. These districts include Gulu, Kitgum, Lira, Otuke, and Oyam. The results of the spatial correlation demonstrate the clusters of districts with a high prevalence of USN correlate with distance from surgical center, coverage area of each center, and respondent-reported travel time in bivariate analysis. The most consistent associations occurred in the listed districts in the Northern Region. The present analysis helps to guide district-specific interventions which may reduce the burden of surgically treatable conditions. Public resources for the health sector are limited and projected to decrease in Uganda; thus, we argue that highest priority should be given to expansion of surgical services in the Northern Sub-Region.

Various factors likely influence Northern Uganda's higher proportion of USN. This area experienced 20 years of conflict, leading directly to a high burden of traumatic injuries [20]. Moreover, relatively fewer health facilities, as well as diminished physician density and service availability, exist in this region [36]. The road infrastructure in the north is poorer than in the rest of the country as well [37]. By the Ugandan government's own reporting, the Northern Region's poverty level is double the national average [37]. In analyzing the self-reported travel times, our results align with Linden et al.'s surgical capacity survey [4], showing that residents in Northern Uganda on average have longer travel times to reach surgical centers at secondary and tertiary levels as seen in Table 1. All of these factors likely contribute to poorer health indicators in the Northern Region. As such, the higher proportion of USN in this region is likely part of larger health system capacity issue. Conversely, the Kampala capital region and surrounding urban, peri-urban, and rural areas have a much higher density of health facilities than the national average. Even so, the proportion of USN is elevated in the capital region compared to many Ugandan districts elsewhere. When examining if this was a sampling issue, we determined the sub-region intentionally oversampled, Karamoja, had the lowest rate of USN. Therefore, we are confident the high rate observed for the North Sub-Region and hence the Northern Region overall is not a product of oversampling. As a possible underlying cause, injury researchers have posited that the exponential growth in motor vehicle use, especially motorbikes, coupled with an urban population boom, have contributed to higher incidence of injuries requiring surgical intervention [38, 39]. Further characterization of the specific factors contributing to these findings will be important going forward.

The inverse finding that care availability is greatest in the Northern region likely reflects differences in population density in this area. This metric is based on the rate of available beds compared to the population. These results indicate that distance and travel to these facilities are limiting factors for residents of Northern Uganda.

Multiple analyses from LMICs and Uganda have demonstrated a distance-decay effect on utilization of healthcare and surgical services; that is, a lower utilization rate is observed the further the individual is located from the reference facility [40–42]. The low area of coverage may explain why although the Eastern Region has highest total fertility rates [22], our survey indicates it has the lowest USN as the ratio since the care availability proportion to population is consistently higher (Fig. 3d). Our study is one of the first to examine USN in relation to distance to surgical center. The distance-decay effect was seen in our results, as higher proportions of USN correlated with areas of highest distance from surgical centers. The Lancet Commission on Global Surgery describes an "access zone" as a 2-h time limit to access a surgical center [43]. If an individual lives within the 2-h access zone, assuming all forms of transport to arrive under 2 h, surgical treatment is highly effective for meeting acute needs while also reducing non-emergent surgical needs for catchment population. This concept of "access zone" may explain the correlation we found. Our study determined that the Northern Region (including the North, West Nile, and Karamoja Sub-Regions) had an average reported travel time greater than 120 min for both secondary (HCIV and district hospital) and tertiary facilities (general, regional referral, and national referral hospitals). In conjunction with the results of the LISA analysis, these findings suggest the Northern Region and its three sub-regions represent the areas most in need of investment in new healthcare centers to address the unmet need for surgical care.

The Lancet Commission on Global Surgery recently released key recommendations for improving delivery of surgical care in LMICs in desperate need of expanded services. The commission identified eastern sub-Saharan Africa, including Uganda, as one of the areas with the lowest surgical rate globally, far below the recommended level of 5000 cases per 100,000 individuals [2]. By providing regionally specific data generated by our SOSAS Survey data and GIS analysis, we have identified the specific Sub-Regions throughout the country in greatest need of expanded surgical care. This study delineates where investment should be targeted to provide the most substantial improvements for Uganda. It is our hope that this work may be used to provide a framework to increase access to and delivery of surgical services to meet the needs of the Ugandan people and contribute to the health sector development plan.

While this study helps to define for the first time areas of USN throughout Uganda, we recognize that there are limitations that warrant discussion. The study population was selected using probability proportional to size sampling rather than a systematic sampling of the entire national population. As such, the various EAs used as the basis for defining our clusters did not capture every district throughout Uganda. Thus, some districts were represented by two to three EAs, while other districts were not represented at all. At the regional level, the sample was intentionally designed to oversample the Northern Region given historic preponderance of health research in the North compared to the Central Region. Another limitation of this study is the use of Euclidean metric to define the distance from each EA to the nearest surgical center. This displacement value may not accurately reflect the true distance that must be traveled. The same limitation applies to self-reported travel time as time to travel may be influenced by socioeconomic status; we dealt with this limitation by requiring a standard list of reference government health facilities pertinent to each EA for primary to tertiary levels. Moreover, the random sampling of EAs and households within EAs should reduce any potential bias that one EA is overrepresented by wealthy individuals with better means of transport. This study could be improved by incorporating other factors, such as socioeconomic status by accounting for household property and income levels, but we were advised to avoid this due to participant fatigue and our data collection's proximity to the 2014 Uganda National Population and Housing Census data collection. This analysis cannot account for patient access to adequate transportation due to economic issues such as a lack of suitable transportation in certain areas. Difference in access to public transportation between districts is an important factor in determining the true need for surgical care throughout the country. However, we sought to overcome these limitations by including the respondent-reported travel time to healthcare centers to further validate our findings. In addition to investment in new health centers in these regions, improvement in transportation options and infrastructure available to residents may improve the rates of USN in these regions as well. Finally, we chose to use different sources of geographical access to care measures to be able to cross-validate the findings considering that each measure has its limitations due to the lack of data available for Uganda. Data on terrain or other geographic barriers that impact travel would also improve the study.

Moving forward, this study has many implications for the future of Ugandan healthcare policy dealing with provision of safe, affordable surgical care. We have identified the areas throughout this country with the highest burden of USN, the North and Southwest Sub-Regions. As the Ugandan Ministry of Health, non-governmental organizations, and international development agencies plan for future health system strengthening projects, this study will be vital in determining the districts of highest priority.

Additionally, similar studies can be conducted in other countries throughout the world to make the greatest impact in planning of facilities to deliver surgical care. Finally, this same methodology may be used to identify the unmet needs of several other specific diseases or disease categories within Uganda through disease-specific sentinel surveys.

Conclusions

Our group delivered the SOSAS Survey throughout Uganda for the first time in 2014. We then collaborated with the Ministry of Health of Uganda to conduct a GIS analysis to determine the areas with highest burden of USN. We found certain clusters of districts in the Northern Sub-Region that represent areas with the highest prevalence of USN. Moreover, the various geospatial factors we analyzed correlated with this high prevalence in the same district clusters. This analysis demonstrates the areas in Uganda that should be the focus of increased support from both the government and private organizations to meet this need of the Ugandan population. Moreover, this same methodology can be applied in other LMICs to target regions most in need of increased surgical care.

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Author contributions SHF, TMT, ATF, and EKB conducted the literature search. TMT, LA, and JRV made the tables and figures. ATF, EKB, CS, FM, SL, CM, DBN, JGC, MG, and MMH designed the study. ATF, TMT, and CM supervised data collection. SHF, JRV, TMT, ATF, EKB, LA, CS, FM, SL, JGC, MG, and MMH analyzed and interpreted the data. DBN helped interpret the data. SHF, JRV, and TMT wrote the report. All authors commented on and critically revised the manuscript.

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Compliance with ethical standards

Conflict of interest The authors report no conflicts of interest.

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