Geographical Research

Geographic information system-based evaluation of spatial accessibility to maternal health facilities in Siaya County, Kenya

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Abstract

Maternal mortality is a major problem in middle-income and low-income countries, and the availability and accessibility of healthcare facilities offering safe delivery is important in averting maternal deaths. Siaya County, in Kenya, has one of the highest maternal mortality rates in the country—far more than the national average. This study aimed to evaluate geographic access to health facilities offering delivery services in Siaya County. A mixed-methods approach incorporating geographic information system analysis and individual data from semi-structured interviews was used to derive travel time maps to facilities using different travel scenarios: AccessMod5 and ArcGIS were used for these tasks. The derived maps were then linked to georeferenced household survey data in a multilevel logistic regression model in R to predict the probability of expectant women delivering in a health facility. Based on the derived travel times, 26 per cent (13,140) and 67 per cent (32,074) of the estimated 46,332 pregnant women could reach any facility within one and two hours, respectively, while walking with the percentage falling to seven per cent (3,415) and 20 per cent (8,845) when considering referral facilities. Motorised transport significantly increased coverage. The findings revealed that the predicted probability of a pregnant woman delivering in a health facility ranged between 0.14 and 0.86. Significant differences existed in access levels with transportation-based interventions significantly increasing coverage. The derived maps can help health policy planners identify underserved areas and monitor future reductions in inequalities. This work has theoretical implications for conceptualising healthcare accessibility besides advancing the literature on mixed methodologies.

Keywords *maternal health; geographic information systems; travel times; healthcare access; multilevel modelling; Kenya*

Introduction

Maternal mortality is a major health challenge faced in most developing countries today. Approximately 303,000 women died in 2015 alone from complications resulting from childbirth (Bongaarts, 2016), with 99 per cent of those deaths occurring in middle-income and low-income countries. The single biggest contributor to high maternal mortality rates is poor geographic access to maternal healthcare facilities that are staffed by appropriately trained, qualified personnel, and that offer delivery services and life-saving obstetric interventions at birth (Chen *et al.*, 2017). As Malqvist *et al.* (2010) note, this state of affairs is because life-threatening complications, such as obstetric haemorrhage, cannot be handled in time. In the literature on maternal health, geographic access has been defined in terms of distance to facility (Gage & Guirlène Calixte, 2006), availability of one comprehensive and four basic emergency obstetric care facilities for every 500,000 people and travel times—with the WHO, UNFPA, UNICEF, and AMDD (2009) recommending that pregnant women should not be more than two hours away from a facility offering life-saving treatments.

Advances in geographic information system (GIS) technology have made it possible to compute sophisticated spatial separation measures, with many standard GIS software providing tools for the same using different data models (Ebener *et al*., 2015; Makanga *et al*., 2016; Salonen, 2014). Those advances have been enhanced by the availability of data in fine resolution, more disaggregated scales, and increased computational capacity. A number of studies have made use of travel impedance incorporating travel times to define accessibility to maternal healthcare health facilities (Chen *et al*., 2017; Masters *et al*., 2013; Munoz & Källestål, 2012; Ruktanonchai *et al*., 2016). Calculation of fixed distance buffers around health facilities is another method that has been used to estimate accessibility (Ivers *et al*., 2008). Other studies have used gravity potential models to estimate spatial accessibility to maternal health services (Song *et al*., 2013; Vadrevu & Kanjilal, 2016).

In Kenya, an estimated 6,300 women die annually from pregnancy-related complications (World Health Organization and UNICEF, 2014) with 14 per cent of all deaths among women aged 15 to 49 arising from causes related to pregnancy and childbirth (Kenya National Bureau of Statistics (KNBS), 2014). In Siaya County, the most recent data indicate a maternal mortality rate of 691 per 100,000, far higher than the national average of 362 per 100,000. Indeed, the county has some of the poorest obstetric and prenatal and postnatal health indicators (Kenya National Bureau of Statistics (KNBS), 2014). The county is ranked at position six out of the top 10 counties leading in maternal deaths, with most such deaths causally related to pregnancy and childbirth (Omondi & Omollo, 2015). At a national level, access to primary healthcare facilities offering maternal healthcare and delivery services remains an issue of considerable concern. It has important implications as far as health policy is concerned, yet it has remained relatively unstudied in the context of local geographic scales.

In this study, we use a novel methodology where qualitative evidence reflecting individual experiences from a cross-sectional survey is combined with statistical and spatial analyses of measures of access to investigate differences in spatial accessibility to maternal health facilities in a low-resource setting and predict the probability of pregnant women delivering in a health facility. This approach was informed by the need for increased credibility and complementarity whereby the results from the qualitative phase helped to better understand the findings of the quantitative phase. In this study, both methods were given equal priority and were considered equally important in addressing the aims of the study. We also identify specific geographic areas where access is substantially worse and explore relative geographic inequalities within sub-counties. This work was done with the aim of developing robust maps of spatial accessibility and contemporary travel times at a fine spatial resolution useful for decision-making by health service policymakers and service delivery providers.

Materials and methods

Study area

Siaya County (Figure 1) is one of the 47 counties in Kenya and is located in the Western region of the country. It has seven sub-counties—namely, Ugenya, Ugunja, Gem, Siaya, Alego Usonga, Rarieda, and Bondo, with an estimated total population of 935,555 people an area of approximately 2,498 square kilometres. The county has sex-balanced ratio of female to male (52:48) and the population is predominantly youthful; 23 per cent of the population comprise women of reproductive age (Omondi & Omollo, 2015). There are 156 health facilities, of which 122 are government facilities, with six of these being referral facilities.

Cross-sectional survey of women of child-bearing age

A cross-sectional survey was conducted between October and November 2017 to collect data on health-seeking behaviour of women of child-bearing age. This survey formed the qualitative aspect of this analysis and involved administering semi-structured in-depth interviews to understand individual women’s experiences as they access delivery services. The aim of this qualitative component of the study was to help develop a

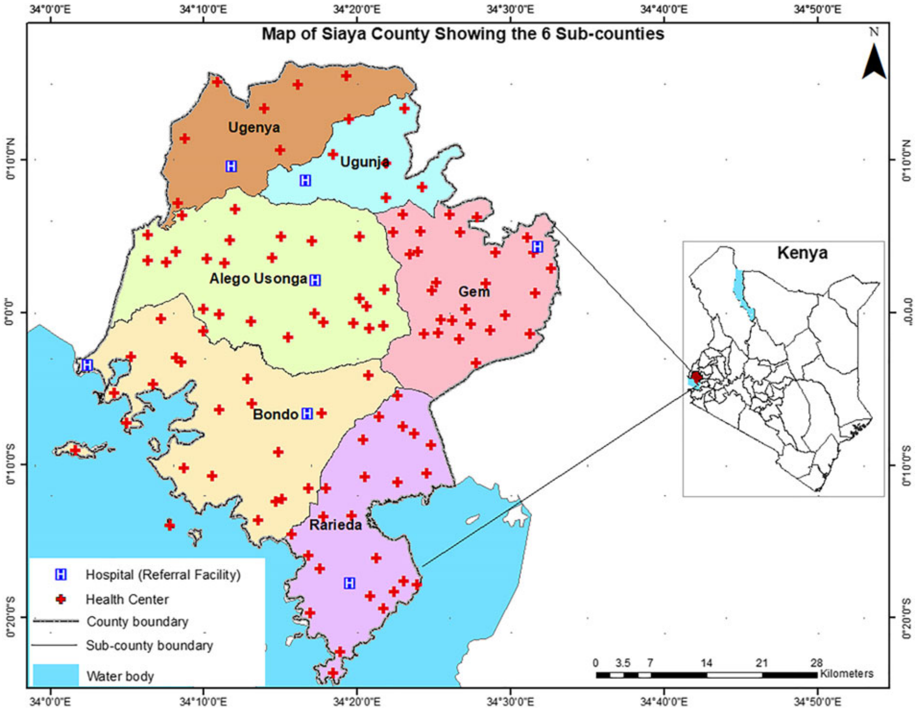

Figure 1 Study area

general understanding of why the region registers such high maternal mortality rates by illuminating the health-seeking practices of pregnant women. This type of information was necessary to complement the purely distance or time-based measures resulting from the accessibility analysis. The questions posed to the participants were focused on the mode of transportation method used to access a health facility for delivery services, the type of health facility used for delivery services, and challenges encountered in accessing delivery services. These questions were important in that they helped determine the transportation methods used to access delivery services and type of health facilities used for delivery services, which were included in the subsequent spatial analysis to derive travel times. A total of 360 women were interviewed, with a purposive sample of 60 respondents being drawn from each of the six sub-counties. Thirty respondents were interviewed at the local sub-county hospital, 20 from a health centre and 10 from a dispensary. The sub-county hospitals were in urban areas, while the health centres and dispensaries included in the study were located in rural areas of the individual sub-counties. The target was women who had delivered in the last two years and were within the age limit of 15 to 45.

Geographic information system data assembly

The data used for the analysis were homogenised in terms of projection and resolution to ensure compatibility between the different sources. The Universal Transverse Mercator coordinate system was employed because of the need to have datasets in a metric system when using AccessMod version 5—a free and open-source GIS-based software, developed by the World Health Organization and used for modelling physically accessibility to existing health services. The spatial resolution adopted for the analysis was that of the pregnancy raster, which was 100 × 100 m when unprojected and which corresponded to 92 × 92 m when projected. All the datasets used in the analysis were clipped to the boundaries of the study area.

Siaya County pregnancy distribution maps for 2015 from the WorldPop data portal (WorldPop (n.d)) were used for this analysis. These gridded population data show the estimated number of pregnant women within each 100 × 100 m grid cell. These maps were constructed using dasymetric spatial modelling techniques that involved the redistribution of the most recent census data. These were then linked to ancillary remote-sensing and gazetteer data on settlement locations and sizes and then further disaggregated using algorithms based on probability distributions and projected for different years (Tatem *et al*., 2014). The datasets present the finest resolution pregnancy distribution data available for Africa.

The road network dataset was sourced from the Kenya Roads Board and cleaned by removing duplicates and short sections of the roads. As outlined in the Kenya Roads Bill of 2015 (Government of Kenya, 2015), the roads were classified as primary, secondary, and tertiary roads. Primary roads were mainly those that connect to international boundaries; secondary roads were those that connect major towns within the county while also feeding into the primary roads; and tertiary roads were those that connect small market centres while also feeding into the secondary roads. The National Aeronautics and Space Administration Shuttle Radar Topography Mission 90 m digital elevation model (DEM) version 4.1 was used for the analysis. The DEM was re-projected and up-sampled to a resolution of 92 m to match the resolution set for the analysis. The DEM was crucial because it allows for slope to be included as one of the parameters that affect travel speed over a given land-cover type. The topography of a given area is an important consideration because it may positively or negatively influence the travelling speed, depending on the travel scenario. This observation especially applies when pregnant women are walking to a healthcare facility.

The health facilities data were sourced from the Kenya Master Health Facility Listing (Government of Kenya, 2017). The Kenyan public healthcare sector is organised into five levels—namely, level 1 (community hospitals), level 2 (dispensaries), level 3 (health centres), level 4 (county and sub-county hospitals), and level 5 (national referral facilities). The results of the cross-sectional survey revealed that a majority of the women interviewed used county hospitals, sub-county hospitals, and health centres for delivery purposes; hence, only these facilities were included in the analysis. Coordinate information related to the selected facilities was updated using a previously mapped health facility database (Noor *et al*., 2009). Unmapped facilities were mapped using Google Earth and confirmed using Garmin Etrex Global Positioning System devices.

Land-cover information was obtained from a Landsat 8 image taken in 2016. The image was reclassified using the method of unsupervised classification in Erdas Imagine v15. Five land-cover classes were adopted for the resulting image—namely, cultivated areas, water bodies, bare areas, dense vegetation, and artificial/built up areas. Secondary household survey data used in the analysis were extracted from the most recent household survey data from the Kenya Demographic and Health Survey (KDHS). This survey was carried out by the Kenya National Bureau of Statistics and Measure Evaluation (Kenya National Bureau of Statistics (KNBS), 2014) and is normally carried out after every five years. The KDHS sampling strategy employed a two-stage design: the first stage involves the identification of clusters, while the second stage involves the selection of households within the identified clusters. Siaya County had a total of 34 clusters comprising nine urban clusters, with the remaining 25 being rural clusters. Each cluster had between 18 and 25 households, and 801 households were interviewed. In addition, 671 women of childbearing age were interviewed during the survey. Women were asked information relating to place of delivery as concerns the most recent birth in the last five years, and only 426 women reported the births location. The outcome variable considered for the analysis was delivery place, which was equal to one in case of health facility and zero if otherwise.

In order to protect and maintain the confidentiality of participants, the DHS clusters are usually scrambled with rural clusters being scrambled by five kilometres with one per cent of these clusters being scrambled by 10 kilometres, while urban clusters are scrambled by up to two kilometres (Burgert *et al*., 2013). To minimise the scrambling effect, two and five kilometre Euclidian buffers were drawn around urban and rural clusters, respectively, and population distribution layers (WorldPop (n.d)) used to redistribute the clusters to the most probable populated area. Table 1 shows the input geospatial datasets.

Estimating travel times to maternal healthcare facilities

Travel times to maternal healthcare facilities were modelled using three travel scenarios. These were (a) a walking scenario, (b) a walking and public transportation scenario, and (c) a walking and motorcycle scenario. Choice of scenario was informed by the results of the cross-sectional survey, where a majority of the women reported using these means of transportation to access delivery services. In the walking scenario (a), the study assumes that pregnant women are walking from their places of residence all the way to the health facility offering maternal care. The walking and public transportation scenario (b) assumes that

Table 1 Characteristics of the input geospatial layers

	Data layers					
	Land cover	River network	Road networks	Digital elevation model	Pregnancies density raster	Health facilities coordinates
Data format	Raster	Shapefile	Shapefile	Raster	Raster	Shapefile
Year	2017	2015	2015	2009	2015	2016
Spatial resolution	30 m	NA	NA	90 m	100 m	NA
Source	Classified from 2017 Landsat data	Global lakes and Rivers Network	Kenya Roads Board	Shuttle Radar Topography Mission	WorldPop	Kenya Master Health Facility List
Usage in the analysis	Provide non-road land features, i.e. farmlands and forests	Acts as a barrier to movement	Provide road land feature class	Provides elevation for modifying travel speeds	Provides estimated distribution of the count of pregnant women	Provides location of health facilities

NA, not applicable.

pregnant women are walking to the nearest road where public transportation is available and finishing the rest of the journey using a car. The walking and motorcycle scenario (c) assumes that pregnant women walk to the nearest road and take a motorcycle for the rest of the journey to the facility. This analysis formed the quantitative aspect of the study, and the main aim was to characterise access to maternal health facilities, identify areas with the least access, and determine what intervention measures can be put in place. Quantitative data helped to generalise findings from the qualitative phase to a wider population of pregnant women within the study area. The quantitative component is also important because it helps in exploring and explaining the patterns of maternal healthcare access at the macrolevel while studying the perceptions of pregnant mothers at the microlevel as regards accessing healthcare services in the qualitative phase.

Raster grids were created using AccessMod version 5 and used to estimate the minimum time required to reach the nearest health facility. In deriving these grids, each of the GIS layers—that is, land cover, road networks, and rivers—was converted into raster grids of 92 × 92 m, with each pixel being assigned an impedance value. The resulting raster layers were then combined into a single land-cover grid based on the cumulative speeds of travel. Travel speeds were allocated to each land-cover class based on the three travel time scenarios adopted for the study—that is, walking, walking and public transportation, and walking and motorcycle scenarios. The speeds for each mode of travel (Table 2) were based on the recommendations from previous studies (Alegana *et al.*, 2012; Munoz & Källestål, 2012; Ray & Ebener, 2008). The inclusion of the DEM made it possible for a slope-based correction to be carried out for the walking scenario. This correction uses Tobler's formula (Tobler, 1993) that links walking speed with the slope of the terrain through the following formula:

$$V = 6 * \exp\left(-3.5\ \text{abs}\left[\text{Tan}\left(S + 0.05\right)\right]\right),$$

where V is the corrected walking speed in kilometres per hour (km/h) and S is the slope. On a flat terrain, this works out to five kilometres per hour, with the speed decreasing to 0.7 kilometres per hour for a 30° rise in slope, derived from the DEM using the slope tool in ArcMap 10.5.

The output of each scenario of the analysis was a continuous raster surface of travel time that contains the travelling time values presenting visual summary of the level of accessibility to health facilities in an area, where highly accessible and least accessible areas can be easily visualised in terms of the time taken to reach a certain point. The resultant travel time grids were then reclassified using ArcGIS 10.5 (ESRI, Redlands, CA) into three incremental zones of travel time, namely, within one hour, between one and two hours, and greater than two hours. Summary statistics of the number

Table 2 Travel speeds adopted for the study

Travel speeds to the nearest health centre and referral hospital by land-cover types					
	Travel speeds in km $hour^{-1}$				
	Walking scenario	Motorcycle scenario		Car scenario	
Land-cover type	Walking	Walking	Motorcycle	Walking	Car
Dense vegetation	1	1	—	1	—
Farmland	1.5	1.5	—	1.5	—
Bare area	2	—	6	2	—
Built-up area	3	—	5.5	3	—
Water body	0	—	0	—	0
Primary road	5	—	28	—	60
Secondary road	4	—	24	—	50
Tertiary road	3	—	10	—	30
DEM (degree of slope)					
<5°	4.9				
5°	3.7				
10°	2.7				
20°	1.4				
30°	0.7				

DEM, digital elevation model.

of pregnant women falling within any of the three travel time zones in each of the six sub-counties in Siaya County was summed up using the zonal statistics tool in ArcGIS 10.5.

Estimating the probability of using maternal healthcare facility

The study made use a multilevel logistic regression model to model the probability of a pregnant woman delivering in a health facility by assessing the influence of distance on deliveries. A multilevel logistic model was preferred because such models explicitly account for the hierarchical nature of DHS data (Rabe-Hesketh & Skrondal, 2006). The number of DHS-sampled women who delivered in a health facility was extracted from the Kenya National Bureau of Statistics (KNBS), (2014) and aggregated at cluster level. Each individual level data retained the individual ID, cluster identification number, and place of delivery (yes = 1 and no = 0). The derived travel time raster was then used to extract travel time between cluster locations and health facilities using ArcGIS 10.5. The result was that all individuals in a cluster were assigned an average travel time to the nearest facility offering maternal healthcare. A multilevel logistic regression model was fitted using the "lme4" package in R software to estimate health facility delivery based on the extracted travel times, on assumption that pregnant women used the nearest health facility for delivery services. Health facility delivery was the outcome variable with the explanatory variable being travel time to facility. The model coefficients resulting from the multilevel regression were then applied to the travel time grid in ArcGIS 10.5 using the raster calculator tool in the spatial analyst extension to generate a probability raster. The probability grid was created using the following equation.

$$p(y=1) = \left(\frac{1}{1+e^{-\left(\beta_o \; + \; \Sigma_1^n \beta_i \; + \; \chi_i\right)}}\right),$$

where $p(y = 1)$ represents the probability of health facility delivery, *e* represents the exponential constants, ? represents the logistic coefficients, and ? represents the independent variable (travel time). The probability raster resulting from this analysis was then multiplied with the pregnancy distribution raster to obtain the number of women likely to deliver in a health facility.

Results

Descriptive summary of cross-sectional survey data

A total of 360 women were interviewed in the cross-sectional survey, with 60 women being interviewed in each sub-county. The findings suggest that 53 per cent (95% confidence interval (CI): 0.48–0.58) of the population walked to the nearest maternal healthcare facility, 38 per cent (95% CI: 0.33–0.43) used a motorcycle, while nine per cent (95% CI: 0.06–0.12) used public transportation to access the nearest health facility (Figure 2). Regarding difficulties encountered in accessing facilities, 58 per cent (95% CI: 0.53–0.63) of the participants cited long distances to the facility, 10 per cent (95% CI: 0.07–0.14) reported cost of care, with 32 per cent (95% CI: 0.27–0.37) of the participants reporting poor services offered as the main hindrance in accessing delivery services. For those who delivered in a health facility, 68 per cent (95% CI: 0.63–0.73) delivered in a hospital compared with 26 per cent (95% CI: 0.22–0.31) who delivered in a health centre, while six per cent (95% CI: 0.04–0.09) delivered in a dispensary.

Travel time to the nearest maternal healthcare facility

Modelling the spatial accessibility to health facilities took into consideration the constraints presented by the landscape using the travel scenarios summarised in Table 2. Based on the results of the cross-sectional survey, three transportation scenarios were considered. These were walking, walking and motorcycle use, and walking and public transportation using cars. A total of 68 health facilities were considered for this analysis, and these included seven level 4 facilities offering referral services and 61 level 3 facilities made up of health centres. This selection was also informed by the results of the qualitative interview where a majority of the women (94%) reported delivering in these facilities. The walking scenario (Figure 3) exhibited the lowest levels of spatial accessibility. Accessibility significantly increased in motorcycle travel scenario where women walked and then finished the rest of the journey using motorcycle. The highest levels of access were witnessed in the car travel scenario where women walked to the nearest road and finished the rest of the journey using public transportation.

In 2015, 26 per cent (13,140) of the estimated 46,332 pregnant women were within one hour's travel time to the nearest health facility while walking (Table 3). This proportion increased to 66 per cent (31,625) when considering a two hour travel time, with 33 per cent (14,261) of the population being beyond the two hour travel time. Considering access to referral facilities (county and sub-county hospitals), seven per cent (3,415) of the pregnant population had access within one hour with the proportion increasing to 19 per cent (8,845) when considering a two hour travel time with 81 per cent (37,490) being beyond the two hour travel time while walking. The analysis further revealed significant differences in access at the sub-county level with Alego Usonga having the highest proportion (41%) of the population living within one hour's travelling time, while Ugenya had the lowest proportion (9%) of pregnant women living within one hour's travel time (Table 4).

In the motorcycle travel scenario, the findings suggest that 66 per cent (31,625) of the population were residing within one hour's travel time to the nearest facility offering any type of care (Table 3). This increased to 95 per cent (43,986) at the two hour travel time band. When considering facilities offering referral services, 34 per cent

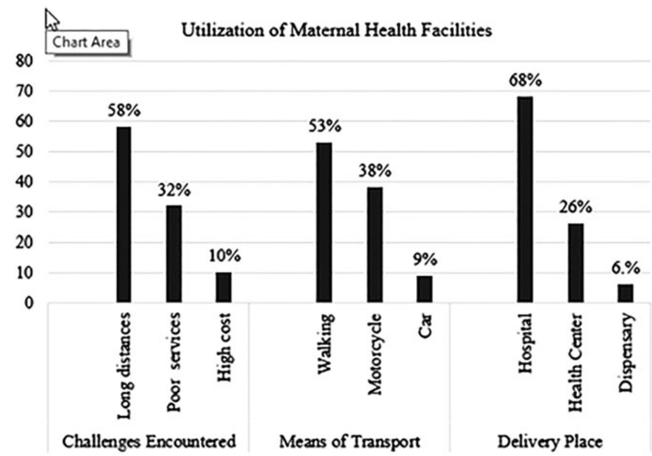

Figure 2 Response from the qualitative interviews on healthcare utilisation by pregnant women

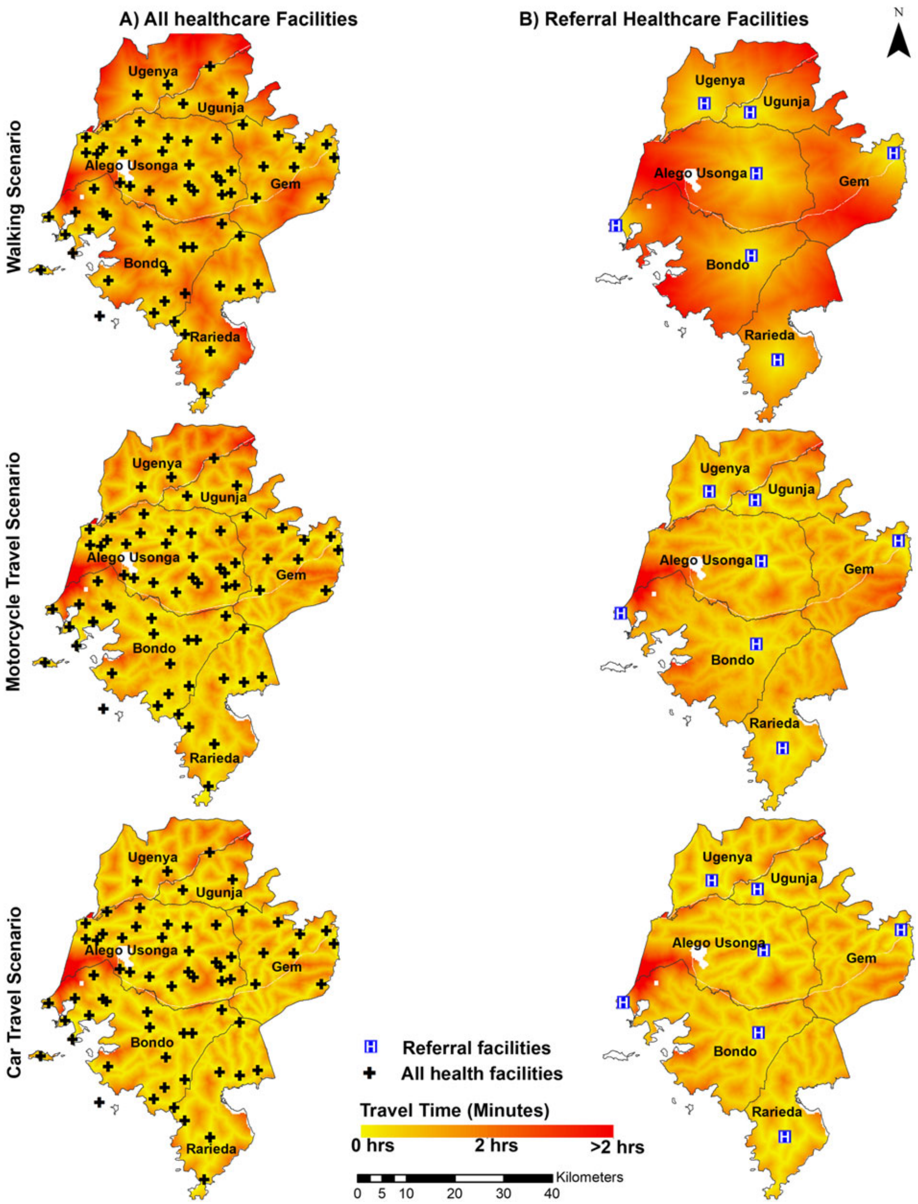

Figure 3 Map of Siaya County showing travel time from each grid, for the different transportation modes, to the nearest health facility offering delivery services

Table 3 Summary of geographic access to the two levels of care at county level and mode of transportation

Estimated travel time (hours)	Any facility offering care: number (per cent)			Referral facilities: number (per cent)		
	Walking	Motorbike	Car	Walking	Motorbike	Car
<1	13,140 (**26.2**)	31,625 (**66.4**)	38,198 (**81.9**)	3,415 (**7.4**)	15,911 (**34.9**)	32,316 (**69.7**)
1–2	32,074 (**66.5**)	43,986 (**94.6**)	45,254 (**97.4**)	8,845 (**19.8**)	38,552 (**83.4**)	44,115 (**95.2**)
>2	14,261 (**33.5**)	2,349 (**5.4**)	1,081 (**2.6**)	37,490 (**80.2**)	7,783 (**16.6**)	2,220 (**4.8**)

Table 4 Summary of the geographic access to the two levels of care by sub-county and mode of transportation

Sub-county	Total pregnancies	Estimated travel time (hours)	Any facility offering care			Referral facilities		
			Walking	Motorbike	Car	Walking	Motorbike	Car
Alego Usonga	10,522	<1	41.4	78.4	85.4	9.9	45.9	75.2
		1–2	87.0	97.4	97.7	22.3	89.1	95.4
		>2	13.0	2.6	2.3	77.7	10.9	4.6
Bondo	8,171	<1	37.3	73.0	81.0	8.3	24.4	58.3
		1–2	78.7	93.8	94.6	17.7	72.0	88.2
		>2	21.3	6.2	5.4	82.3	28.0	11.8
Ugenya	6,278	<1	8.6	41.7	73.7	6.2	39.9	71.9
		1–2	32.9	87.4	96.7	21.1	83.9	96.0
		>2	67.1	12.6	3.3	78.9	16.1	4.0
Gem	8,772	<1	25.7	68.3	84.6	5.7	25.8	67.2
		1–2	69.7	96.1	99.0	15.6	78.9	97.1
		>2	30.3	3.9	1.0	84.4	21.1	2.9
Ugunja	4,843	<1	16.9	62.7	81.3	10.6	46.6	76.7
		1–2	61.8	96.1	98.3	30.5	89.0	97.7
		>2	38.2	3.9	1.7	69.5	11.0	2.3
Rarieda	7,749	<1	27.4	74.5	85.1	3.8	26.6	71.1
		1–2	68.7	96.8	98.3	11.4	87.7	98.1
		>2	31.3	3.2	1.7	88.6	12.3	1.9

(15,911) of women were within one hour's travel time to the nearest facility offering care with the proportion increasing to 83 per cent when considering a two hour travel time. Within all the sub-counties, 70 per cent of the pregnant population had access to any facility offering care while using a motorcycle (Table 4).

In the car travel scenario, 82 per cent (38,198) of the pregnant population had access to any facility offering care within one hour's travel time with the proportion increasing to 97 per cent (45,254) when considering a two hour travel time. Regarding referral facilities, 70 per cent (32,316) had access within one hour, with the proportion increasing to 95 per cent when considering a two hour travel time. As might be expected, there was greater access whenever pregnant women used a car as the mode of transportation with over 80 per cent of pregnant women having access to health facilities.

Probability of delivering in a healthcare facility

The probability of using a health facility for delivery services was estimated based on the regression coefficients and the travel time raster. The probability raster and the pregnancy distribution raster were summed to obtain the number of women who delivered in a health facility in 2015 (Figure 4). Overall, the probability of delivering in a health facility within the study area varied from 0.14 to 0.86. Of the estimated 46,332 pregnant women, the findings suggest that 30,952 women delivered in a health facility, representing 65 per cent of the population. As noted with the accessibility levels, there were significant variations between the sub-counties in terms of facility use. Alego Usonga sub-county had the highest proportion (74%) of women using a health facility, while Ugenya sub-county had the lowest proportion (53%) of pregnant women using a health facility (Table 5).

Discussion

Geographic access is a critical factor that can seriously impact the use of health services. Application of GIS methods in the health sector can help in evaluating access and identifying both the underserved areas and the disadvantaged populations. Using qualitative and quantitative methods, this study modelled travel times to measure geographic access to maternal health facilities in Siaya County and assessed the coverage of existing facilities. First, a cross-sectional survey was carried out to better understand the maternal healthcare landscape in the study area and the experiences of women as they seek delivery services. Second, a metric of travel time to existing health facilities offering maternal care was derived, and this was in turn used to create a probability raster showing the predicted probability of pregnant women using

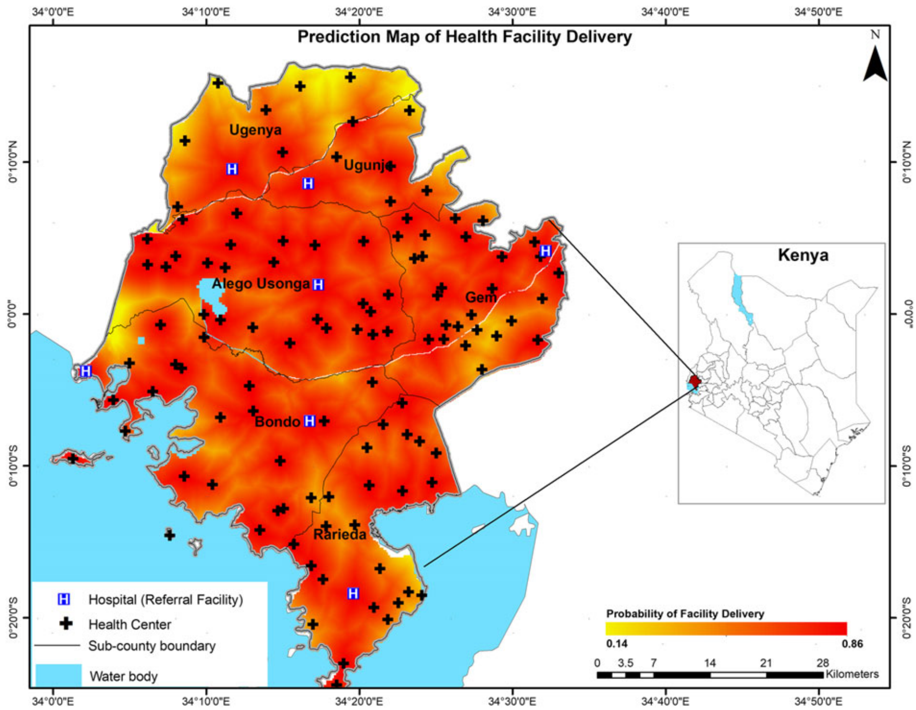

Figure 4 Map of probability of pregnant women delivering in a health facility in Siaya County. The lowest probability was 0.14 with the highest being 0.86

a facility for delivery purposes. Fifty-eight per cent of respondents reported distance to the facility as being a major challenge in accessing delivery care, while 58 per cent mentioned walking as the predominant means of transportation to a facility offering care. Respectively, 26 per cent and 67 per cent of the pregnant population were within one and two hours' walking time to the nearest health facility, with 87 per cent residing in areas where the probability of attendance was ≥0.50, with 67 per cent of the pregnant population likely to deliver in a health facility.

The findings from this study mirror previous studies that also report walking as a predominant means of transportation to health facilities among pregnant mothers in Siaya County (Asweto *et al.*, 2014; Kawakatsu *et al.*, 2014; Omondi & Omollo, 2015). Indeed, walking remains a principal means of transportation in most rural areas characterised by high poverty levels. Widespread adoption of motorcycles for transportation has alleviated the situation, but their use is subject to accessibility and affordability. The use of vehicular transport remains low in the study area and can be attributed to cost and poor road network across most areas (Asweto *et al.*, 2014).

At a national level, it has been shown that a high proportion of pregnant women in Kenya are within a reasonable distance to a health facility offering maternal health services; however, access to emergency services remains poor (World Health Organization and UNICEF, 2014). In line with recommendations that pregnant women should have access to delivery facilities within two hours' travel time (Hussein, 2012), this analysis used two hours as the maximum travel time. Areas that could be accessed in more than two hours were classified as underserved areas. The findings of the study highlighted problems, especially in the walking scenario, whereby 33 per cent of the population were not able to access healthcare facilities within the recommended time. This proportion

Table 5 Probability of delivering in a health facility by sub-county

Sub-county	Population	Facility delivery	%
Alego Usonga	10,522	7,803	74.2
Ugunja	4,843	3,115	64.3
Ugenya	6,278	3,334	53.1
Gem	8,772	5,995	68.3
Bondo	8,171	5,393	66.0
Rarieda	7,749	5,323	68.7

increased to 80 per cent when considering referral facilities only, with significant disparities at the sub-county level. Previous studies by Kawakatsu *et al.* (2014) have revealed that women, especially those carrying their first pregnancy, are more likely to deliver in referral healthcare facilities offering comprehensive care as compared with those on subsequent pregnancies; this is mainly because of the high likelihood of complications during labour and delivery. The fact that a high percentage of women are not able to access such facilities offering comprehensive care within two hours is an issue of concern.

Considering the urgency and more often unpredictable nature of maternal emergencies, the spatial inequities in access evident in this study portray serious implications to pregnant women, especially those residing in underserved areas. The long travel times greatly reduce their chances of surviving an obstetric emergency: this is because longer travel times, as pointed out by Echoka *et al.* (2013), may lead to women arriving in such severe conditions that it may be impossible to save their lives.

Accessibility is greatly increased when pregnant mothers opted to use motorised means to reach a health facility. The use of motorcycles in the study area significantly increases the extent to which pregnant women were able to access facilities offering maternal care. The fact that motorcycles could access areas that normally cannot be accessed by motor vehicles made them an excellent medium for transportation as far as accessing facilities offering maternal services is concerned. Coupled with the fact that most vehicles operate within the urban centres or along intra-urban roads, this fact makes motorcycles the best alternative means of transport. More than half of the road network appears to comprise tertiary roads, and thus, the limited road network also limits the extent to which vehicles can travel. Although the accessibility problem is less pronounced in the motorised scenario, not many people use their car or public transportation especially in the rural areas because of poor infrastructure and lack of motorised transportation.

The limited numbers of pregnant women accessing healthcare facilities in the walking scenario reinforces the findings reported by Omondi and Omollo (2015), who noted that in Siaya County, those who walked or used a bicycle as a means of transportation were less likely to access skilled maternal health services compared with those who used motorcycles or private cars. They also established that the probability of facility delivery decreased with increasing travel time to the facility; this is consistent with the literature on delivery services in other developing countries (Gabrysch *et al.*, 2011; Masters *et al.*, 2013).

The performance of an efficient maternal healthcare system is more often gauged by how equitable it is in terms of provision of healthcare services. As noted by Echoka *et al.* (2013), equity can be measured in terms of the spatial distribution and accessibility of health facilities, which in turns dictates their level of use. Our study showed a non-uniform distribution of health facilities, hence signifying unequitable access. Sub-county-level analysis showed that Ugenya had the lowest concentration of health facilities and some of the highest travel times, while Alego Usonga had the highest density of health facilities and registered the lowest individual travel times.

Overall, the methodologies applied in this study can also be used to assess the best locations for placing health facilities based on a target population and realistic travel times. We were able to show the use of supplementary information from preliminary field surveys in determining realistic travel times. Interpreting the maps, it is possible for readers to conclude that contributing factors for the emerging accessibility patterns could be social or economic. Although such theories are useful, they may not be locally specific enough to provide decision-makers with key factors to inform effective policy ideas. These gaps are filled by data from the qualitative interview that illuminated the practices of pregnant women as they sought care. Adopting a mixed-methods approach therefore helped in reducing the uncertainty among policymakers regarding the occurrence of particular spatial patterns of maternal healthcare access. The combination of computational accessibility models with the qualitative data that reveals the true mobility patterns of pregnant women while seeking healthcare services further makes it easy for policymakers to identify key areas for local policy interventions especially as regards transport infrastructure and location of new facilities or upgrade of existing ones. All the data used in this study are freely available in the public domain for different countries, hence making it easy to replicate this study for different areas, subject to the availability of the requisite technical skills.

There are a number of limitations in the current study that are likely to have a bearing on the final results obtained. First, the study assumed a closed system where the population does not seek services outside the study area. In reality, pregnant mothers are likely to travel beyond the borders to seek maternal healthcare services, especially those residing near the borders. Second, the study assumed that women seek delivery services at the closest health facility, while in reality, women are likely to seek services from facilities further away depending on the quality of services being offered. Third, the study ignored the effect of seasonality on transport services, the speeds applied for the study applied to the dry season, yet it is well known that during the rainy road, conditions change because of flooding, and this affects speeds on such roads.

Conclusion

This study has highlighted the spatial patterns in accessibility using different travel scenarios and estimated the inequalities in maternal healthcare access and use at the sub-national level throughout Siaya County. The analysis demonstrates that there exist considerable spatial variations in geographic accessibility with the walking scenario being the most problematic. The majority of women had access to basic services offered by health centres as compared with comprehensive services offered by referral facilities.

A critical finding is that reducing transportation barriers would most likely help in reducing the inequity in geographic access to maternal healthcare facilities and most likely improve the coverage of institutional delivery. This initiative has the potential of helping health policymakers in Kenya and other resource-constrained countries to better understand the possible impacts of health infrastructure on improving maternal health outcomes.

The study also contributes to the literature on mixed-methods research and is unique in that it incorporates both quantitative and qualitative aspects in an accessibility model, thereby deviating from conventional GIS analyses with their focus on quantitative data over qualitative data. This is a significant contribution to the spatial accessibility analysis literature that has often relied on quantitative indicators extracted solely from secondary data sets. It demonstrates the value of mixed-method research in uncovering patterns of use and accessibility in low-resource settings. The work also presents a more individualised and contextualised understanding of accessibility to maternal health services by helping to reveal trends in accessibility that would have been otherwise overlooked.

Finally, the results of the study demonstrate how spatial approaches can be used to identify and measure spatial inequalities in maternal healthcare access and support evidence-based decision-making as far as interventions are concerned. The maps and the analytical approach presented here provide a means for monitoring future reductions in inequalities in the coverage of access to maternal health facilities. The maps can also be used by healthcare planners to help identify populations that must travel long distances to receive maternal healthcare; this is particularly crucial in the development of policies touching on equity of access to maternal health care. The findings of this study further provide evidence to decision-makers within the maternal healthcare system that future resource planning to improve maternal health should focus on increasing the number of health facilities capable of offering delivery services to improve spatial accessibility; this is especially for those areas that are underserved. These policies will be key in bringing down the high rates of maternal mortality through improved access in the study area.

References

Alegana, V.A., Wright, J.A., Pentrina, U., Noor, A.M., Snow, R.W. and Atkinson, P.M., 2012. Spatial modelling of healthcare utilisation for treatment of fever in Namibia. *International Journal of Health Geographics*, 11(1), p.1–13.

Asweto, C.O., Aluoch, J.R., Obonyo, C.O., and Ouma, J.O., 2014. Maternal autonomy, distance to health care facility and ANC attendance: findings from Madiany division of Siaya County, Kenya. *American Journal of Public Health Research*, 2(4), pp.153–8.

Bongaarts, J., 2016. World Health Organization health in 2015: from MDGs, millennium development goals, to SDGs, sustainable development goals Geneva: WHO Press, *Population and Development Review*, 42(3), p.575.

Burgert, C.R., Colston, J., Roy, T. and Zachary, B., 2013. *Geographic Displacement Procedure and Georeferenced Data Release Policy for the Demographic and Health Surveys*. Calverton, Maryland, USA: ICF International; (No. 7). DHS Spatial Analysis Report. Available at http://dhsprogram.com/pubs/pdf/SAR7/SAR7.pdf. [Accessed 24/02/2018].

Chen, Y.N., Schmitz, M.M., Serbanescu, F., Dynes, M.M., Maro, G. and Kramer, M.R., 2017. Geographic access modeling of emergency obstetric and neonatal care in Kigoma Region, Tanzania: transportation schemes and programmatic implications. *Global Health: Science and Practice*, 5(3), pp.430–45.

Ebener, S., Guerra-Arias, M., Campbell, J., Tatem, A.J., Moran, A.C., Johnson, F.A. and Porter, R., 2015. The geography of maternal and newborn health: the state of the art. *International Journal of Health Geographics*, 14(1), pp.1–10.

Echoka, E., Kombe, Y., Dubourg, D., Makokha, A., Evjen-Olsen, B., Mwangi, M., Byskov, J., Olsen, Ø.E. and Mutisya, R., 2013. Existence and functionality of emergency obstetric care services at district level in Kenya: theoretical coverage versus reality. *BMC Health Services Research*, 13(1), p.113.

Gabrysch, S., Cousens, S., Cox, J., Campbell, O. M., 2011. 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 Medicine*, 8(1), pp.1–12.

Gage, A.J. and Guirlène Calixte, M., 2006. Effects of the physical accessibility of maternal health services on their use in rural Haiti. *Population Studies*, 60(3), pp.271–88.

Government of Kenya. Kenya Roads Bill 2015.2015 Nairobi, Kenya.

Government of Kenya, Ministry of Health., 2017. Kenya Master Health Facility Listing. http://kmhfl.health.go.ke/#/home. [Accessed 20/11/2017].

Hussein, J., Kanguru, L., Astin, M. and Munjanja, S., 2012. The effectiveness of emergency obstetric referral interventions in developing country settings: a systematic review. *PLoS Medicine*, 9(7), pp.22–31.

Ivers, L.C., Garfein, E.S., Augustin, J., Raymonville, M., Yang, A.T., Sugarbaker, D.S. and Farmer, P.E., 2008. Increasing access to surgical services for the poor in rural Haiti: surgery as a public good for public health. *World Journal of Surgery*, 32(4), pp.537–42.

Kawakatsu, Y., Sugishita, T., Oruenjo, K., Wakhule, S., Kibosia, K., Were, E. and Honda, S., 2014. Determinants of health facility utilization for childbirth in rural western Kenya: cross-sectional study. *BMC Pregnancy and Childbirth*, 14(1), pp.1–10.

Kenya National Bureau of Statistics (KNBS). 2014. *Kenya Demographic and Health Survey 2014*. Nairobi, Kenya. https://dhsprogram.com/pubs/pdf/FR308/FR308.pdf. [Accessed 26/01/2018].

Makanga, P.T., Schuurman, N., von Dadelszen, P. and Firoz, T., 2016. A scoping review of geographic information systems in maternal health. *International Journal of Gynecology & Obstetrics*, 134(1), pp.13–7.

Malqvist, M., Sohel, N., Do, T.T., Eriksson, L. and Persson, L. A., 2010. Distance decay in delivery care utilization associated with neonatal mortality. A case referent study in northern Vietnam. *BMC Public Health*, 10(1), pp.1–9.

Masters, S.H., Burstein, R., Amofah, G., Abaogye, P., Kumar, S. and Hanlon, M., 2013. Travel time to maternity care and its effect on utilization in rural Ghana: a multilevel analysis. *Social Science & Medicine*, 93(September), pp.147–54.

Munoz, U.H. and Källestål, C., 2012. Geographical accessibility and spatial coverage modeling of the primary health care network in the Western Province of Rwanda. *International Journal of Health Geographics*, 11(1), pp.1–11.

Noor, A.M., Alegana, V.A., Gething, P.W. and Snow, R.W., 2009. A spatial national health facility database for public health sector planning in Kenya in 2008. *International Journal of Health Geographics*, 8(1), pp.19–26.

Omondi, O.E. and Omollo, A.S., 2015. Correlates of utilization of skilled maternal health services in Siaya County, Western Kenya. *International Journal of Science and Research*, 6(3), pp.98–110.

Rabe-Hesketh, S. and Skrondal, A., 2006. Multilevel modelling of complex survey data. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 169(4), pp.805–27.

Ray, N. and Ebener, S., 2008. AccessMod 3.0: computing geographic coverage and accessibility to health care services using anisotropic movement of patients. *International Journal of Health Geographics*, 7(1), pp.1–17.

Ruktanonchai, C.W., Ruktanonchai, N.W., Nove, A., Lopes, S., Pezzulo, C., Bosco, C., Alegana, V.A., Burgert, C.R., Ayiko, R., Charles, A.S., Lambert, N., Msechu, E., Kathini, E., Matthews, Z. and Tatem, A.J., 2016. Equality in maternal and newborn health: modelling geographic disparities in utilisation of care in five East African countries. *PLoS ONE*, 11(8), pp.1–17.

Salonen, M., 2014. Analysing spatial accessibility patterns with travel time and distance measures: novel approaches for rural and urban contexts (Doctoral Dissertation). University of Helsinki, Helsinki, Finland.

Song, P., Zhu, Y., Mao, X., Li, Q. and An, L., 2013. Assessing spatial accessibility to maternity units in Shenzhen, China. *PLoS ONE*, 8(7), pp.1–7.

Tatem, A.J., Campbell, J., Guerra-Arias, M., De Bernis, L., Moran, A. and Matthews, Z., 2014. Mapping for maternal and newborn health: the distributions of women of childbearing age, pregnancies and births. *International Journal of Health Geographics*, 13(1), pp.1–10.

Tobler, W. 1993. Three presentations on geographical analysis and modeling. https://escholarship.org/uc/item/05r820mz. [Accessed 31/01/2019].

Vadrevu, L. and Kanjilal, B., 2016. Measuring spatial equity and access to maternal health services using enhanced two step floating catchment area method (E2SFCA)—a case study of the Indian Sundarbans. *International Journal for Equity in Health*, 15(1), pp.1–12.

World Health Organization and UNICEF. 2014. Trends in maternal mortality: 1990 to 2013: estimates by WHO, UNICEF, UNFPA, the World Bank and the United Nations Population Division: executive summary.

WHO, UNFPA, UNICEF, and AMDD, 2009. *Monitoring Emergency Obstetric Care: A Handbook*. Geneva: WHO.

WorldPop. http://www.worldpop.org.uk/data/. [Accessed 03/12/2018].