Published in final edited form as:

Prehosp Emerg Care. 2016 ; 20(6): 768–775. doi:10.3109/10903127.2016.1164775.

Population-level spatial access to prehospital care by the National Ambulance Service in Ghana

Gavin Tansley, Barclay Stewart, Ahmed Zakariah, Edmund Boateng, Christiana Achenah, Daniel Lewis, and Charles Mock

Abstract

Background—Conditions requiring emergency treatment disproportionately affect low- and middle-income countries (LMICs), where there is often insufficient prehospital care capacity. To inform targeted prehospital care development in Ghana, we aimed to describe spatial access to formal prehospital care services and identify ambulance stations for capacity expansion.

Methods—Cost distance methods were used to evaluate areal and population-level access to prehospital care within 30 and 60 minutes of each of the 128 ambulance stations in Ghana. With network analysis methods, a two-step floating catchment area model was created to identify district-level variability in access. Districts without NAS stations within their catchment areas were identified as candidates for an additional NAS station. Additionally, five candidate stations for capacity expansion (e.g. addition of an ambulance) were then identified through iterative simulations that were designed to identify the stations that had the greatest influence on the access scores of the ten lowest access districts.

Results—Following NAS inception, the proportion of Ghana's landmass serviceable within 60 minutes of a station increased from 8.7 to 59.4% from 2004 to 2014, respectively. Over the same time period, the proportion of the population with access to the NAS within 60-minutes increased from 48% to 79%. The two-step floating catchment area model identified considerable variation in district-level access scores, which ranged from 0.05 to 2.43 ambulances per 100,000 persons (median 0.45; interquartile range 0.23–0.63). Seven candidate districts for NAS station addition and five candidate NAS stations for capacity expansion were identified. The addition of one ambulance to each of the five candidate stations improved access scores in the ten lowest access districts by a total 0.22 ambulances per 100,000 persons.

Conclusions—The NAS in Ghana has expanded its population-level spatial access to the majority of the population; however, access inequality exists in both rural and urban areas that can be improved by increasing station capacity or adding additional stations. Geospatial methods to identify access inequities and inform service expansion might serve as a model for other LMICs attempting to understand and improve formal prehospital care services.

Introduction

Conditions requiring emergency treatment are a major contributor to the global disease burden (1). Although public health interventions in the form of well-planned and organized prehospital care services reduce the morbidity and mortality associated with these conditions, such services are largely limited to high-income countries where only a fraction of deaths occur [2–5]. Among the reasons for this disparity is lack of access to prehospital

care and low-quality emergency medical services in many low- and middle-income countries (LMICs). Consequently, a significant proportion of preventable deaths occur in the prehospital setting in LMICs (6).

In response to global inequalities in emergency care, the World Health Assembly (WHA) passed Resolution 60.22 in 2007 (7). This document supported the effectiveness of improving emergency care services, including the need to “assess comprehensively the prehospital and emergency-care context including, where necessary, identifying unmet need” (7,8). Despite this, there remains a paucity of emergency care service evaluations in LMICs and none from Ghana.

The National Ambulance Service (NAS) in Ghana is one of the few formalized pre-hospital care systems in Africa. As such, it provides a unique opportunity to study spatial access to prehospital care services in an LMIC. Established in 2004 and expanded over the following decade, the NAS provides nationally coordinated around-the-clock prehospital care services nationally through 128 ambulance stations that respond to more than 20,000 calls annually (9). Although the NAS is a model prehospital care system in an LMIC, its utilization is relatively low and significant unmet prehospital care needs remain (10). For example, Ghana has an estimated 19 – 27 major injuries per 1,000 person years (11). Extrapolating to NAS service delivery, formal prehospital care is provided to fewer than 5% of these injuries, ignoring all other emergencies (10). In a country where the majority of trauma deaths occur before reaching hospital care, improving prehospital care services may have a substantial impact on trauma-related mortality.

The geographic organization of the NAS relative to the population, which has both access and equity implications for patients with emergency conditions, has not been evaluated. To address this gap, we aimed to quantify spatial access to NAS services nationally within a geographic information system (GIS). Using related methods, we also aimed to identify potential expansion locations to improve service equity. Quantifying population-level access to prehospital care is important for benchmarking and planning emergency infrastructure expansion for Ghana, as well as other LMICs more generally.

Methods

Setting

Ghana is a West African nation of 25.9 million people and a population density of 101.5 persons/km² (12). With a gross domestic product of US\$ 48.1 billion, Ghana is classified as a lower-middle income country by the World Bank (12). Although it is predominantly urbanized with several densely populated cities (e.g., Accra, Kumasi, Tamale), 47% of Ghana’s population lives in rural areas (12). Ghana has a road network of 101,000 km, 13% of which is paved (12). The major geographic features of Ghana are illustrated in Supplementary figure 1.

Study Data

NAS stations—A list of 128 ambulance station locations was provided by the NAS. Each station was geolocated using Google Earth (Google, Mountain View, CA). Data on the year

each station became operational and the number of ambulances per station were also provided by the NAS.

Population—National population data were represented by a 100 m² gridded population surface generated by the WorldPop project (13). This open-access initiative combines census data with ancillary datasets such as settlement locations and land use to model population distributions. As the majority of a census enumeration area's population resides within settlements, this method provides higher resolution approximations of the spatial distribution of populations than estimates based exclusively on the census-derived population counts of administrative areas (14,15). For Ghana, the dataset was built using the most recent census in 2010 and modeled estimates for 2015 based on United Nations population projections.

Road network—To create a suitable national road network, we combined data from Open Street Map (OSM) and the Centre for Remote Sensing and Geographic Information Services (CERSGIS). Primary roads (i.e., trunk roads connecting major cities) and secondary roads (i.e., inter-regional routes) were obtained from OSM, a crowd sourced mapping service that generates digitized, open-access maps through the use of aerial imagery, Global Positioning System (GPS) technology, and field maps (16). Tertiary roads (i.e., minor roads, tracks) were obtained from CERSGIS, a public centre commissioned by the Environmental Protection Agency that conducted a national survey of all engineered and non-engineered roads and digitized them using GPS technology (17). Two data sources were required as neither one on their own had the topology or resolution required for routing analyses.

Using ArcMap 10.3 (Esri, Redlands, CA), tertiary roads were extracted from the CERSGIS dataset and integrated with the OSM dataset with a 200-meter tolerance. Following topological verification, speed limits were assigned to each road class based on national traffic laws: 100 kmh⁻¹, 50 kmh⁻¹ and 30 kmh⁻¹ for primary, secondary and tertiary roads, respectively (18,19).

Data Analysis

Cost distance analysis—A cost distance analysis was performed to determine spatial access to NAS services. We superimposed a grid (i.e. cost surface) over the country; each cell was assigned an impedance value corresponding to the time required to traverse that cell. The technique identified the least time consuming path from any point on the grid to the nearest NAS service station. The cost surface was constructed using the national road network and each road's corresponding speed limit. Background cells were assigned a value corresponding to a speed of travel of 5 kmh⁻¹ (i.e. the average speed of walking). As ambulances are expected to remain on roads, other barriers, such as hydrological features, were not incorporated into the cost surface.

The proportion of the population with access to NAS services was evaluated by overlaying the gridded population surface over the cost distance analyses and identifying the sum of the population within 30- and 60-minutes of an NAS station. In Ghana, NAS stations are typically located near hospitals, therefore the 30- and 60-minute catchment areas used in our analyses were chosen to approximate prehospital intervals of 60- and 120-minutes, respectively. Both of these intervals have been used to define accessible health systems in

the emergency and trauma system literature (20,21). The primary outcome of this analysis was the proportion of Ghana's population residing within 30- or 60-minutes of an NAS station.

Sensitivity analysis—To evaluate model stability, two additional network datasets were built; travel speed for each road segment was augmented by $\pm 20\%$. The analysis was repeated for each of these road networks to create a lower and an upper estimate of the population proportion within each catchment (i.e. uncertainty interval).

Two-step floating catchment areas—To more accurately capture the interactions between ambulance availability and the population distribution, a two-step floating catchment area method (2SFCA) was used. This method generated an access score for each of Ghana's district through a two-step process:

1. The station-level ambulance to population ratio was calculated by dividing the number of ambulances at a station by the population living within the station's 60-minute catchment area.
2. The ambulance to population ratios for all stations located within a 60-minute catchment area of a district's geographic centroid were then summed to create an access score that corresponded to a district-level ambulance to population ratio.

The 60-minute catchment areas were constructed using network analysis. Network analysis is a vector-based GIS method that estimates travel times based on the accumulated travel costs associated with traversing road segments and their connecting nodes (19). The analysis generated overlapping line segments around every station and district centroid corresponding to all roads within 60-minutes of travel time from each origin. District and NAS station catchment areas were created through the generation of a 2,500-meter buffer around each location's network of road segments. A 2,500-meter buffer was chosen as it was the minimum search tolerance required to link all NAS stations and district centroids to the road network for the network analysis. Selecting this buffer size therefore ensured all points could potentially be incorporated into a service area.

If a district's centroid was within a NAS station's catchment area, the district's population was included in the first calculation for that station. Similarly, if a NAS station was located within a district's catchment area, the station's ambulance to population ratio was included in the second calculation for that district. The resulting values represented the NAS access scores for each district, defined as the number of ambulances/100,000 persons.. Lower values represented lower spatial access. Districts with no NAS stations within their 60-minute catchment areas were identified as candidate districts for an additional NAS station and excluded from the expansion simulation.

Capacity expansions were modeled within ArcMap by recalculating the district access scores following the iterative addition of one ambulance to each NAS station. The five stations with the greatest influence on the ten lowest access districts were identified through

this simulation as candidate stations for additional ambulances. Associations between access scores and district populations were analyzed using linear regression.

Results

All 128 NAS stations were successfully geolocated. The distributions of the NAS stations and population were grossly similar and the road network utilized in all analyses provided adequate national coverage (Supplementary figure 1).

Areal and population-level spatial access

The growth of the NAS between 2004 and 2014 is shown in Figure 2. Since the inception of the NAS, the proportion of Ghana's landmass that is serviceable within 60-minutes of an NAS station has increased from 8.7 to 59.4%.

Similarly, population-level access to NAS services within 60-minutes increased over the same period. Specifically, the proportion of the population within a 60-minute catchment area of a NAS station has increased from 37% in 2004 (uncertainty Interval [UI] 33.2–40.5%) to 79% in 2014 (UI 74.8–80.4%). The population within a 30-minute catchment area of a NAS station also increased over the 10-year period: 26% (UI 24.2–27.6%) to 61% (UI 55.3–66.0%) in 2004 and 2014, respectively (Table 1).

Identifying targets for station addition and expansion

The demographic and geographic properties of Ghana's districts are described in Table 2. Using the 2SFCA method, access scores were calculated for each district. These values were plotted by quintile with the corresponding population quintiles of each district (Figure 3). The catchment areas of seven districts, representing 3.9% of the country's population, did not contain any NAS stations (e.g. Sekyere East, Sene, Tain) (Table 3). These districts would potentially benefit from the addition of a NAS station.

There was a negative correlation between a district's population and access to NAS services: the more populated areas, particularly those in the southern half of the country, had correspondingly lower population-level spatial access to NAS services ($\beta -0.17$; $p=0.046$; $R^2=0.03$). Further, the level of access in each district was variable. District access scores among serviced districts ranged from 0.05 ambulances per 100,000 persons in the Obuasi Municipal District to 2.4 ambulances per 100,000 persons in the Sissala West District (median 0.45, interquartile range 0.23–0.63).

In addition to identifying districts without NAS stations within their 60-minute catchment areas, sequential infrastructure expansion simulations determined which stations had the greatest influence on the access scores of the ten lowest access districts. The five stations with the greatest impact are plotted in Figure 3. The addition of one ambulance to each of these five stations improved the access scores of the lowest access districts by a total of 0.22 ambulances per 100,000 persons (Table 4).

Discussion

This study aimed to describe spatial access to NAS services as a benchmark of prehospital care capacity and to inform emergency infrastructure expansion priorities for Ghana. Further, the study might be useful for other LMICs working to improve pre-hospital care coverage. From 2004 to 2014, the percent of the population with spatial access to NAS services within 30- and 60-minutes increased from 26 to 61% and 37 to 78%, respectively. However, significant disparities in spatial access exist; these areas would be useful targets for station creation and/or expansion to reduce unmet prehospital care needs.

GIS-based analyses are being used increasingly to improve healthcare organization (22). Although initially developed to describe spatial access to primary care, the 2SFCA and related models have subsequently been adapted to analyses of prehospital transport in high-income settings (23–25). The use of GIS-based methods for health service organization in LMICs has been more limited due, in part, to the limited availability of spatial data of sufficient quality (26).

Comparisons between the NAS and other prehospital care systems are challenged by a lack of published benchmarks from LMICs. In the United States, a response time target of 8-minutes for 90% of calls has been suggested, but this guideline is based largely on the results of one study of patients who suffered cardiac arrest (27,28). However, exceeding this standard for the other emergencies has not been shown to negatively impact outcome (27). A multicenter study by Newgard and colleagues did not demonstrate an association between prehospital interval and patient outcomes (29). However, the majority of the response time intervals in this study were less than 40 minutes, all participating sites provided professional prehospital care and care was provided within an integrated trauma system. Thus, the findings provide little generalizability to LMICs. South Africa, a middle-income nation with a more mature prehospital care system than Ghana, aims to respond to calls within 15 minutes in urban centers and 40 minutes in more rural areas (30,31). The findings from our analysis suggest that NAS expansion and resultant improvements in population-level spatial access to prehospital care is broadly compatible with this target. Nonetheless, 22% of the population remains outside of 60-minute NAS catchment areas (5.7 million individuals). Thus, significant opportunity to avert death and disability related to unmet prehospital care need exists. The documented NAS average prehospital time of 20-minutes suggests service utilization is predominantly occurring in more urban centers located proximally to NAS stations (10). Prior to NAS expansion, prehospital care services could be provided to populations currently without access by creating a tiered prehospital care system that incorporates trained laypeople to provide transport and basic care. This model has been effective in countries without formal prehospital care systems, including Iraq and Cambodia (32).

Despite the relatively high population-level spatial access to NAS services found in our analysis, there are notable variations in spatial access across Ghana. A significant proportion of the country and population remains unreachable within 1-hour given the current distribution of NAS stations (40.6% and 22%, respectively). While this results in inequalities for some rural populations, there are also considerable variations in access among urban

populations. The current single-ambulance capacity of most NAS stations in densely populated areas has resulted in poor access to formal prehospital care services relative to more sparsely populated serviceable areas. Detection of underserved areas is the major advantage of geospatial analyses, as they can inform the targeted creation and/or expansion of capacity to address these deficiencies and inequalities in access. Here, we demonstrate the adaptation of the 2SFCA technique to identify underserved districts and which stations, if expanded by the addition of a single ambulance, would have the greatest benefit for the most underserved populations. As this technique disregards district boundaries, it has the advantage of identifying stations that can simultaneously service multiple underserved districts. This results in more efficient improvements than simply adding stations to districts without them, or adding ambulances to stations in districts with low ambulance to population ratios. The districts and stations identified in our analysis provide guidance for the equitable expansion of NAS services in Ghana.

Although Ghana has relatively good population-level spatial access to prehospital care, NAS service utilization remains low. In 2014, the NAS performed 0.21 responses per ambulance per day, compared to the ambulance services of Shenzhen, China and New South Wales, Australia, which performed 6.0 and 46.7 responses per ambulance per day, respectively. Non-spatial barriers to access such as the knowledge, acceptability and affordability of NAS services and/or healthcare may affect utilization and are potential explanations for this disparity that require exploration (33). It is common to ignore non-spatial factors in analyses of prehospital emergency care by assuming the necessity of service overrides the knowledge, preferences and financial constraints of the patients (34). Such assumptions may be more reasonable in high-income settings with well-established prehospital care services. The results from this study suggest that these assumptions are invalid in Ghana. Thus, research regarding non-spatial barriers to prehospital care is required to identify factors contributing to the low utilization of NAS services that are amenable to intervention.

This study provides a robust analysis of population-level access to NAS services. However, certain limitations should be considered when interpreting the findings. First, this analysis did not incorporate the contributions of operational protocols, dispatch times, potential variations in traffic patterns, navigation errors and/or scene time. Although our results were stable with regards to changes in road travel speed, these additional factors might significantly impact revealed spatial access. This limitation underscores the need for georeferenced utilization data from prehospital care systems so that detailed comparisons between potential and revealed spatial access can be made. Second, the 2SFCA expansion simulation technique requires geographic centroids of districts being contained within NAS service areas before they can be included in the expansion simulation. In our analysis, seven districts were excluded due to the lack of proximity of their catchment areas to a NAS station. However, this represented only 3.9% of the population, maintaining the overall validity of the simulation to the vast majority of the population and provides important data for specific-district expansion. Third, we did not incorporate travel time from the scene to a capable facility. This is difficult to estimate given the critically low and variable emergency care capacity in Ghana, like other LMICs (35,36). Therefore, the access models we developed represent the time from response to prehospital care. Lastly, the models did not account for emergency condition rates nationally or by specific areas. Prehospital care need

may not be uniform across the country. Community-based studies of emergency condition incidence have not been systematically performed across Ghana to include in spatial access models. Despite these limitations, the results from this study demonstrate significant improvement in potential population-level spatial access of the NAS since its inception. Further, reasonable conclusions can be drawn regarding areas where spatial access could be improved with station capacity expansion.

Conclusion

The NAS in Ghana has expanded its spatial access to the majority of the population; however, more than 20% of the population remains unable to receive prehospital care within 60 minutes. Further, inequities in access persist in both rural and urban areas of the country and overall utilization rates remain low. To improve spatial access, several sites where station creation or expansion could provide the greatest benefit were suggested. Significant efforts to identify and redress non-spatial determinates of prehospital care access (e.g., knowledge, acceptability, affordability) are needed to improve NAS utilization. The use of GIS-based methods to identify access inequality, inform service expansion and suggest evaluation of other utilization barriers might serve as a model for other LMICs attempting to understand and improve formal prehospital care services.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

References

1. Mathers, C.; Fat, D.; Boerma, J. The Global Burden of Disease: 2004 Update. Geneva: World Health Organization; 2004.
2. Nathens AB, Brunet FP, Maier RV. Development of trauma systems and effect on outcomes after injury. *Lancet*. 2004 May 29; 363(9423):1794–1801. [PubMed: 15172780]
3. MacKenzie EJ, Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, Egleston BL, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006 Jan 26; 354(4):366–378. [PubMed: 16436768]
4. Dutton RP, Stansbury LG, Leone S, Kramer E, Hess JR, Scalea TM. Trauma mortality in mature trauma systems: are we doing better? An analysis of trauma mortality patterns, 1997–2008. *J Trauma*. 2010; 69:620–626. [PubMed: 20093983]
5. Norton R, Kobusingye O. Injuries. *N Engl J Med*. 2013 May 2; 368(18):1723–1730. [PubMed: 23635052]
6. Hofman K, Primack A, Keusch G, Hrynokow S. Addressing the Growing Burden of Trauma and Injury in Low- and Middle-Income Countries. *Am J Public Health*. 2005 Jan; 95(1):13–17. [PubMed: 15623852]
7. World Health Assembly. World Health Organization Website; 2007. Health systems : emergency-care systems [WHA Resolution 60.22]; p. 21-23.
8. World Health Assembly. Health Systems-Emergency Care Systems. 2007
9. Mock C. Strengthening care for the injured: success stories and lessons learned from around the world. 2010
10. Zakariah A, Stewart B, Boateng E, Achena C, Tansley G, Mock C. The birth and growth of the National Ambulance Service in Ghana: Instructive lessons for planning pre-hospital care in low- and middle-income countries. 2015

11. Mock CN, Abantanga F, Cummings P, Koepsell TD. Incidence and outcome of injury in Ghana: a community-based survey. *Bull World Health Organ.* 1999 Jan; 77(12):955–964. [PubMed: 10680242]
12. The World Bank. Ghana [Internet]. [cited 2015 Jun 30] Available from: <http://www.worldbank.org/en/country/ghana>.
13. The WorldPop Project. WorldPop Data [Internet]. [cited 2015 Jan 11] Available from: <http://www.worldpop.org.uk/>.
14. Linard C, Gilbert M, Snow RW, Noor AM, Tatem AJ. Population distribution, settlement patterns and accessibility across Africa in 2010. *PLoS One.* 2012; 7(2)
15. Tatem AJ, Noor AM, von Hagen C, Di Gregorio A, Hay SI. High resolution population maps for low income nations: combining land cover and census in East Africa. *PLoS One. Public Library of Science.* 2007 Jan 12; 12(12):e1298.
16. OpenStreetMap [Internet]. [cited 2015 Jun 29] Available from: <http://www.openstreetmap.org/#map=6/-1.494/36.310>.
17. Mensa, M.; Sablah, E.; Amamoo-Otchere, E.; Mensah, F. Digital Mapping and GIS-Driven Feeder Road Network Database Management System for Road Project: Planning and Implementation Monitoring in the Feeder Road Sector. Accra, Ghana: 2006.
18. Damsere-Derry J, Afukaar FK, Donkor P, Mock C. Assessment of vehicle speeds on different categories of roadways in Ghana. *Int J Inj Contr Saf Promot.* 2008 Jun; 15(2):83–91. [PubMed: 18642165]
19. Derry JD, Afukaar FK, Donkor P, Mock C. Study of vehicle speeds on a major highway in Ghana: implication for monitoring and control. *Traffic Inj Prev.* 2007 Jun; 8(2):142–146. [PubMed: 17497517]
20. Hameed SM, Schuurman N, Razek T, Boone D, Van Heest R, Taulu T, et al. Access to trauma systems in Canada. *J Trauma.* 2010 Dec; 69(6):1350–1361. discussion 1361. [PubMed: 20838258]
21. Meara, JG.; Leather, AJM.; Hagander, L.; Alkire, BC.; Alonso, N.; Ameh, EA., et al. Lancet. Elsevier; 2015 Apr 21. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development.
22. Cromley, EK.; McLaffery, S. GIS and Public Health. 2nd. New York, NY: The Guilford Press; 2012.
23. Lee, E. Systems. Vol. 2. Multidisciplinary Digital Publishing Institute; 2014 Mar 6. Designing Service Coverage and Measuring Accessibility and Serviceability of Rural and Small Urban Ambulance Systems; p. 34–53.
24. Wang F, Luo W. Assessing spatial and nonspatial factors for healthcare access: towards an integrated approach to defining health professional shortage areas. *Health Place.* 2005 Jun; 11(2): 131–146. [PubMed: 15629681]
25. Peters J, Hall GB. Assessment of ambulance response performance using a geographic information system. *Soc Sci Med.* 1999 Dec; 49(11):1551–1566. [PubMed: 10515636]
26. Gething PW, Amoako Johnson F, Frempong-Ainguah F, Nyakro P, Baschieri A, Aboagye P, et al. Geographical access to care at birth in Ghana: a barrier to safe motherhood. *BMC Public Health.* 2012; 12(1):1. [PubMed: 22214479]
27. Pons PT, Markovchick VJ. Eight minutes or less: Does the ambulance response time guideline impact trauma patient outcome? *J Emerg Med.* 2002; 23(1):43–48. [PubMed: 12217471]
28. Eisenberg MS, Bergner L, Hallstrom A. Cardiac resuscitation in the community. Importance of rapid provision and implications for program planning. *JAMA.* 1979; 241(18):1905–1907. [PubMed: 430772]
29. Newgard CD, Schmicker RH, Hedges JR, Trickett JP, Davis DP, Bulger EM, et al. Emergency medical services intervals and survival in trauma: assessment of the “golden hour” in a North American prospective cohort. *Ann Emerg Med.* 2010 Mar; 55(3):235.e4–246.e4. [PubMed: 19783323]
30. The World Bank. South Africa [Internet]. [cited 2015 Jul 4] Available from: <http://www.worldbank.org/en/country/southafrica>.
31. MacFarlane C, van Loggerenberg C, Kloock W. International EMS systems in South Africa—past, present, and future. *Resuscitation.* 2005 Feb; 64(2):145–148. [PubMed: 15680521]

32. Husum H, Gilbert M, Wisborg T, Van Heng Y, Murad M. Rural prehospital trauma systems improve trauma outcome in low-income countries: a prospective study from North Iraq and Cambodia. *J Trauma*. 2003 Jun; 54(6):1188–1196. [PubMed: 12813342]
33. McIntyre D, Thiede M, Birch S. Access as a policy-relevant concept in low- and middle-income countries. *Health Econ Policy Law*. 2009; 4(Pt 2):179–193. [PubMed: 19187569]
34. Schuurman N, Hameed SM, Fiedler R, Bell N, Simons RK. The spatial epidemiology of trauma : the potential of geographic information science to organize data and reveal patterns of injury and services. 2008; 51(5):389–395.
35. Stewart B, Quansah R, Gyedu A, Ankomah J, Donkor P, Mock C. Strategic assessment of trauma care capacity in Ghana. *World J Surg*. 2015
36. Ankomah J, Stewart B, Oppong-Nketia V, Koranteng A, Gyedu A, Quansah R, Donkor P, et al. Strategic assessment of the availability of pediatric trauma care equipment, technology and supplies in Ghana. *J Pediatr Surg*. 2015

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1. Areal coverage of the National Ambulance Service in Ghana between 2004 and 2014
Cost distance analysis illustrating improvements in areal coverage of the National Ambulance Service between 2004 and 2014.

Figure 2. District-level National Ambulance Service access scores and populations by quintile
 A) Results of 2-step floating catchment area model demonstrating variations in spatial access. To create access scores, an ambulance/population ratio within a 60-minute service area of each National Ambulance Service (NAS) station was calculated. The ambulance/population ratios for all stations contained within each district's 60-minute catchment were then summed. The resulting values represented the access scores of the NAS for each district. Lower quintiles represent lower access. Expansion candidates represent the five ambulance stations that, when expanded by one ambulance, most significantly improved the ambulance/population ratio of the ten lowest access districts. B) District population quintiles to illustrate the relationship between population and spatial access to the NAS.

Table 1

Population-level spatial access to the National Ambulance Service in Ghana between 2004 and 2014.

Year	Population within 30-min area (%)	Uncertainty interval (%)	Population within 60-min area (%)	Uncertainty interval (%)
2004	26	24.2–27.6	48	33.2–40.5
2008	41	36.2–44.5	58	52.8–62.6
2014	61	55.3–66.0	79	74.8–80.4

Proportion of Ghana's population within 30- and 60-minute NAS catchment areas in 2004, 2008 and 2014. Uncertainty intervals represent the results of sensitivity analyses where road travel speeds were augmented by $\pm 20\%$. % - percent of national population; min – minutes.

Table 2

Geographic and demographic characteristics of Ghana's districts

Feature	Median	Interquartile Range
Area (km ²)	1180.6	674.5–2199.8
Population	144,637	111,782–192,148
Number of NAS stations	1	0–1

Table 3

Districts currently most underserved by the National Ambulance Service in Ghana identified as candidates for station creation.

District	Population (%)
Sekyere East	147,710 (0.54)
Sene	141,566 (0.52)
Tain	231,026 (0.85)
Asuogyaman	126,942 (0.47)
Aowin-Suaman	142,970 (0.52)
Bia	120,006 (0.44)
Nzema East	157,471 (0.58)
Total	1,067,693 (3.92)

Districts and their corresponding populations that had geographic centroids outside of any NAS service area. % - percent of national population.

Table 4

National Ambulance Service stations with the greatest influence on the ten lowest access districts

Station City	Absolute increase in access scores (ambulances per 100,000 persons)
Yendi	0.07
Bekwai	0.05
Tarkwah	0.04
Tolon	0.03
Goaso	0.03
Total	0.22

Results of the two-step floating catchment area expansion simulation. Cities represent where their corresponding NAS station's expansion most significantly improves the ambulance/population ratios in the ten lowest access districts. Values represent the absolute increase in the access scores of the ten lowest access districts following expansion of the station by one ambulance.