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AVERTING MATERNAL DEATH AND DISABILITY

Using a GIS to model interventions to strengthen the emergency referral system for maternal and newborn health in Ethiopia

Patricia E. Bailey [a,*], Emily B. Keyes [a], Caleb Parker [a], Muna Abdullah [b], Henok Kebede [c], Lynn Freedman [d]

[a] *FHI 360, Research Triangle Park, NC, USA*
[b] *UNFPA, Addis Ababa, Ethiopia*
[c] *WHO, Addis Ababa, Ethiopia*
[d] *Averting Maternal Death and Disability, Columbia University, New York, USA*

A R T I C L E   I N F O

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A B S T R A C T

Objectives: To show how GIS can be used by health planners to make informed decisions about interventions to increase access to emergency services. *Methods:* A combination of data sources, including the 2008 national Ethiopian baseline assessment for emergency obstetric and newborn care that covered 797 geo-coded health facilities, LandScan population data, and road network data, were used to model referral networks and catchment areas across 2 regions of Ethiopia. STATA and ArcGIS software extensions were used to model different scenarios for strengthening the referral system, defined by the structural inputs of transportation and communication, and upgrading facilities, to compare the increase in access to referral facilities. *Results:* Approximately 70% of the population of Tigray and Amhara regions is served by facilities that are within a 2-hour transfer time to a hospital with obstetric surgery. By adding vehicles and communication capability, this percentage increased to 83%. In a second scenario, upgrading 7 strategically located facilities changed the configuration of the referral networks, and the percentage increased to 80%. By combining the 2 strategies, 90% of the population would be served by midlevel facilities within 2 hours of obstetric surgery. The mean travel time from midlevel facilities to surgical facilities would be reduced from 121 to 64 minutes in the scenario combining the 2 interventions. *Conclusions:* GIS mapping and modeling enable spatial and temporal analyses critical to understanding the population's access to health services and the emergency referral system. The provision of vehicles and communication and the upgrading of health centers to first level referral hospitals are short- and medium-term strategies that can rapidly increase access to lifesaving services.

1. Introduction

Despite welcome news of reductions in maternal and child mortality over the last 2 decades across the world, many countries will not meet Millennium Development Goals (MDGs) 4 and 5, and stillbirth rates continue to be unacceptably high. At the global level, much attention has been devoted to identifying packages of effective interventions and estimating their cost and potential contribution to mortality reduction [1–3]. Models such as the Lives Saved Tool (LiST) estimate the number of deaths averted if specific interventions were to be scaled up. For example, recent estimates suggest that 45% of stillbirths, 38%–68% of neonatal deaths, and 75% of maternal deaths could be averted if 90%–99% of the population had access to these packages of interventions including emergency obstetric and newborn care (EmONC) [4–7].

While the literature usefully lays out the ideal scenario in which these and other proven effective interventions are arrayed along a home-to-hospital continuum, the immediate challenge that policymakers often face involves a poorly equipped, skeletally staffed, badly functioning infrastructure, often distributed across the population and geographic area in ways that are irrational at best and inequitable at worst. Moreover, inadequate health management information systems have left policymakers with little evidence as to how the actual functioning of their systems deviates from the optimistic picture that successive health sector strategies have put forward.

The challenge for policymakers, then, is first to get a solid understanding of the status quo, and then to develop short-, medium-, and long-term plans for targeted investments that will move their health systems toward the aspirational ideal described in the global literature. In addition, they must have agile strategies to implement those plans in a dynamic environment, where multisectoral developments—such as new roads, explosive transformation in information and communications technology, and changing social norms—will bring rapid and often unpredictable changes.

Where maternal and newborn mortality is high, the deficit in skilled human resources is often a limiting factor. Even when countries adopt innovative task-sharing strategies and move to put them

* Corresponding author.
E-mail address: pbailey@fhi360.org (P.E. Bailey).

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into action, it will still take many years to ramp up training systems that can generate enough clinicians to deliver higher-level services, such as EmONC, to the entire population. Short of importing cadres of skilled clinicians from outside the country, this process simply cannot be made to happen any faster than the minimum of 3 years of training needed, even assuming (naively) that enough training capacity with qualified tutors and students could be brought online immediately and that graduates could be deployed shortly after qualification. Recent experience in different settings with community health workers who can be trained and deployed far more quickly has shown that there is potential for these cadres to contribute significantly to mortality declines (particularly for newborns), but only when they can link to a health infrastructure that can deliver emergency care when complications occur [8–10].

An emerging strategy for managing this set of changing variables that make up a district health system is to put heightened focus on referral systems, broadly defined to include not only transport, but the full range of inputs needed to efficiently move emergencies across the home-to-hospital continuum to reach definitive treatment in time to survive [11]. A well-designed, systems-sensitive referral strategy can coordinate in a dynamic way with a short-, medium-, and long-term human resources and infrastructure investment strategy to generate steady reductions in mortality and to meet other important goals such as improving equity.

Referral has both temporal and spatial characteristics, influenced by terrain, distance, road system quality, seasonality, population location, and the geographic coverage of health facilities. Geographic information systems (GIS) are tools to support decision makers to visualize relationships such as these inherent in referral, and to use them in the design, planning, and evaluation of healthcare programs. For example, GIS has been used to measure coverage of primary healthcare interventions such as childhood immunization and to map the burden of disease and the spatial dynamics of HIV/AIDS, malaria, tuberculosis [12,13], and neglected tropical diseases [14]. GIS has also been used to identify inequities in access and coverage of health services. It has helped determine where new health facilities or specialized trauma centers should be placed, or where best to post fieldworkers or helicopters [15–17]. Only recently, researchers have begun to use GIS to explore maternal and newborn health issues [18–20]. These authors used different geographic information systems to assess accessibility of childbirth services for pregnant women.

To our knowledge, GIS has not yet been used as a tool to strengthen referral systems in low- or middle-income countries. Decisions about where to place or upgrade facilities to provide comprehensive EmONC and where to station transport or communications resources are often based on administrative or political considerations rather than on evidence about improving access, equity, or health outcomes. Even the working assumptions about the status quo are more often derived from the hopeful picture painted in well-intentioned policies than from actual performance of key functions. Disconnects of this type lead to the misallocation of resources and contribute to the failure of health systems to achieve their desired outcomes, including the building of trust among the communities they are supposed to serve.

In this paper we show how GIS can be used to facilitate a set of multicriteria decision analyses that can help health system managers and planners to improve their understanding of the existing emergency referral system and its potential to contribute to mortality reduction over the short, medium, and long term. This includes describing networks of sending and receiving facilities, identifying which facilities lack essential components of a well-functioning referral system, and what proportion of the population is served by facilities that provide key services. The paper also presents exploratory modeling of “what if” scenarios that can be used to identify short- or medium-term strategies to increase access to comprehensive EmONC. The models we chose focus primarily on inputs to the existing health system: motorized vehicles for emergency transport, telecommunication systems, and upgrading facilities to provide obstetric surgery.

The choice of Ethiopia for this exercise is well suited because it is predominantly a rural country where access to services is challenged by poor road infrastructure and relatively few healthcare facilities. The demand for services is low but the government commitment is strong. The northern regions of Tigray and Amhara of Ethiopia were selected because of their shared topography and contiguous location, but also because of their dissimilar health system indicators. The choice was timely given the Federal Ministry of Health's (FMOH) recent prehospital healthcare initiative to tackle the referral system on a national scale. One of their goals is to ensure that each district has its own emergency vehicle (personal communication, Dr Abreham Endeshaw, Medical Services, FMOH).

2. Methods

2.1. Scenario setting

To identify short- or medium-term strategies to increase access to services, we built spatial models of the status quo referral networks and determined the time it currently takes to transfer patients from first level facilities to referral level facilities. By overlaying these spatial referral networks onto population density maps and defining catchment areas, we were able to determine what proportion of the population is currently served by first level facilities that are situated within a 2-hour travel time from a facility that does obstetric surgery. To determine whether upgrades in transport and/or facility infrastructure could improve population access, we built 3 models or “what if” scenarios to strengthen those referral networks:

1. What if all facilities without a communication system and/or without their own means of transport were provided with these inputs? Although facilities with their own transport would not require calling ahead to request a vehicle, a communication system is critical to alert the receiving facility of the arrival of a patient in certain conditions, or to obtain advice regarding prehospital care among other reasons.
2. What if we altered the current configuration of referral networks by upgrading strategically selected facilities to be able to provide obstetric surgery? Although facilities experience many benefits by having their own motorized vehicles for transporting referrals, supplying transport to all facilities at any one time is likely to be unaffordable. A reconfiguration of the referral networks would lead to reductions in transfer time for facilities in designated strategic areas.
3. What if we combined the two strategies?

To select facilities for upgrading, we gave priority to those with relatively high levels of utilization for delivery care; number of obstetric beds (having 5 or more beds); infrastructure (those with piped water and electricity); current capacity to provide EmONC (how many signal functions the facility had performed in the last 3 months, comprising parenteral antibiotics, oxytocics and anticonvulsants, manual removal of placenta, removal of retained products, assisted vaginal delivery, neonatal resuscitation with bag-mask, cesarean delivery, and blood transfusion); and the availability of an operating theater, surgical equipment, and human resources. Proximity to a functioning referral hospital was also considered to determine a more equitable distribution of referral hospitals. Finally, the location-allocation tool of the Network Analyst extension in ArcGIS (Esri, Redlands, CA, USA) was used to identify 5 facilities among 11 suitable candidates based on the greatest reduction in travel time for the greatest number of facility catchment areas. Two facilities were chosen outright based on their high functioning status and the availability of an operating theater, equipment, and human resources.

2.2. Sources of data

Several types of data are required to answer these questions: comprehensive facility-specific information such as whether a facility has its own means of emergency transport, a landline or cell phone, and what clinical services the facility routinely provides. Other types of data include population density, elevation, and information related to the road system.

Several sources of data were pooled to enable this set of analyses. The primary dataset was the Ethiopian Baseline Assessment for Emergency Obstetric and Newborn Care [21]. In 2008, the Federal Ministry of Health of Ethiopia, UNICEF, UNFPA, WHO, and Columbia University's Averting Maternal Death and Disability program partnered to conduct this national cross-sectional facility-based assessment. Data were collected from October 1, 2008 until January 15, 2009. Details of the survey can be found elsewhere [21,22]. Data were collected from 112 hospitals and 685 health centers/clinics nationwide. Although intended to be a full census of public and private (for profit and not-for-profit) hospitals, health centers, and higher clinics, a small number of private higher clinics and hospitals were not included because their names did not appear on the list of licensed facilities, or they did not provide maternity services, or in two cases facility personnel did not wish to collaborate with data collection. The EmONC assessment was the source for all facility-specific information.

An innovative feature of the assessment was that every facility visited was geocoded. During the data collector and supervisor training, all team members were taught to use GPS devices. Local CDC and WHO staff trained and supervised the accuracy of the GPS readings. Of the 797 facilities in the final dataset, only two were inaccurately geo-referenced.

Spatial population data came from the LandScan Global Population Dataset from 2008 produced by Oak Ridge National Laboratories. The road network dataset was developed by integrating datasets from Google Maps, Digital Chart of the World, United Nations Development Program (UNDP), Esri, and the Intergovernmental Authority in Development. The sources of the digital elevation data were the US Geological Survey, the Earth Resources Observation and Science Center, and UNDP. The road network data differentiated most roads as all-weather roads of asphalt, all-weather roads of gravel, dry-weather roads, and motorable tracks. Considerable desk work was required to review and revise the road network data.

2.3. Software

The different data sources were linked to the EmONC assessment data using Stata version 10 (StataCorp LP, College Station, TX, USA) and ArcGIS 10 (Esri). They were analyzed using ArcGIS software extensions Network Analyst and Spatial Analyst. With these tools we modeled the current referral networks of facilities, calculated the population within catchment areas that were modeled, and finally modeled the "what if" scenarios.

2.4. Definition of variables and terms

We defined a *referral network* as a cluster of facilities that refer patients to one specific higher functioning facility that routinely conducts cesarean deliveries, as determined by its performance during the 3 months prior to the assessment visit. These surgical centers were called Tier A facilities, or receiving facilities. All other facilities were considered Tier B or sending facilities (in 2 cases, small private facilities were demoted to Tier B since they were located close to large busy Tier A facilities and they were considered less likely to receive referrals than their larger public neighbors). Tier A facilities were further refined by taking into consideration the annual number of deliveries and their proximity to other Tier A facilities. Referral networks were based on the shortest distance along the road system from a Tier B facility to a Tier A facility as determined by GIS using the Network Analyst extension. Each Tier B was assigned to the closest Tier A.

We calculated *direct travel time* from each Tier B facility to its closest Tier A facility based on distance along the road network, taking into consideration the road surface and season (Table 1). All measurements were calculated using the dry season, biasing our scenarios in a more favorable direction.

Actual time to transfer a patient should also consider the notification time (time to communicate with the referral dispatcher), and the response time (time for the dispatcher to handle the emergency call and reach the driver) as well as the direct travel time (time to reach the Tier A facility). Based on how well equipped each facility was for referral—whether they had an ambulance or some other type of motorized vehicle and whether they had some form of communication (landline, cell phone, or radio)—we calculated the *adjusted transfer time* as follows:

- If a Tier B facility had transportation on site the transfer time would be equal to the direct travel time to Tier A.
- If Tier B did not have transportation on site, but could communicate with Tier A, we assumed that the Tier B facility would request Tier A to send a vehicle and the direct travel time was doubled.
- If Tier B had neither transportation nor a means of communication, the transfer time would be double the direct travel time plus an additional 30 minutes (notification and response time).
- We assumed that each Tier A had a vehicle that could be used for such out-and-back purposes, that it was functioning, and that this was accepted practice.

The core principle of emergency medicine is rapid intervention. The concept of a "golden hour" between severe trauma and the operating theater is well recognized as a standard goal in emergency medicine for maximizing survival, although its evidence base is not clear [23]. Among the major direct causes of maternal death, postpartum hemorrhage may be the most lethal obstetric complication as women can die within a 2-hour window or less [24,25]. Desired transfer times of 1–2 hours have been adopted by several low- and middle-income countries [26,27]. Given the topography and current distribution of infrastructure in Ethiopia, we adopted 2 hours as the minimum acceptable transfer time in this context of referral between facilities.

When discussing coverage of health facilities, the entire population of any specific area must be allocated to a health facility. Thus, the 2 regions were divided into *catchment areas* where each household has only 1 choice of facility based on geographic proximity and travel time [16]. Using the cost allocation tool (cost in terms of energy expended, not in terms of currency), the GIS delineated each catchment area by calculating the closest facility for each square meter in the study area, along the easiest path. Ease of movement was defined by 3 variables: slope, road availability, and presence of major rivers. Higher degrees of slope were given higher cost values, road availability decreased the cost value of the slope by half, and major rivers were given extraordinarily high cost values, making them nearly impermeable boundaries except where bridges exist. Catchment area polygons were then generated by outlining the group of cells that go to the same facility. Using the LandScan population dataset, the population

Table 1
Assumptions for estimating direct travel time.

Road type	Dry season, kph/mph
All weather – paved	80/50
All weather – gravel	55/35
Dry weather	55/35
Motorable tracks	15/10

Table 2
Regional and national characteristics.

	Tigray	Amhara	National
Population 2007 Census	4 400 000	12 200 000	73 900 000
Number of facilities in assessment	60	189	797
Number of facilities that attended deliveries	56	177	751
Percentage of facilities with motorized transport	58%	41%	47%
Percentage of facilities with telecommunications	72%	62%	63%
Percentage of recommended Basic and Comprehensive EmOC	25%	8%	11%
Percentage of minimum recommended C-EmOC	55%	19%	39%
Institutional delivery rate	9%	5%	7%
Met need (proportion of expected women with obstetric complications treated)	13%	4%	6%
Percentage of health centers with desired staffing	45%	2%	NA
Ratio of skilled birth attendants to 100 expected births	0.72	0.28	0.46
Cesarean delivery rate (population based)	0.7%	0.2%	0.6%
Public health expenditure per capita (2007)	US $2.81	US $1.50	US $2.20

Sources: [21,32].
Notes: The recommendation is 5 EmOC facilities per 500 000 population where at least 1 is C-EmOC [33]; the Federal Ministry of Health recommends that health centers should be staffed by 2 midwives and 1 health officer; skilled attendants were defined as midwives, nurses, health officers, medical doctors, and obstetrician/gynecologists. UNFPA recommends 1 midwife for every 100 expected births. The exchange rate was US $1 = 10.118 Ethiopian birr on January 1, 2009.

within each catchment area was calculated. Because some facilities had a neighboring facility within a few kilometers, some catchment areas contained 2 or 3 facilities, but most contained only 1.

3. Results

The two regions Tigray and Amhara are compared in Table 2. In general, Tigray performs above the national average and Amhara below.

3.1. Defining the referral networks and catchment areas

Fig. 1 shows Tier A and Tier B facilities, the road system and the location of facilities that make up the referral networks. Of the 256 facilities in the greater study area, Tigray had 12 Tier A facilities and Amhara had 10. The 22 referral networks varied in size from just a single Tier A facility, or only 1 Tier A and 1 Tier B, to networks with as many as 40 Tier B facilities. Sixteen facilities were considered “off network” since they were not located on a roadway. (They were

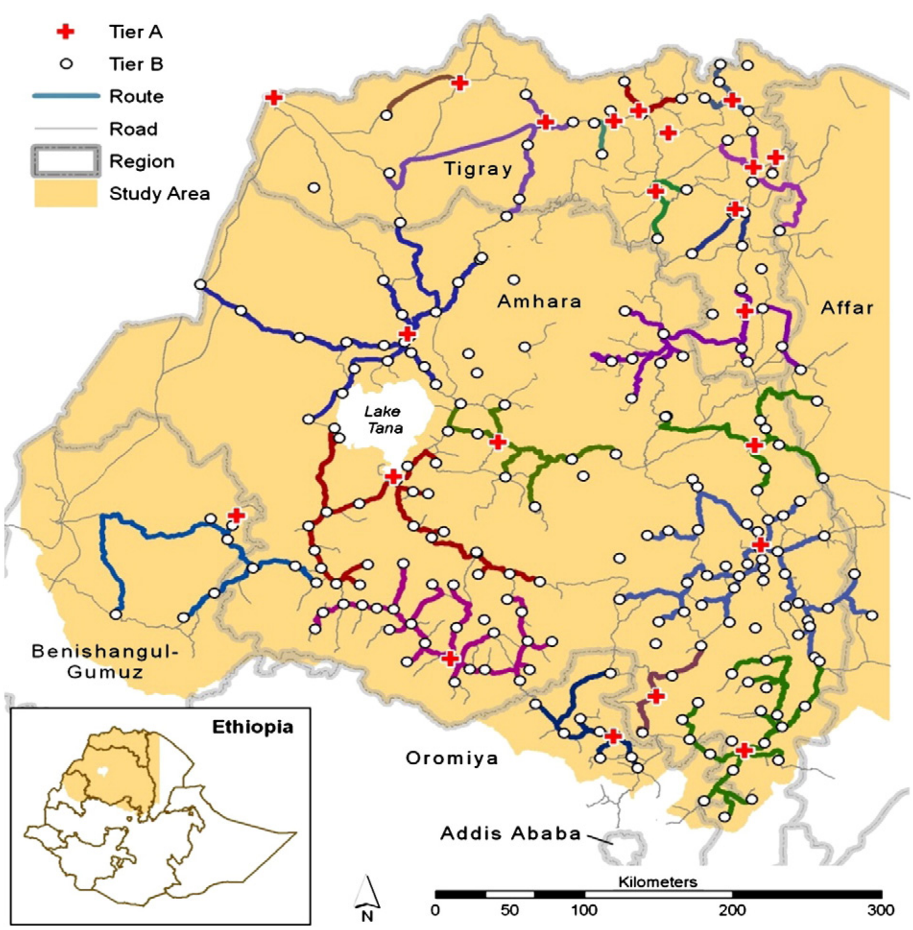

Fig. 1. Referral networks of Tier A and Tier B facilities in Tigray and Amhara.

assigned a 240-minute trip that never changed in the models. Even though their travel time would likely change in some of the models, we have no way of calculating the time as we did for facilities that were on a roadway.)

Thirty-seven percent of the Tier B facilities were located within 60 minutes travel time of a Tier A facility, 29% between 61 and 120 minutes, and 35% were at a distance greater than 2 hours. However, to put this into the context of the *population* these facilities serve, we defined facility catchment areas.

Fig. 2 shows Tier A and Tier B catchment areas and the larger catchment area clusters that make up each referral network. We determined the size of the population served by each Tier B facility and by the entire referral network (the sum of all Tier B catchment areas that refer to 1 Tier A). The 22 referral networks serve a population of 28.6 million inhabitants. A difference of more than 10 million inhabitants exists between the population estimate determined by using the data provided by LandScan and the 2007 census. The higher estimates may reflect recent population growth, the fact that we included catchment areas that are outside the administrative boundaries of Tigray and Amhara, but may also reflect other LandScan techniques for estimation. Since catchment areas do not adhere to administrative boundaries we included Tier B facilities located in the neighboring regions of Benishangul-Gumuz, Oromiya, and Affar if the network model calculated a shorter travel time to a Tier A facility in Tigray or Amhara than to a Tier A in its own region. We also included Tier A facilities in a neighboring region if a Tier B facility in Tigray or Amhara referred to it.

Applying the 2-hour transfer time to all Tier B facilities, Fig. 3 shows highlighted in a darker shade those catchment areas that met this time-limiting criterion. Of the 28.6 million residents, 70% were served by Tier B facilities that are located within the 2-hour transfer time to obstetric surgery (68% in Amhara and 80% in Tigray) (Table 3 Current Status Model 0). The average transfer time from Tier B facilities to a Tier A was 121 minutes.

3.2. Modeling different scenarios

3.2.1. Model 1: Providing transportation and communication

The first "what if" scenario (Model 1) involves providing each facility with its own transportation and communication if one or both were missing. In the current status model depicted in Fig. 3, 116 Tier B facilities had no functioning transportation and 73 had no means of communication on site. In Fig. 4, the darkest catchment areas are those that benefited from the introduction of a vehicle and telephone and now are within the 2-hour transfer time. With this adjustment, 83% of the overall population is served by Tier B facilities less than 2 hours away from a Tier A facility; this is an increase of 15 percentage points in Amhara and 5 points in Tigray over the current status model (Table 3, Model 1). Overall, an additional 35 Tier B facilities and catchment areas were added, the equivalent of more than 3.8 million people now fell within the 2-hour travel time, and the average transfer time for the population of Tigray and Amhara declined by 32%, or from 121 minutes to 82.

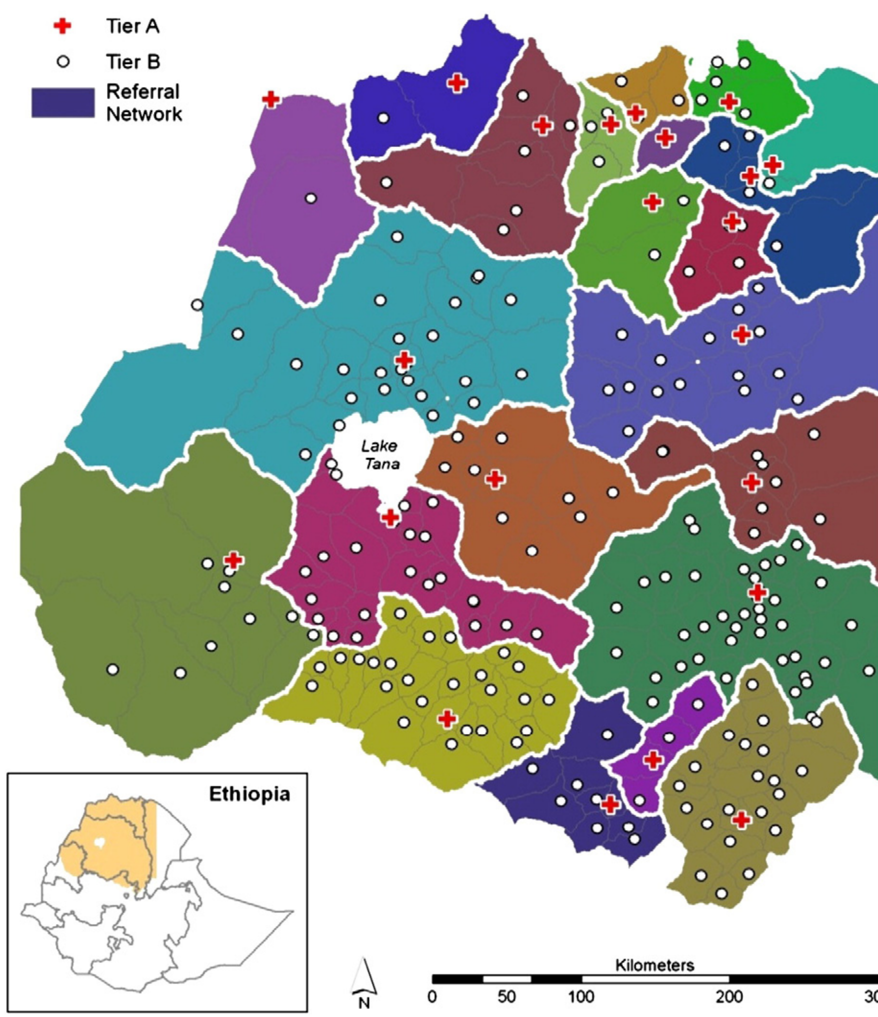

Fig. 2. Tier A and B facilities and referral network catchment areas.

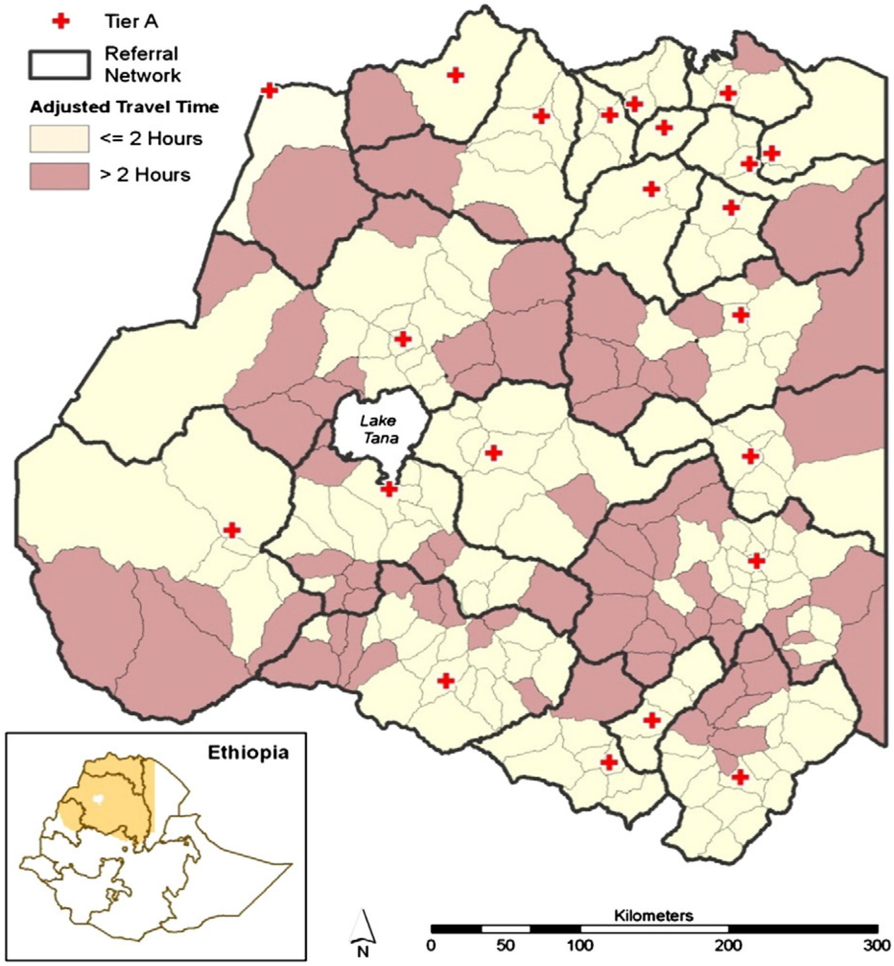

Fig. 3. Current status (Model 0) of Tier B catchment areas by 2-hour transfer time to a Tier A facility.

3.2.2. Model 2: Upgrading facilities and reconfiguring referral networks

A total of 7 upgraded facilities was our goal although 7 was an arbitrary number. As it turned out, none of the selected facilities was located in Tigray given the greater need in Amhara (Fig. 5). However, several Tier B facilities physically located in Tigray shifted their referrals to a Tier A in Amhara as a result of the reconfiguration of the referral networks.

Compared with the model of the current status, the consequences of upgrading and adding 7 additional Tier A referral networks added 26 Tier B facilities to those already within a 2-hour travel timeframe. This translated into serving an additional 3.1 million inhabitants, or increasing from 70% to 80% of the population served by Tier B facilities within the 2-hour transfer time to a Tier A facility. Access in Amhara increased from 68% of the population to 79% and in Tigray from 80% to 86% (Table 3, Model 2). The average travel time overall declined by 15%, or from 121 minutes to 103.

Table 3
Percentage of the population served by a facility within a 2-hour transfer time to obstetric surgery and mean travel time for each model, by region.

	Total population	Current status Model 0	Model 1	Model 2	Model 3
Amhara	22 283 540	68%	83%	79%	90%
Tigray	6 350 382	80%	85%	86%	91%
Overall	28 633 922	70%	83%	80%	90%
Mean transfer time		121 minutes	82 minutes	103 minutes	64 minutes

3.2.3. Model 3: The combination of Model 1 and 2 interventions

A third scenario combined the inputs of transport and communication of Model 1 and the upgrading of 7 facilities of Model 2 (Fig. 6). Compared with current status, an additional 5.8 million inhabitants or 50 Tier B facilities or catchment areas would be served, and travel time was reduced by almost half (Table 3, Model 3).

4. Discussion

We used GIS to model the impact of 2 structural interventions on the population's access to emergency surgical services. Prior to any interventions we estimated that one-third of midlevel facilities in Tigray and Amhara were located more than 2 hours from a facility that provides obstetric surgery. These “distant” facilities served a population of 8.6 million people whose lives would be at increased risk if an obstetric or newborn emergency developed. Upgrading a small number of strategically selected facilities reduced the underserved population to 5.7 million. Providing transportation and communication to facilities without those amenities reduced the underserved population from 8.6 million to 4.9 million, but the 2 interventions together reduced it to 2.9 million. Although 3 million is not an insignificant number of people, it meant that 90% of the women and infants with pregnancy or childbirth complications would be served by a lower level facility within 2 hours of a facility providing lifesaving obstetric surgery.

We proposed these interventions to the referral system and overall health system as short- or medium-term solutions that could be implemented while longer-term strategies such as training human resources and building and equipping new facilities were also being

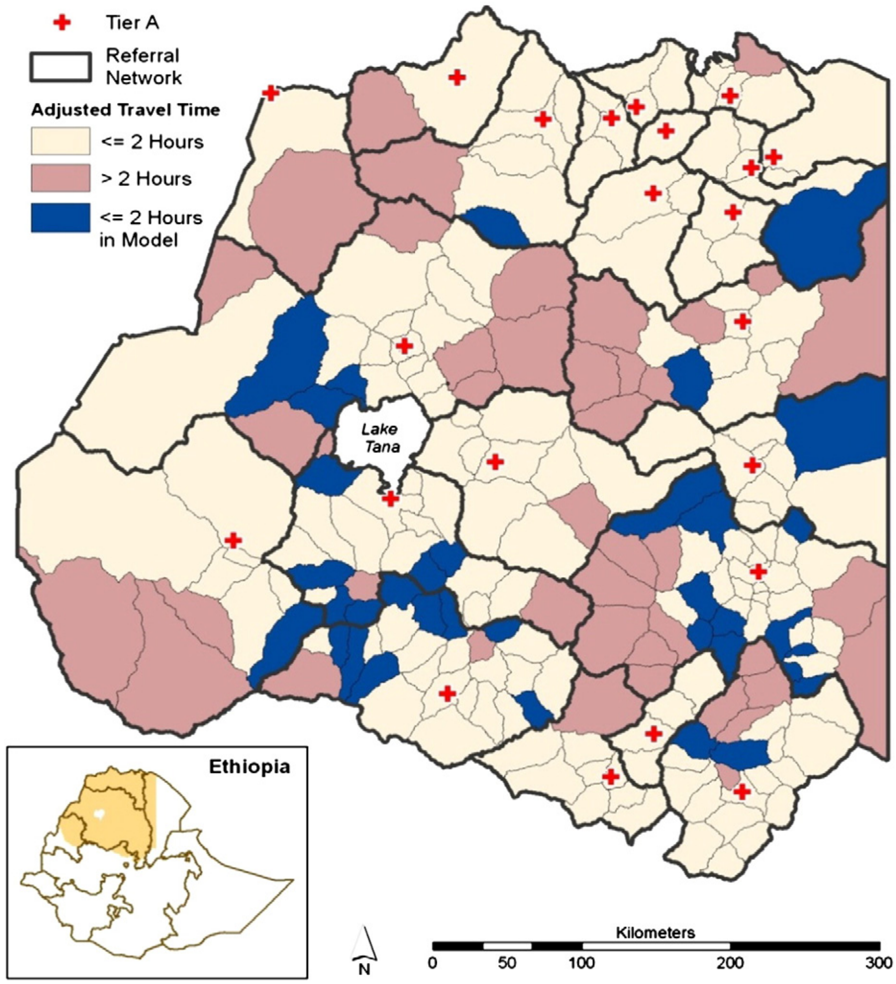

Fig. 4. Model 1 – Providing transportation and telecommunication to all facilities.

implemented. In fact, the government of Ethiopia is advancing on all these fronts: training nonphysician clinicians to provide surgery, extensive building of new health centers and posts, upgrading facilities, and the recent initiative for prehospital health care by distributing new ambulances.

As in any modeling exercise, we made a number of assumptions that affect our results and the applicability of our findings to the actual conditions that exist in Tigray and Amhara. Perhaps the most critical assumption was that Tier A facilities would have vehicles and it would be a common practice for Tier A facilities to send their vehicles to retrieve patients from lower level facilities if called upon. In fact, this is not now standard practice in Ethiopia. The time required for someone at a Tier B facility to arrange private or public transport to take them to a Tier A facility will vary widely. It might be longer or shorter than the doubling of direct travel time that was part of our assumptions. Nevertheless, this "out and back" practice is not uncommon in other African countries [28,29] and might be worth testing in select referral networks of Tigray and Amhara as they wait for longer-term solutions to be implemented.

We restricted our modeling to the dry season thus choosing parameters that would be more favorable than rainy season parameters, but the methodology would not change. It is also possible that our travel time assumptions based on the different road surfaces were unrealistically optimistic. Future analyses could include a rainy season model as well as a scenario of the impact of improved road conditions. The modeling also imposed a fixed "hierarchy" for referral and did not allow for the practice of bypassing, not uncommon in the context of personal choice. In fact, no "ground-truthing" has been conducted to compare the modeled referral networks with actual referral patterns. Validation would be required before results of this type could be used by program managers and planners.

As critical as the inter-facility referral link is for the continuum of maternal and newborn care, the distance between rural communities and what we have called a Tier B facility presents an enormous challenge for a country such as Ethiopia that is 85% rural. In the 1990s Ethiopia had the lowest road density in the world. Since its inception in 1997, the Road Sector Development Program has made great strides to improve the quality and quantity of road infrastructure. In 1997, 79% of the land area lay more than 5 km from an all-weather road; by 2010 it had been reduced to 64%. On average, households have to travel 11 km to get to an all-weather road, but often households are farther from public transport services [30]. Our own calculations indicate that 75% of the population of Tigray and Amhara live more than 3 hours walking distance from the closest Tier B facility.

Thus, the link between community and the first level must get significant attention, and will require different solutions from those in the scenario building we describe here. The role of community health workers such as the Ethiopian health extension workers (HEWs) to educate families about danger signs in pregnancy, childbirth, and the postnatal period, to encourage the use of maternity waiting homes where these exist, and to mobilize communities for emergency evacuation becomes all the more critical. In Ethiopia, in the case of

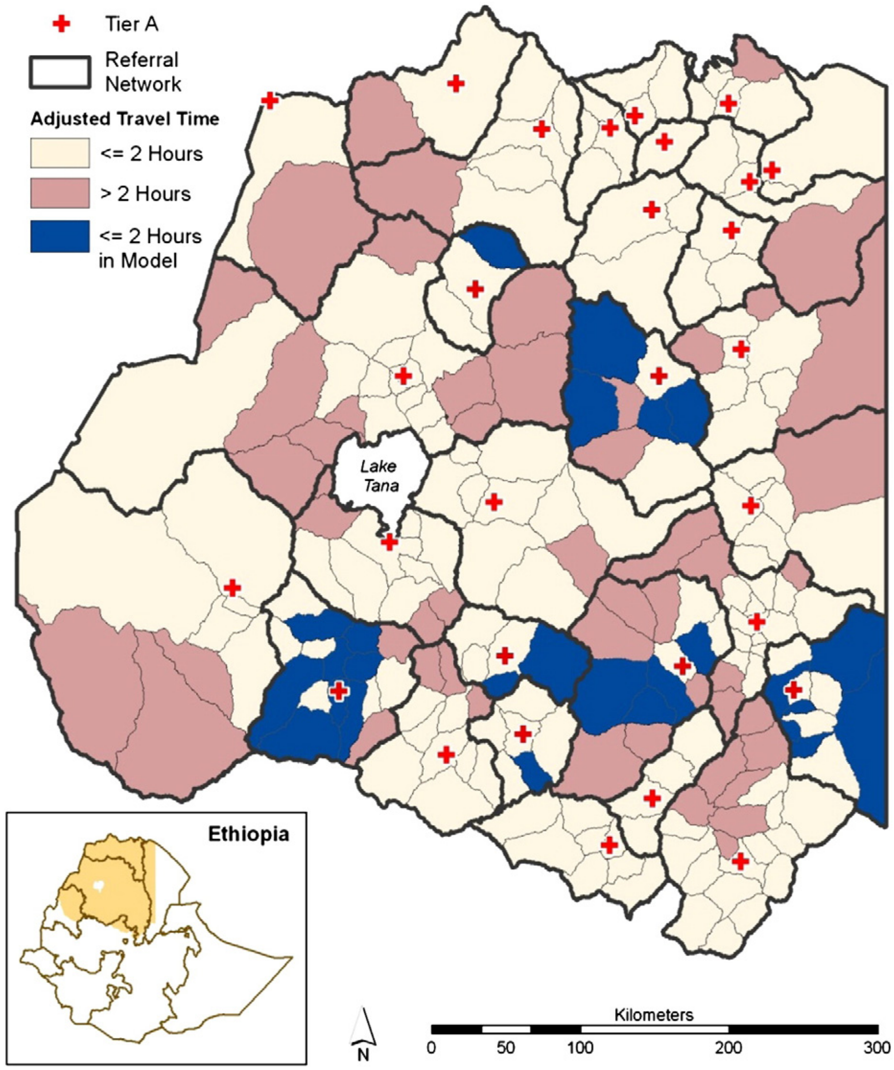

Fig. 5. Model 2 – Upgrading 7 Tier B facilities to Tier A.

an emergency, HEWs are trained to detect degrees of severity and encourage a family to bypass intermediary levels of care when the patient's condition warrants a route other than the hierarchical trajectory prescribed for cold referrals or non-emergencies. According to the Ministry of Health's 2010 *Guideline for Implementation of a Patient Referral System* a financial penalty for bypassing is waived in emergency situations [31]. Currently being tested in 2 regions of Ethiopia as part of a larger project to reduce obstetric fistula, emergency access cards or flag-like signs were introduced that are recognized by transport service providers, the Regional Transport Authority, and communities [30].

Using GIS to analyze referral systems presents a number of benefits. Visualization through maps can ground what is often abstract; modeling exercises such as these provide a platform for multisectoral advocacy and planning. The use of the location-allocation tool to inform choices about where interventions should be placed would be difficult to reproduce by hand. The calculation of “rational or logical” catchment areas allows managers to appreciate the limitations and artificiality of administrative boundaries, and pressures planners to work jointly, across regional or district boundaries, or across sectors. Finally, the tool can be adapted as new data become available or for modeling the impact of other interventions. Used judiciously, GIS makes the decision-making process more evidence based.

5. Conclusions

Referral is a critical link in the continuum of care but it is only one piece in a complex health system that must respond to many other problems. Adding emergency transport vehicles and upgrading facilities will go a long way to solving problems of accessing lifesaving care. Not only will they benefit women and their newborns, but also the many other patients in need of emergency services such as those injured in traffic accidents.

Developing geographic information systems and linking them to datasets such as the Ethiopian EmONC national assessment is a powerful tool for planners in their efforts to strengthen the health system. We have shown that GIS is helpful when describing referral networks and identifying which facilities to prioritize for upgrading, and finally how these strategies impact the population's access to emergency services.

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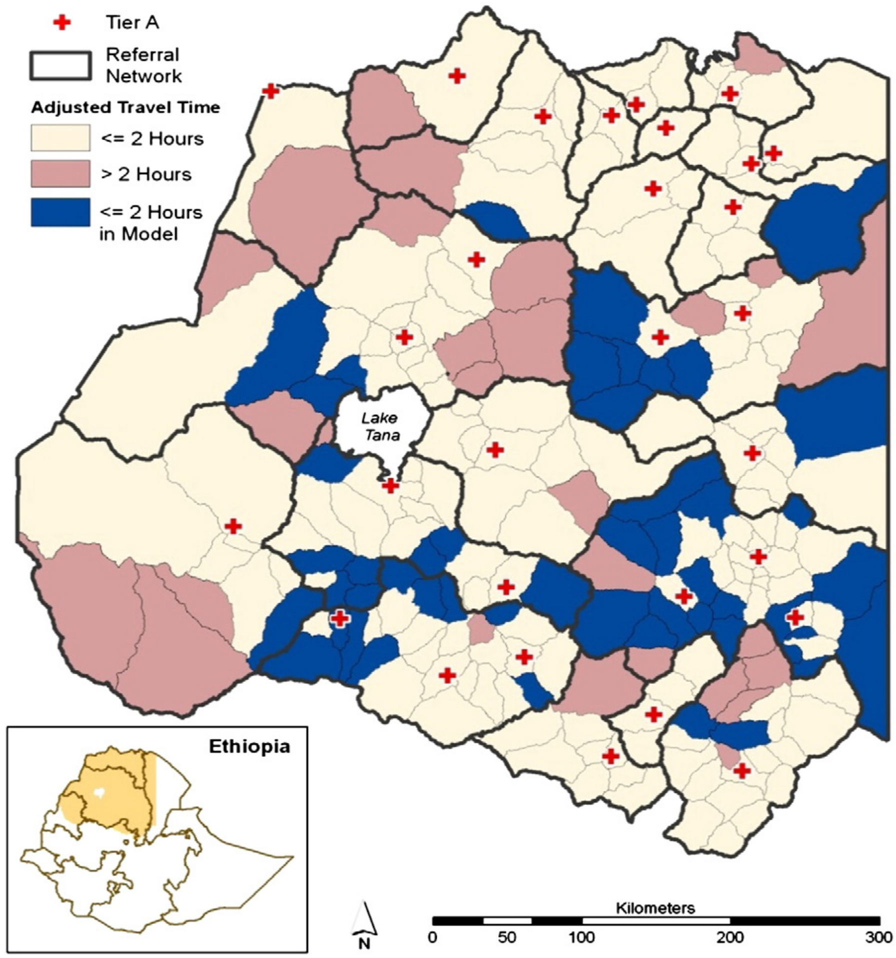

Fig. 6. Model 3 – Providing transportation and communication to all facilities and upgrading 7 Tier B to Tier A.

References

[1] Kidney E, Winter HR, Khan KS, Gulmezoglu AM, Meads CA, Deeks JJ, et al. Systematic review of effect of community-level interventions to reduce maternal mortality. BMC Pregnancy Childbirth 2009;9(2).

[2] Bhutta ZA, Lassi ZS. Empowering communities for maternal and newborn health. Lancet 2010;375(9721):1142–4.

[3] McCoy D, Storeng K, Filippi V, Ronsmans C, Osrin D, Matthias B, et al. Maternal, neonatal and child health interventions and services: moving from knowledge of what works to systems that deliver. Int Health 2010;2:87–98.

[4] Bhutta ZA, Yakook MY, Lawn JE, Rizvi A, Friberg IK, Weissman E, et al. Stillbirths: what difference can we make and at what cost? Lancet 2011;377(9776):1523–38.

[5] Darmstadt GL, Bhutta ZA, Cousens S, Adam T, Walker N, de Bernis L. Evidence-based, cost-effective interventions: how many newborn babies can we save? Lancet 2005;365:977–88.

[6] Goldie SJ, Sweet S, Carvalho N, Natchu UCM, Hu D. Alternative Strategies to Reduce Maternal Mortality in India: A Cost-Effectiveness Analysis. PLoS Med 2010;7(4): e1000264.

[7] Darmstadt GL, Walker N, Lawn JE, Bhutta ZA, Haws RA, Cousens S. Saving newborn lives in Asia and Africa: cost and impact of phased scale-up of interventions within the continuum of care. Health Policy Plan 2008;23(2):101–17.

[8] Mandahar DS, Osrin D, Shrestha BP, Mesko N, Morrison J, Tumbahangphe KM, et al. Effect of a participatory intervention with women's groups on birth outcomes in Nepal: cluster-randomised controlled trial. Lancet 2004;364(9438): 970–9.

[9] Jokhio AH, Winter HR, Cheng KK. An intervention involving traditional birth attendants and perinatal and maternal mortality in Pakistan. N Engl J Med 2005;352(20):2091–9.

[10] Nyonator FK, Awoonor-Williams JK, Phillips JF, Jones TC, Miller RA. The Ghana Community-based Health Planning and Services Initiative for scaling up service delivery innovation. Health Policy Plan 2005;20(1):25–34.

[11] Murray SF, Pearson SC. Maternity referral systems in developing countries: Current knowledge and future research needs. Soc Sci Med 2006;62(9):2205–15.

[12] Cooke GS, Tanser FC, Barnighausen TW, Newell ML. Population uptake of antiretroviral treatment through primary care in rural South Africa. BMC Public Health 2010;10:585.

[13] Wilkinson D, Tanser F. GIS/GPS to document increased access to community-based treatment for tuberculosis in Africa. Geographic information system/global positioning system. Lancet 1999;354(9176):394–5.

[14] Simarro PP, Cecchi G, Paone M, Franco JR, Diarra A, Ruiz JA, et al. The Atlas of human African trypanosomiasis: a contribution to global mapping of neglected tropical diseases. Int J Health Geogr 2010;9:57.

[15] Schuurman N, Bell NJ, L'Heureux R, Hameed SM. Modelling optimal location for pre-hospital helicopter emergency medical services. BMC Emerg Med 2009;9(6).

[16] Schuurman N, Fiedler RS, Grzybowski SC, Grund D. Defining rational hospital catchments for non-urban areas based on travel-time. Int J Health Geogr 2006;5(43).

[17] Tanser F. Methodology for optimising location of new primary health care facilities in rural communities: a case study in KwaZulu-Natal, South Africa. J Epidemiol Community Health 2006;60(10):846–50.

[18] Gabrysch S, Cousens S, Cox J, Campbell OM. The influence of distance and level of care on delivery place in rural Zambia: a study of linked national data in a geographic information system. PLoS Med 2011;8(1):e1000394.

[19] Chen SC, Wang JD, Yu JK, Chiang TY, Chan CC, Wang HH, et al. Applying the global positioning system and google earth to evaluate the accessibility of birth services for pregnant women in northern Malawi. J Midwifery Womens Health 2011;56(1): 68–74.

[20] Simões PP, Almeida RMVR. Geographic accessibility to obstetric care and maternal mortality in a large metropolitan area of Brazil. Int J Gynecol Obstet 2011;112(1): 25–9.

[21] Federal Ministry of Health of Ethiopia, UNICEF, UNFPA, WHO, AMDD. National Baseline Assessment for Emergency Obstetric and Newborn Care Ethiopia 2008. Addis Ababa, Ethiopia: Federal Ministry of Health; 2009.

[22] Keyes EB, Haile-Mariam A, Tesfaye NB, Wasihun GA, Pearson L, Abdullah M, et al. Ethiopia's assessment of emergency obstetric and newborn care: Setting the gold standard for national facility-based assessments. Int J Gynecol Obstet 2011;115(1):94–100.

[23] American College of Surgeons. Advanced Trauma Life Support Program for Doctors. 8th edition. Chicago: American College of Surgeons; 2008.

[24] Maine D. Safe motherhood programs: options and issues. New York: Center for Population and Family Health; 1991.

[25] AbouZahr C. Antepartum and Postpartum hemorrhage. In: Murray CJL, Lopez AD, editors. Health dimensions of sex and reproduction : the global burden of sexually transmitted diseases, HIV, maternal conditions, perinatal disorders and congenital

anomalies. 1st ed. Boston and Geneva: WHO, World Bank, Harvard School of Public Health; 1998.
[26] Kongnyuy EJ, Mlava G, van den Broek N. Criteria-based audit to improve a district referral system in Malawi: A pilot study. BMC Health Serv Res 2008;8.
[27] National Rural Health Mission. Operational Guidelines on Maternal and Newborn Health. New Delhi: Ministry of Health and Family Welfare; 2010.
[28] Santos C, Diante JD, Baptista A, Matediane E, Bique C, Bailey P. Improving emergency obstetric care in Mozambique: The story of Sofala. Int J Gynecol Obstet 2006;94(2):190.
[29] World Health Organization. The World Health Report: 2005: Make every mother and child count. Geneva: WHO; 2005.
[30] Borrie G. Bridging the gap through designing and constructing socially responsive road infrastructure. In: Rethinking Referral Systems, editor. powerpoint presentation ed. Tarrytown 2010.
[31] Federal Ministry of Health of Ethiopia. Guideline for Implementation of a Patient Referral System. Addis Ababa: Medical Services Directorate; 2010.
[32] Federal Ministry of Health of Ethiopia. Health and Health Related Indicators 2000. Addis Ababa: Planning and Programming Department, MOH; 2008.
[33] WHO, UNFPA, UNICEF, AMDD. Monitoring emergency obstetric care - A handbook. Geneva: WHO; 2009.