Mapping maternal healthcare access in selected West African Countries

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Abstract

Background: The Sustainable Development Goal (SDG) three emphasizes the need to improve maternal and newborn health, and reduce global maternal mortality rate to less than 70 per 100 000 live births by 2030. Achieving the SDG goal 3.1 target will require evidence based data on the distribution of maternal health outcomes and their linkage to healthcare access.

Data and Methods: This study used WorldPop data derived from an integration of satellite, census and household survey. Exploratory spatial analysis techniques were used to examine and visualize the spatial distribution of women of reproductive age (15-19 and 40- 44), live births and pregnancies at subnational level in three "poor resource" West African countries: Mali, Guinea and Liberia. Buffer analysis was used to quantify the number of pregnancies within user-defined distances of a health facility.

Findings: Results showed wide variations in the distribution of maternal health outcomes across the countries of interest and districts of each of the countries. There was also clustering of maternal health outcomes and health facilities at the urban capital cities of Bamako, Conakry, and Greater Monrovia. A considerable number of pregnancies in most districts of northern Mali, northern and forest regions of Guinea and counties in south eastern Liberia were not within 50km distance of a healt facility, indicating inadequate access to health facilities.

Conclusion: To bridge the gap in inequity in healthcare access, and improve maternal and newborn health in the study countries, there is need for equitable distribution of health resources and infrastructure within and across the disadvantaged districts.

Keywords: Maternal health, districts, West Africa, mapping, geospatial analysis, buffer analysis.

Introduction

Improvement in maternal and newborn health in developing countries has been a major priority in public health since the 1980s. This is reflected in the consensus reached at different international conferences, such as the Safe Motherhood conference in Nairobi in 1987 and the International Conference on Population and Development in Cairo in 1994, as well as specific targets in the Millennium and Sustainable Development Goals. In spite of these efforts to increase access to reproductive health services and reduce maternal mortality, maternal health is still poor in most developing countries (Kalule-Sabiti, Amoateng & Ngake, 2014; Ononokpono, 2015).

Globally, about 830 women die from pregnancy- or childbirth-related complications every day, and it was estimated that in 2015, roughly 303 000 women died during pregnancy and childbirth (Alkema, Chou, Hogan, Zhang et al. 2016; World health Organization, 2018).

Unfortunately, almost all of these deaths (99%) occurred in low-resource settings, most of which could have been prevented with adequate access to healthcare (Hogan, Foreman, Naghavi, Ahn et al 2010). An estimated 587 women in Mali, 679 in Guinea and 725 in Liberia die for every 100, 000 live births (United Nations Economic Commission for Africa (UNECA), 2018). Although a number of countries in sub-Saharan Africa halved their levels of maternal mortality since 1990, mortality rates for newborn babies have been slow to decline compared with death rates for older infants. To provide some additional context, Equatorial Guinea was one of the ten countries that reached the MDG target of a 75 per cent reduction in global maternal death (UNFPA, UNICEF, WHO, World Bank, 2012). Furthermore, roughly 1100 women were dying for every 100,000 live births in Nigeria in 1990, while in Sierra Leone 2300 women were suffering the same fate. Trends in maternal mortality have shown that the situation in

both countries has improved dramatically, with the current rate being 814 per 100,000 live births in Nigeria (WHO, 2020) and 1380 per 100,000 live births in Sierra Leone (UNECA, 2018). However, when compared to developed countries these disparities are stark: In Australia, there are 6 deaths for every 1000,000 births while in the United States there are 28 deaths (https://www.who.int/reproductivehealth/publications/monitoring/maternal-mortality-2015/en/; WHO, 2018).

The Sustainable Development Goals (SDGs), target 3.1, is to reduce the global maternal mortality rate to less than 70 per 100 000 live births by 2030 and improve maternal and child health. In addition, one of the key transformational outcomes under African Union Agenda 2063 to improve living standards is to reduce maternal, child and neonatal deaths by half (https://au.int/agenda2063/outcomes). For these targets to be achievable, there has to be a concerted effort to improve the maternal and newborn health in low-income countries, and particularly sub-Saharan African region. This however, requires evidence-based data for adequate planning of safer births and healthier newborns. Data on the geographical distribution of women of reproductive age in low-income countries is sparse due to poor vital registration information. In addition, for effective allocation of human resources and health infrastructure and assessment of coverage of health care services at subnational level, estimates of projected future number of pregnancies and births are needed. Furthermore, there is need to link information on proximity of pregnancies to health facilities in order to obtain better information on maternal and newborn health care access in districts and regions (Tatem, Campbell , Guerra-Arias, de Bernis, Moran & Matthews 2014). Understanding the magnitude of inequities in health outcomes for women is important in improving maternal health. Furthermore, the application of geospatial analysis and mapping of maternal health outcomes in relation to how close they are to health facilities is useful in identifying high priority areas or districts where women have low access to healthcare services; and also important in the fair distribution of these services (Salehi & Ahamdian 2017).

Moreover, data visualization with the use of maps and geospatial analysis is important for understanding geographical variability in health care access and in addressing the need for improved maternal health service provision and access to emergency obstetric care at sub-national scale (Salehi & Ahamdian 2017). In fact, geospatial analysis is highly recommended for application to maternal health programs in poor resource settings (Molla, Rawlins, Makanga,

Cunningham, Avila, Ruktanonchai et al. 2017). Against this backdrop, this study examined the spatial distributions of women of reproductive age, pregnancies and births at subnational level and quantified the number of pregnancies within user-defined distances of a health facility in three West African countries (Mali, Liberia and Guinea) with a high burden of maternal and neonatal deaths. These three countries share borders, and given the porosity of borders in Africa (with communities of the same language group often separated by country borders), we can examine whether there are any differences in accessibility of maternal health services across neighbouring countries.

Literature review and theoretical framework

Several studies using geospatial applications and mapping have focused on child mortality, childhood co-morbidity and postnatal care (Gayawan 2014; Kazembe & Namagale 2007; Ononokpono, Gayawan & Adedini 2020); reviews on the importance of geospatial applications to maternal and newborn outcomes (Makanga, Schuurman, von Dadelszen & Firoz 2016); and geographical factors within the vicinity of severe injury related to motor vehicle accidents (Rahman, Rainis, Noor, & Mohamad, 2016). Other studies have examined the distribution of births and pregnancies in Afghanistan, Bangladesh, Tanzania, Ethiopia and Ghana (Tatem et al. 2014; Neal & Matthews, 2013; Amoako, & Madise 2009), and health metrics and geography of maternal and newborn health (Ebener, Guerra-Arias, Campbell, & Tatem 2015). A study of spatial accessibility of pregnant women to health professionals in France, identified critical areas in need of more healthcare providers, using the Index of Spatial Accessibility (Gao Kihal, Le Meur , Souris & Deguen, 2016). Ruktanonchai and colleagues in their study in five East African countries, found considerable geographic disparities in the utilization of maternal health across the countries (Ruktanonchai, Ruktanonchai, Nove, Lopez, et al. 2016). In addition, a study in Nigeria showed spatial variations in the distribution of healthcare facilities in the country (Fadahunsi, Kufoniyi, & Babatimehin, 2017).

A study on women´s experiences in accessing maternal and child health services in Mali indicated that women had difficulties in accessing healthcare services in the northern regions of Mali due to looting of the healthcare facilities during the armed conflict (Degni, Amara & Klemetti (2015). Alison, El Ayadi, Sidibe, Delvaux, Camara, Sandouno et al. (2017) in their study noted significant reductions in the average numbers of antenatal care attendance and health facility deliveries during the Ebola virus disease outbreak in the forest regions of Guinea. According

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to UNICEF report, the outbreak of Ebola in 2014 and 2015 reversed many gains in child and maternal health in Liberia. There are shortages of trained health staff, medicines are not always available and one in three children and women live five kilometers or more from a health facility (UNICEF, 2018).

To the best of our knowledge, studies on the mapping of maternal health outcomes at subnational level and linkage of proximity of pregnancies and births to health facility in poor resource countries in West Africa is sparse. By poor resource country, we employ the definition of poverty used by World Bank based on the percent of the population living under 1.90 US dollars per day (https://www.worldbank.org/en/publication/poverty-and-shared-prosperity). In view of the fact that most births (60%) take place at home and the burdens of disease and maternal and neonatal deaths are considerably high in Mali, Guinea and Liberia as in most West African countries, this study is timely and adds to the body of knowledge on maternal and newborn health care. In addition, this paper has a distinct usefulness in health systems and policy through showing where there is demand for maternal and newborn health services particularly in the study countries.

Theoretically, our study incorporated the works of Gething, Amoako, Frempong-Ainguah, Nyarko, Baschieri, Aboagye et al. (2012), and Bailey, Keyes, Parker, Abdullah, Kebede & Freedman, (2011). The authors emphasized that estimates of proximities of pregnancies to health facilities link estimates of population in need with locations of facilities designed to meet this need. Furthermore, other studies have demonstrated that the use of maps to display the results is a clear way of showing the spatial heterogeneity that exists at a subnational level, and highlights geographic inequities in service provision (Hay, Noor, Nelson, & Tatem 2005; Utazi, Thorley, Alegana, Ferrari, Takahashi, Metcalf et al. 2018). In line with the tenets of these frameworks, this study intends to identify districts with low maternal healthcare access using choropleth maps. This identification will inform decisions on appropriate maternal health policy and interventions particularly in disadvantaged districts. Specifically, the objectives of this study were to examine and visualize the distribution of women of reproductive age, pregnancies and live births using high-resolution maps; and determine or estimate the percentage of pregnancies within user-defined distances of a health facility. This will serve as indices of maternal health outcomes and healthcare access, in the absence of direct measures.

Data and methods
Data

This study utilized WorldPop data derived from an integration of satellite, census and household survey data for three (3) West African countries, namely Mali, Liberia, and Guinea. The WorldPop dataset was constructed using the most recent and spatially detailed datasets available (Tatem et al. 2014). For the construction of the dataset, detailed maps of settlement extents were derived from Landsat satellite imagery through either semi-automated classification approaches or expert opinion-based analyses (Tatem, Noor, von Hagen, Di Gregorio, Hay et al. 2007; Tatem, Garcia, Snow, Noor, Gaughan, Gilbert et al. 2013). These settlement maps were used to refine land cover data.

Additionally, local census data mapped at enumeration area level from a random selection of countries across the continent were utilized to identify typical regional per-land cover population densities. These were subsequently, applied to redistribute census counts in order to map human population distributions at specified spatial resolution. Additional country-specific datasets such as demographic health and surveillance surveys (where available), that provided data on population distributions not captured by censuses, were incorporated into the mapping process. Estimates of age and sex structures on subnational population compositions were obtained from a variety of census, survey, satellite and GIS data sources for the study countries. Sample weights were applied to household surveys to provide aggregate estimates, and these were matched to corresponding geospatial datasets showing the boundaries of each unit. Africa-wide geospatial linked data on the number of individuals by age and sex within administrative unit were created. Furthermore, UN statistics and other sources on growth rates, age specific fertility rates, live births, stillbirths and abortions were, integrated to convert the population distribution datasets to gridded estimates of births and pregnancies.

Data on health facilities were obtained from the Humanitarian Data Exchange (HDX) (see https://data.humdata.org/), and pre-processed for each country of interest. The Humanitarian Data Exchange collates information from various datasets including international and national organizations and business portals for the purpose of ensuring a coherent response to emergencies, and is managed by the UN's Centre for Humanitarian Data (Datta, Sigdel, Oven, Rosser, Densmore, & Rijal, 2018; Williams, Rosser, Kincey, Benjamin, Oven, Densmore et al. 2015). The health facilities' information from the Humanitarian Data Exchange were geo-located and verified before being uploaded to the repository,

by country experts. This verification process provides an indication of the quality of the data. The HDX provided comprehensive geographic location information on health facilities and health infrastructure (for example number of doctors and nursing staff, services, care management and environment). This allowed us to determine health facilities that have the capacity to provide either basic or comprehensive emergency obstetric and newborn care, as a basis for inclusion in our study. The HDX dataset includes dispensaries, pharmacies and a number of clinic that do not offer emergency services. In this study, we included health facilities that met this criteria and were verifiable and excluded those facilities that did not meet our criteria, of the availability of basic or comprehensive emergency obstetric and newborn care facilities. The final analytical sample included 430 health facilities (62 in Mali, 188 in Guinea, and 180 in Liberia). The map situating the locations of the three study countries is provided in Figure 1.
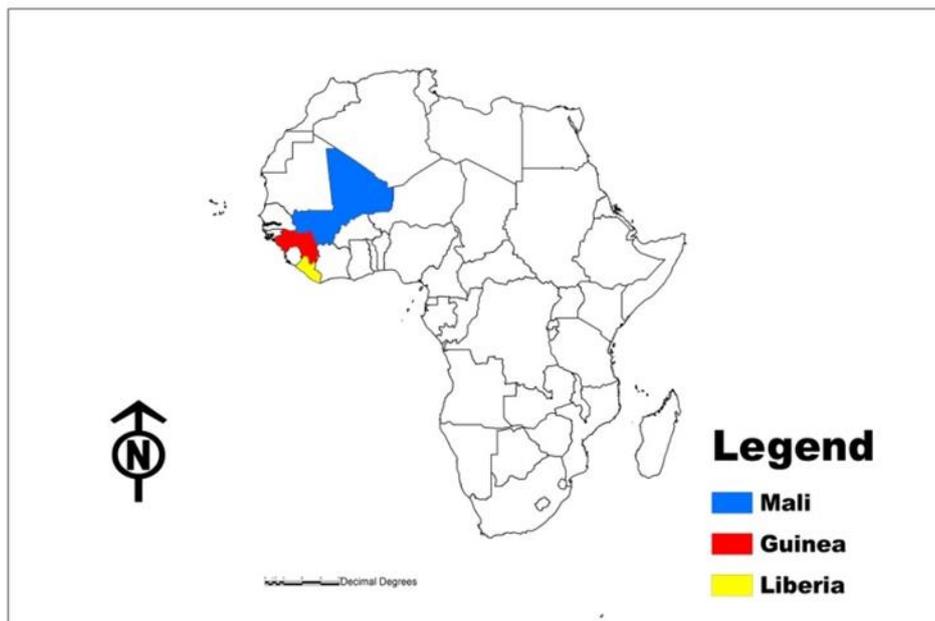
Study Countries

Figure 1 Map of Africa showing the three study countries - Mali, Guinea and Liberia.

Brief profiles of the study countries

In the next section we provide some brief demographic and geographical information about our three study countries to demonstrate the benefits of having better information on maternal mortality. We also identify some specific challenges faced by these countries and how these might impact maternal mortality and access to healthcare.

Mali

Mali is a large landlocked country in the West African Sahel region, with a population of 20.25 million. It is one of the poorest countries in the world (https://www.worldbank.org/en/country/mali/overview). Roughly three-out-of-five people (58%) live in rural areas where roads, schools and health facilities are scarce, and it was estimated that less than 30% of the population lived within 10km of a health facility in 1990 (Ministry of Health – Mali, 1992); this proportion had not changed much fifteen years later (Franco, Hamed, Simpara, Sidibe, et al. 2006). In Mali, the adolescent birth rate per 1000 women aged 15-19 is 174 and this is second only to Niger (UNFPA 2016; World Health Organization 2008).

Guinea

Guinea has a population of 12.77 million. Its large deposits of mineral wealth (bauxite, gold, diamond) potentially makes Guinea one of the richest countries in Africa, but it still remains poor with a gross national income of US$ 2,270 per capita, with 64% of the population living in rural areas (https://www.worldbank.org/en/country/guinea/overview). In December 2013, it was the first country affected by an outbreak of the Ebola virus. Weak surveillance systems and poor public health infrastructure contributed to the difficulty in containing the outbreak, which meant that it quickly spread to bordering countries of Liberia and Sierra Leone (WHO Ebola Response Team 2014). Notably, many of the sociocultural and healthcare related factors increased the risks for women (Delamou et al. 2017). The adolescent birth rate per 1000 women aged 15-19 is 146 (UNPFA 2016).

Liberia

Liberia went through 14 years of civil conflict that ended in 2004, and this had a devastating effect on its population and health infrastructure. Liberia has one of the fastest growing populations in the world with an estimated population of 4.8 million (World Population Prospects 2019). However, with a gross national income of US$710 per capita, the majority of its population remains poor; and about 84% of Liberians live below the international poverty line (UNPFA 2016). This has been made worse by the Ebola epidemic which overwhelmed the already fragile healthcare system (Bernstein 2014). Besides, one in three adolescent girls aged 15-19 in Liberia is either currently pregnant or already experiencing motherhood. Additionally, the adolescent birth rate is 149 per 1000 live births (UNPFA 2016).

Maternal and newborn health in Mali, Guinea and Liberia

The maternal mortality rate (MMR) is a measure of risk of mortality due to pregnancy and childbirth, while neonatal mortality rate (NMR) measures the risk of neonatal mortality. Globally, the risk of dying in the first 28 days of life is roughly 18 deaths per 1000 live births, while the global maternal mortality rate is 216 deaths per 100,000 live births. However, these global figures do not show the disparities in different countries and regions. Table 1 (see below) shows the maternal mortality rate and neonatal mortality rate for sub-Saharan Africa and the three countries included in the study. Although there have been reductions in the rates over time, the levels of neonatal and maternal mortality in the study countries remain unacceptably high. The rates in the Euro-zone area are roughly 100 times smaller than in sub-Saharan Africa as shown in Table 1. Further, all the three study countries have higher maternal and neonatal mortality than the sub-Saharan (average) rate, indicating that women and children in these countries in fact experience worse outcomes than others within the sub-Saharan African region.

Table 1 – Maternal health statistics for the study countries

		1990	2015
Mali	MMR	1010	587
	NMR	72.8	36.8
Guinea	MMR	1040	679
	NMR	61.7	25
Liberia	MMR	1500	725
	NMR	58.4	26.3
Sub-Saharan Africa (excluding high income)	MMR	947	547
	NMR	45.7	28.5
Euro-zone area	MMR	11	6
	NMR	4.8	2.3

MMR – maternal mortality rate is the number of women who die due to complications from pregnancy or childbirth out of 100,000 live births; NMR – neonatal mortality rate is the number of babies who die within 28 days of birth out of 1,000 live births.
Source – World Development Indicators. https://databank.worldbank.org/data/source/world-development-indicators

Analytic methods

This study utilized exploratory spatial data analysis (ESDA) techniques. Data were analyzed using ArcGIS version 10.6. The first technique is a simple inspection or visualization of the distribution of the outcome variables ('at risk' women of reproductive age 15-19 and 40-44, live births and pregnancies), on descriptive choropleth maps. Our analysis focuses on women in these two age groups (15-19 and 40-44 years old), since childbirth at a young age or advanced maternal age is associated with increased risk of adverse maternal and perinatal outcomes (Amoako Johnson & Madise 2009; Neal & Matthews 2013; Bosomprah et al. 2016; amongst others). We refer to this group of women as "'at risk' women of reproductive age (WRA)", subsequently. The analysis tools in Arc Toolbox were used to extract the age structure datasets of each of the three countries of interest from the high resolution age-structured population distribution map of Africa (dataset), while maintaining the clipping geometry and extent of the administrative districts. The values, and areas with high and low clustering of the outcome variables per square kilometre were highlighted and displayed on the map legends.

For the second technique, buffer analysis was performed to quantify the proximity of pregnancies to health facilities. The buffer is a zone of specified radius or width around a selected map feature or raster of grid cells measured in distance. This geographic location or buffer zone allowed us to examine the proximity of pregnancies to health facilities through calculation of user-defined distance to the nearest health facility. We created point geometry shapefiles of health facilities for each of the three countries, and then created buffers of 50km radii around each facility. The reason is because, 50km radii is approximately equivalent to 2 hours travel time by motorized transport based on the standard yardstick used for national disparity assessment of access to health services for international comparison (Alegana, Wright, Pentrina, Noor, Snow, Atkinson et al. 2012; Tatem et al. 2014). These buffer zones were overlaid on each country's pregnancy dataset and the percentages of pregnancies within and outside the 50km buffer zone calculated using spatial analyst tools in ArcGIS. Pregnancies that fell within 50km of a health facility were classified as pregnancies as having 'adequate access' to MNHC, while the pregnancies that fell outside 50km radii were classified otherwise. The results were mapped to provide an understanding of the geographic and spatial variation of health care accessibility and highlight inequities in maternal health service provision. For purpose of comparison, we undertook the same calculation of distances but created buffers of 25 km radii, in order to identify areas where there are persistent spatial inequalities in access to life-saving maternal and newborn health services.

For useful interpretative results from the buffer analysis, we grouped districts within regions, and used zonal statistics to compute the proportion of pregnancies that were outside 50km and or 25km of health facilities in each district of the three (3) countries; and summed these at a regional level to take account of any spatial heterogeneity effects due to small numbers. To identify locations with clusters of pregnancies, live births and 'at risk' women, at sub-regional levels, it is important to familiarize the reader with the unique geographical and administrative context of each country. Mali is divided into ten regions, and one capital district (the Bamako district). Each of these regions are divided into 56 districts referred to as 'cercles'. Guinea is divided into 8 administrative regions which are further divided into 34 sub-regions known as 'prefectures'. Liberia is divided into 15 administrative regions, referred to as counties. These counties are divided into 108 districts. The geographical locations of the regions in Mali, Guinea and Liberia are presented in the administrative maps of the countries (Figure 2a-c).
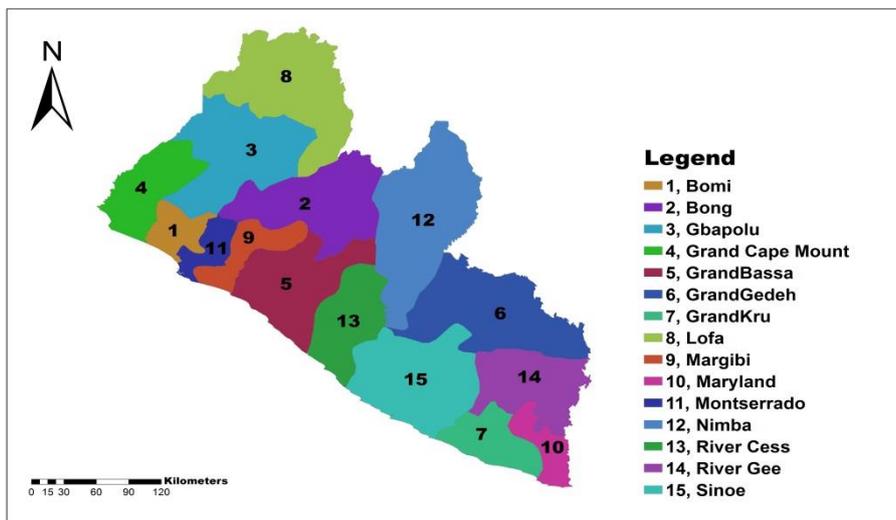
(a)
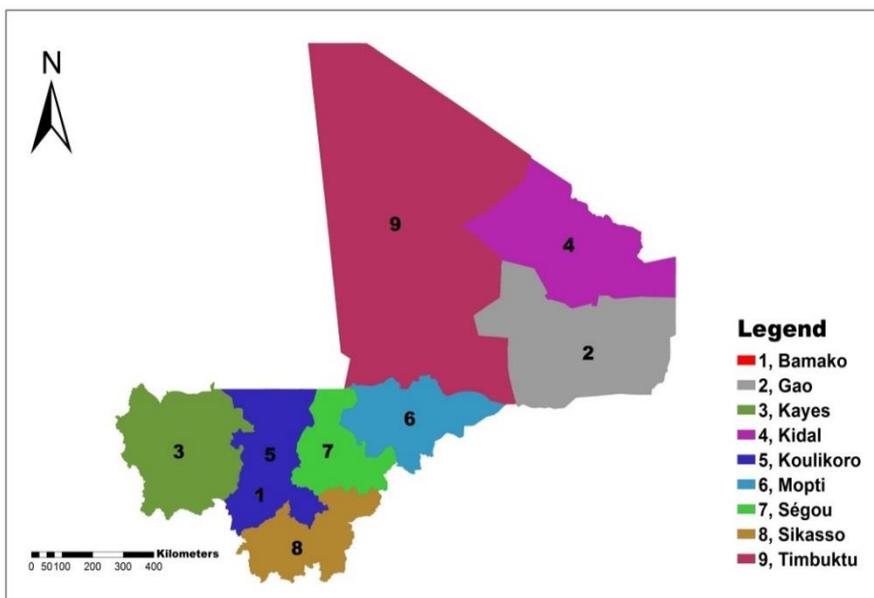
Regions in Mali

(b)
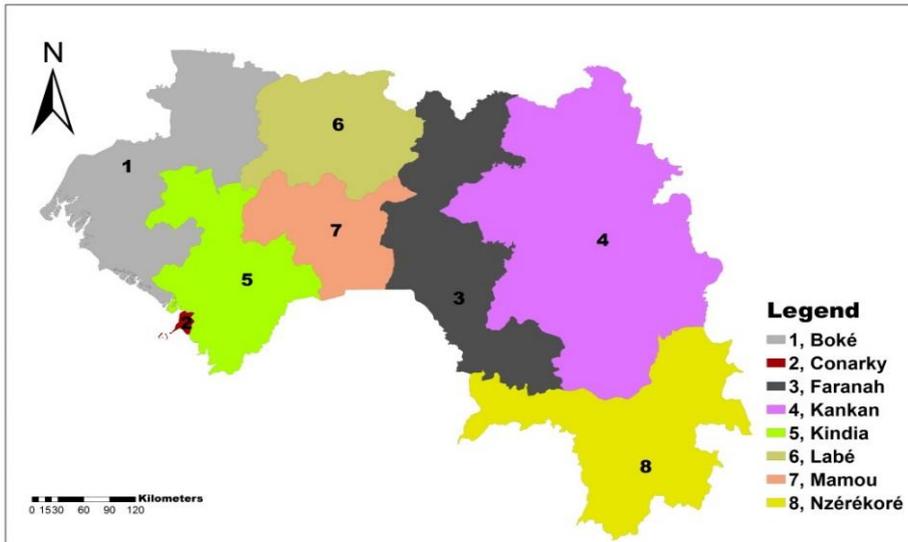
Regions in Guinea

(C)

Counties in Liberia

Results

Spatial distribution of 'at risk' women of reproductive age (WRA): 15-19 and 40-44

The results of the spatial analysis as shown in the visual maps indicated considerable spatial heterogeneities in the distribution of 'at risk' women of reproductive age (WRA) across the urban districts of Mali, Guinea, and Liberia. The highest concentration of 'at risk' WRA per square kilometre was found in the respective metropolitan capital areas of Bamako, Conakry and Greater Monrovia. In Mali, the distribution of women aged (15-19) was high in Bamako (717), Gao (1029) in the Gao region, located in the north, Koulikoro (541) and Kayes district (506), both located in the Kayes region in

western Mali along the Senegal River. The lowest maximum number of WRA was found in almost all the districts in Kidal or Sahel region and other districts such as Meneka (14) in Gao region, Nara (15) in Koulikoro region in the west; and Youwarou (17) in Mopti region, central Mali (these districts are shown in darker red shades in Figure 3a). These results make sense since most of these areas are in the sparsely populated desert regions of Mali. A similar spatial pattern was observed for the older women (40-44) (shown in light pink shades in Figure 3b).

The distribution of WRA in Guinea, varied from 1481 in Conakry, 329 in the prefectures of Macenta in the Nzerekore region (southern Guinea); 306 in Kissindougou in Faranah region, central part of

Guinea to 910 in Toungue located in Labe region in the northern part of the country (these districts are presented in dark blue shades in Figure 3c). The distribution of women aged 40-44 followed similar pattern. However, the maximum number of women was lowest in northern Guinea and varied from 33 in Dubreka (Kindia region), 42 in Pita (Mamou region) to 62 in Lélouma (Labe region). The clustering was as low as 39 in Boffa located in the Boke region, western Guinea (districts shown in light brown shades in Figure 3d).

The districts with the highest clustering of 'at risk' WRA (15-19) in Liberia include Greater Monrovia (877), St Paul River (759), Pleebo/Sodeken in Maryland (529) and Greenville (460) in Sinoe county in the south. These areas are the more densely populated regions of Liberia. In contrast, the lowest distribution of WRA (7) was observed in Mecca district in Bomi county, Zota (6) in Bong county, Bokomu (5) and Kongba (in the Gbarpolu county), Morweh (5) Butaw (4) and Kpayan (4). These districts are located in the forested and sparsely populated regions in south-central and northern Liberia. The results for older women (40-44) exhibited similar patterns. These districts are shown in yellow and light purple shades in figure 3e and 3f respectively.

Spatial distribution of women of reproductive age

(a)

Women age 15-19 per sq km
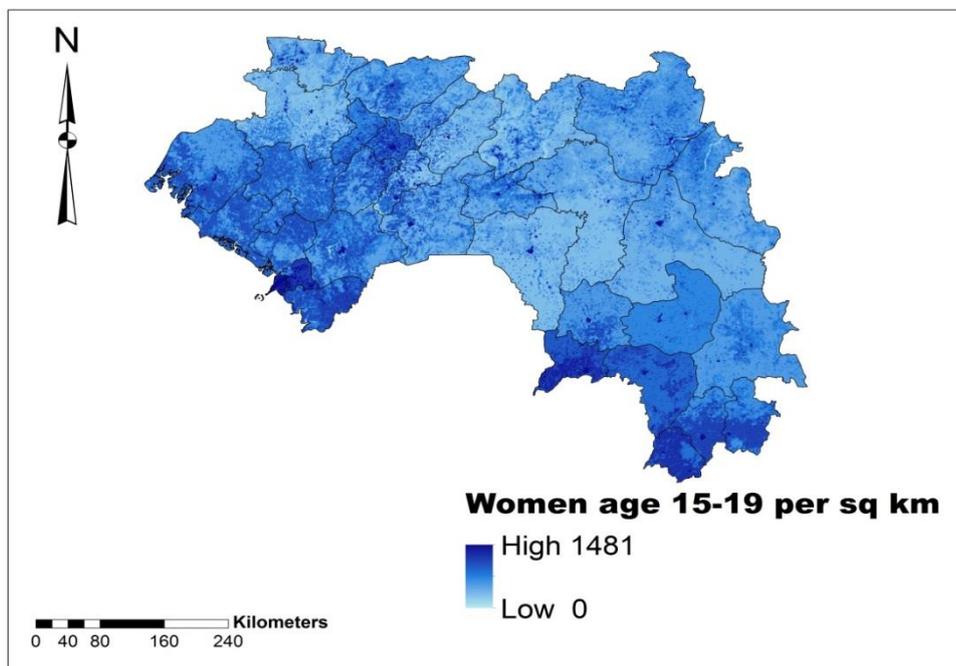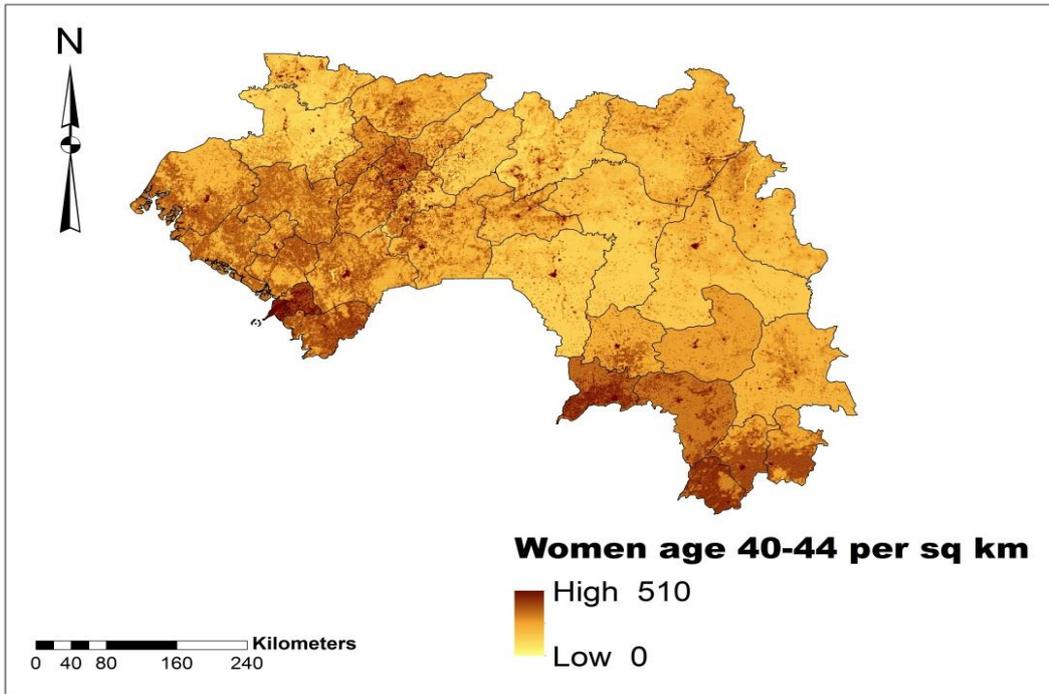High 1029
Low 0

0   130 260   520 Kilometers
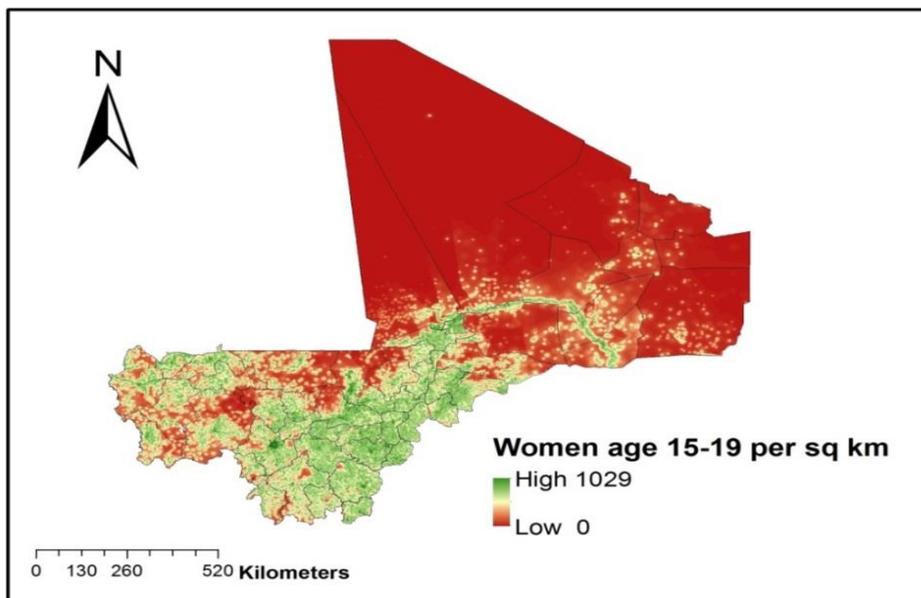
(b)
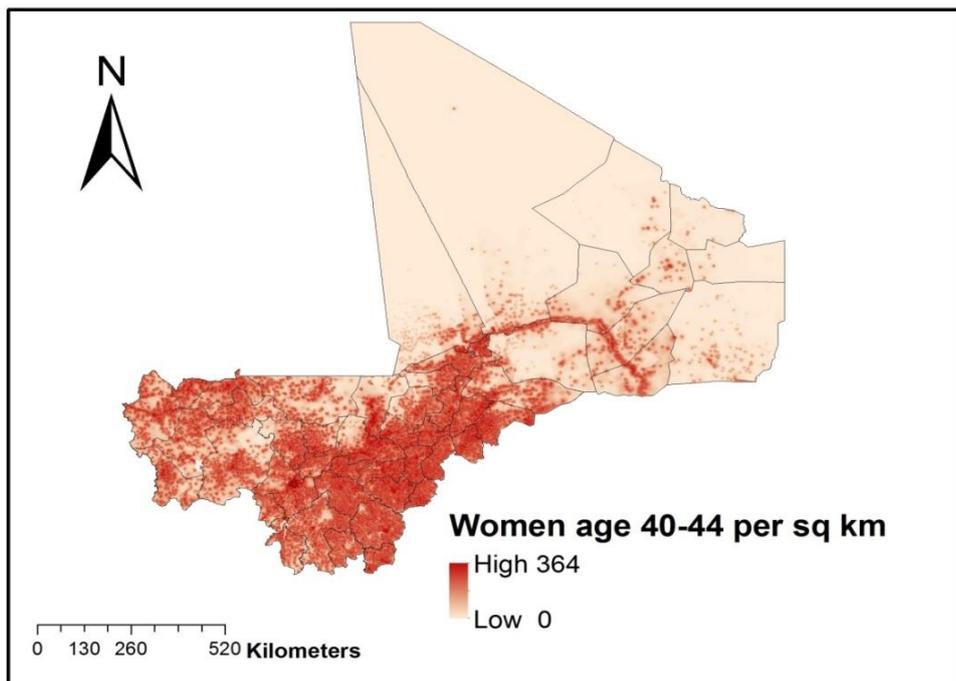
Map of Mali showing the number of women of reproductive age per square km: (a) 15-19 and (b) 40-44

(c)

(d)

Women age 40-44 per sq km

High 510

Low 0

Map of Guinea showing the number of women of reproductive age per square km:
(c) 15-19 and (d) 40-44

(e)

Women age 15-19 per sq km

High 877

Low 0
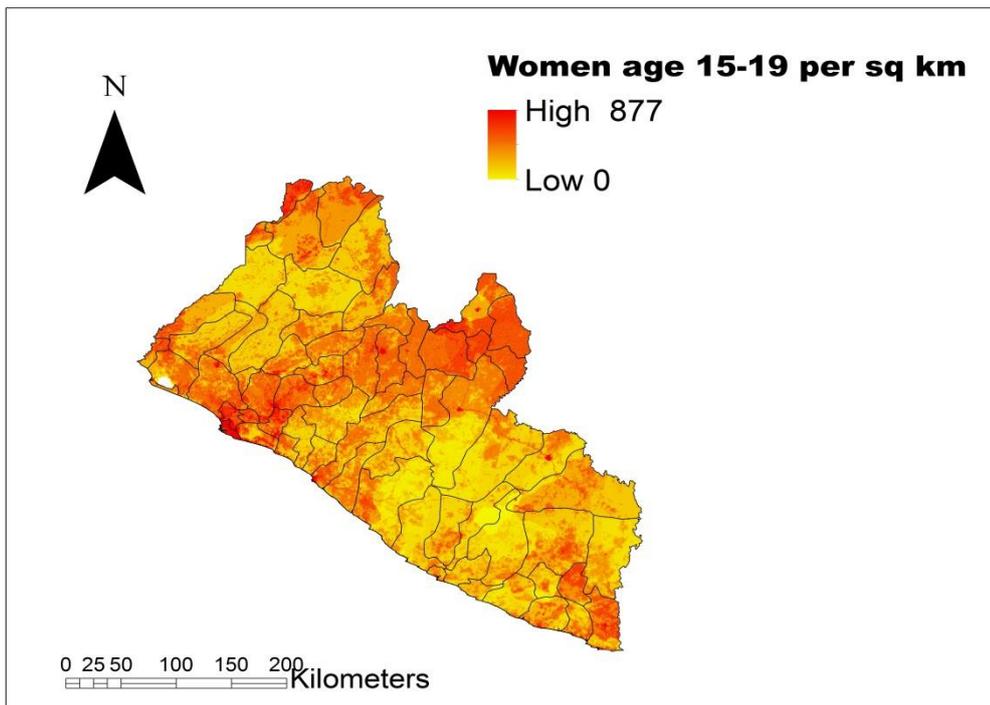
(f)
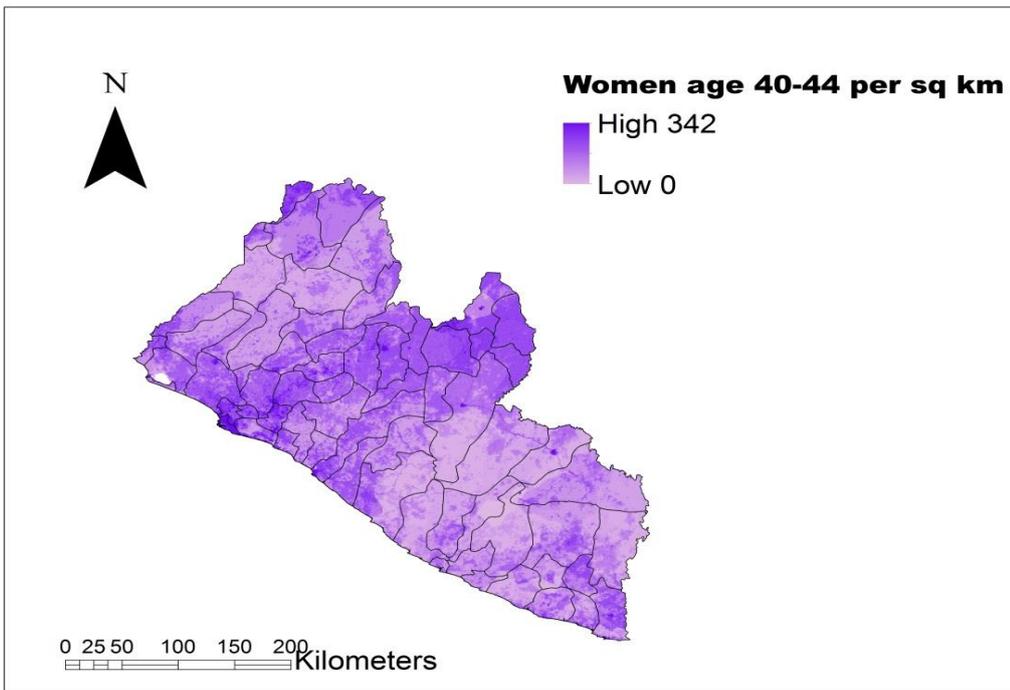
Map of Liberia showing the number of women of reproductive age per square km:
(e) 15-19 and (f) 40-44.
Figure 3: Spatial distribution of women of reproductive age in Mali, Guinea and Liberia

Spatial distribution of Live Births

Results showed clusters of live births in the capital cities of Mali, Guinea and Liberia, as expected due to the large population resident in the urban capital areas. In Mali, the minimum number of live births per km2 was lowest in almost all the districts in the Sahel region in northern Mali including Timbuktu, Abeibara and Tin-Essako (districts shown in light blue shades), and high in districts shown in deep blue shades (Figure 4a). The clustering of live births in Bamako, ranged from 10 to 491 live births per square km. The highest maximum number of live births per km2 (1,063) was observed in Gao district in northern Mali.
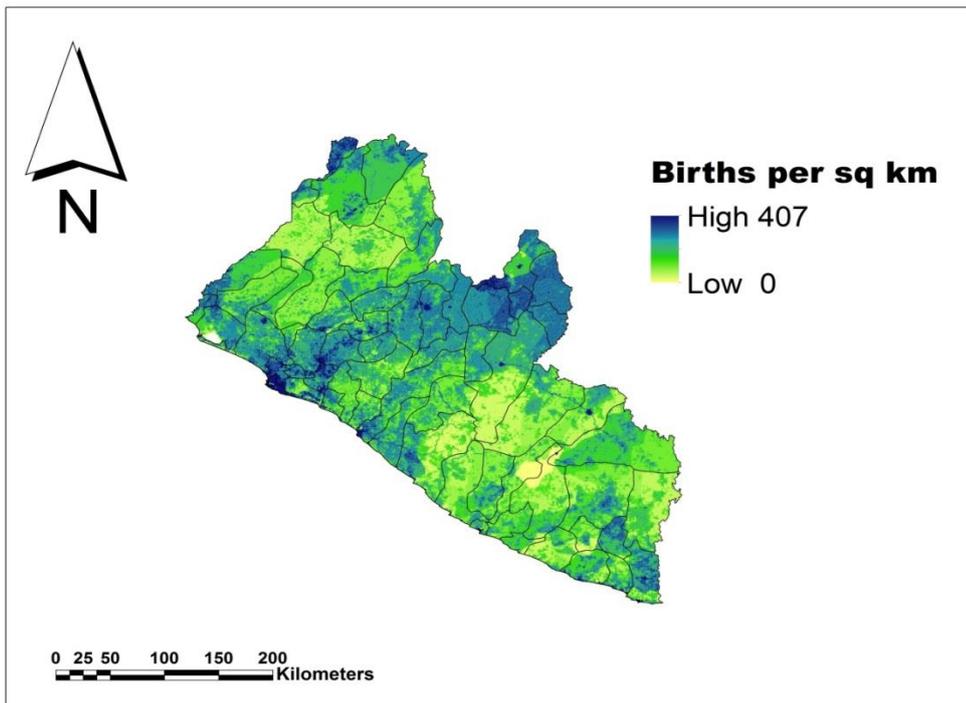
(a)
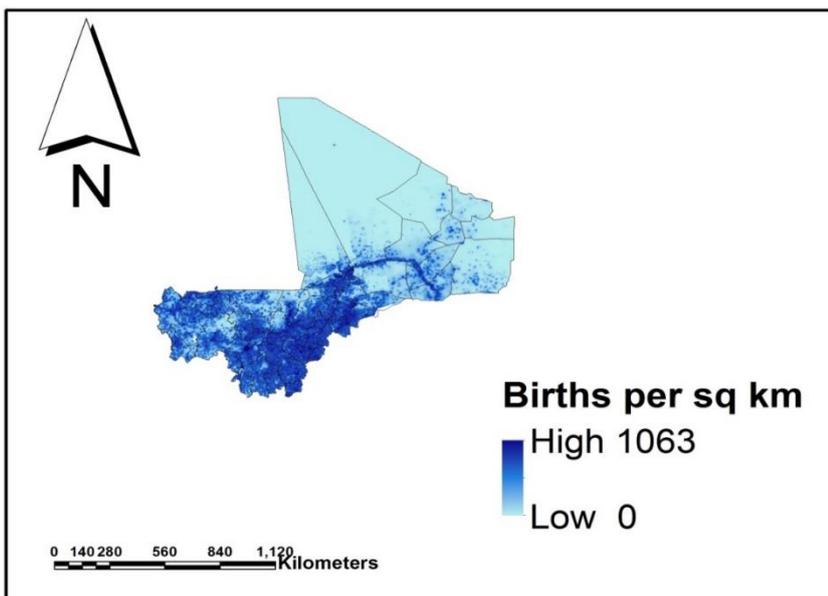
Numbers of live births per square k

(b)
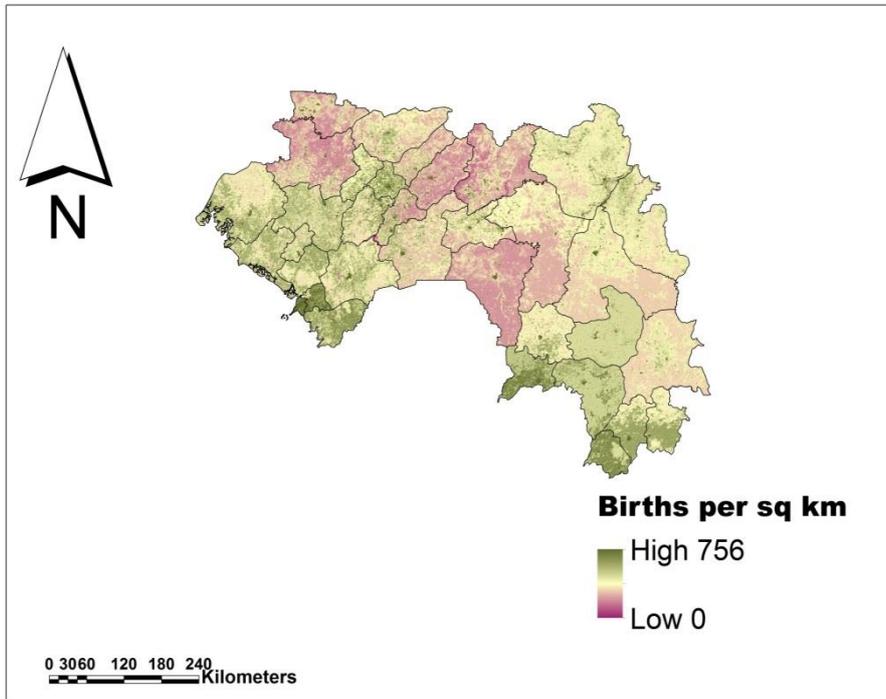
Numbers of live births per square km, Guinea

(c)

Numbers of live births per square km, Liberia

Figure 4: Distribution of the number of live births per square km: Mali, Guinea and Liberia

The maximum number of live births in Guinea was high in Conakry with a maximum of 756 live births per square km and in other districts such as Nzerekore, Mandiana in Kankan region and Tougue in Labe region (see Figure 4b, districts in deep purple shades). Districts in light green shades had the lowest number of births and these include: Boffa in Boke region, Dubréka in Kindia region and Pita in Mamou region located in a valley of the Fouta Djallon area of in central Guinea. These regions of Guinea are characterized by a high degree of migration to neighbouring countries.

The highest number of births (407) per square kilometer occurred in Greenville in Sinoe county

located in south-east Liberia (districts shown in deep blue shades (Figure 4c). Other districts with high number of births include Greater Monrovia and St Paul River in Montserrado county, Sanniquelleh-Mahn and Tappita in Nimba county, Pleebo/Sodeken in Maryland, District 3 in Grand Bassa county, and Mambah-Kaba in Margibi county. To a large extent, there is a high level of correspondence between number of births in these districts and the earlier results of the spatial distribution of 'at risk' women of reproductive age. This is expected because; areas with more women of reproductive age are likely to have more number of births, on average. Districts with less than five estimated births (per square kilometre) include District 2 (in Grand Bassa county),

Bokomu and Kongba (in Gbarpolu region), Kokoyan (in Bong county), Salayea (in Lofa county), Buah and Sasstown (in Grand Kru county), Morweh located in Rivercess county, Butaw and Kpayan (both in Sinoe county). These districts are shown in yellow shades (Figure 4c).

**Spatial distribution of pregnancies**

Although, understanding the spatial distribution of women of reproductive age and live births is important, we are specifically interested in examining the distribution of pregnancies and quantifying the proximity of pregnancies to health facilities in order to determine access to obstetric healthcare.
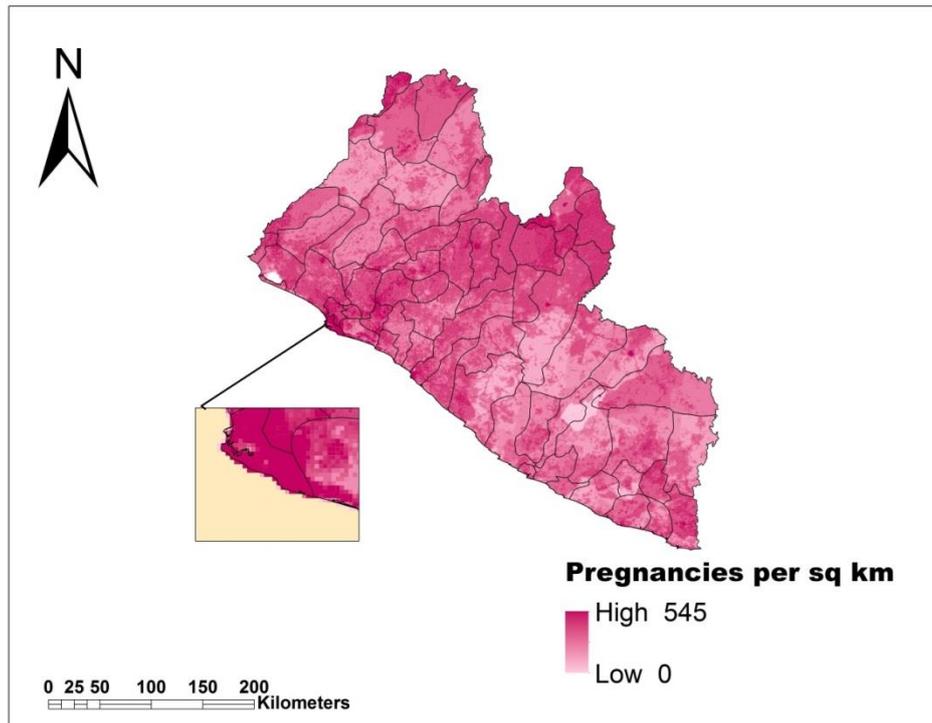
(a)
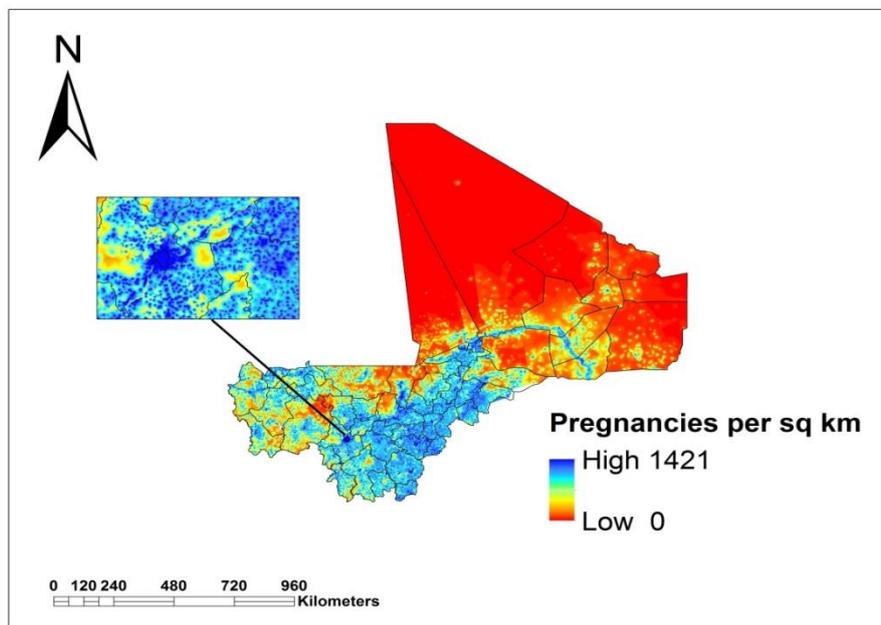
Mali map, with a close up of Bamako are

(b)
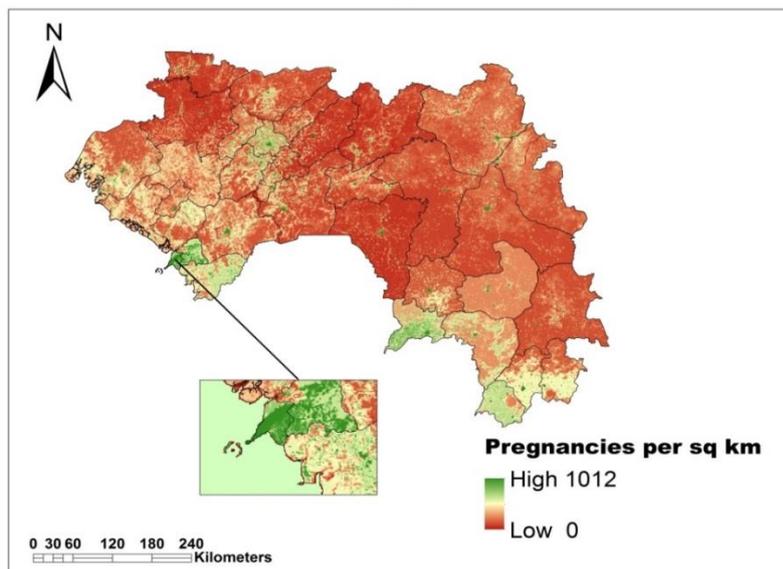
Guinea map, with a close up of Conakry area

(c)

Liberia map, with a close up of Greater Monrovia

Figure 5: Estimated number of Pregnancies per square km: Mali, Guinea and Liberia

Notably, there was considerable clustering of pregnancies in all the urban capital cities of the three countries of interest (Figure 5). For Mali, the estimated number of pregnancies was higher in districts that are shaded with blue, with a maximum of 1421 pregnancies per square km in Gao district (Gao region). This region has been rapidly growing, with a large urban settlement developing along the Niger River. Other districts with high number of pregnancies are located in western and southern Mali. For instance, Kita and Kayes (in Kayes region), Koulikoro and Kati (in Koulikoro region), San in Segou region, Mopti, (located at the confluence of the Niger and the Bani Rivers), Sikasso in Sikasso region and Timbuktu located at the southern edge of the Sahara desert. Regarding Guinea, the highest maximum number of pregnancies (1012) occurred in Conakry, Gousal and Fria (in Boke region), Kissidougou, Mandiana and Nzerekore. In Liberia, the districts represented in deep purple shade (Figure 5c) had the highest cluster of estimated pregnancies per square kilometer and these include Greater Monrovia with estimated 490 pregnancies, Greenville (545), and Pleebo/Sodeken (421) – all these areas are located in the Southern counties of Sinoe and Maryland respectively.
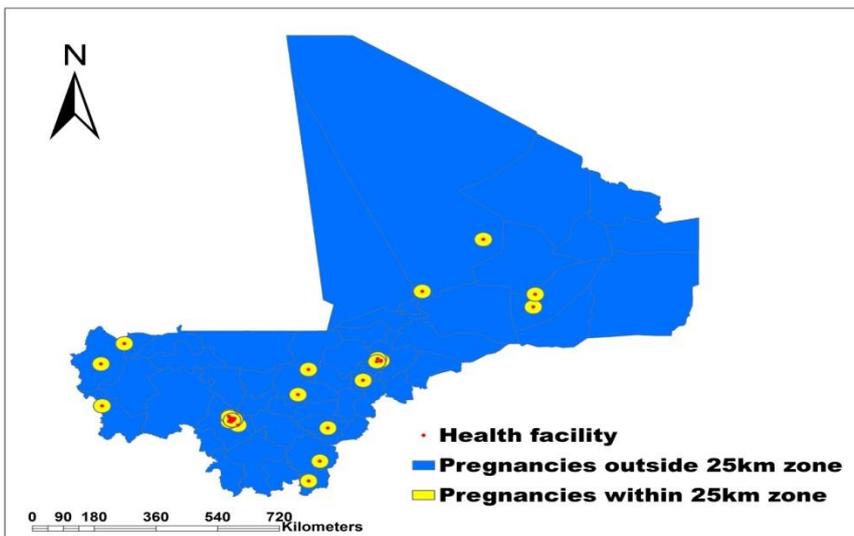
Quantifying the proximity of pregnancies to health facilities (Buffer Analysis)

(a)
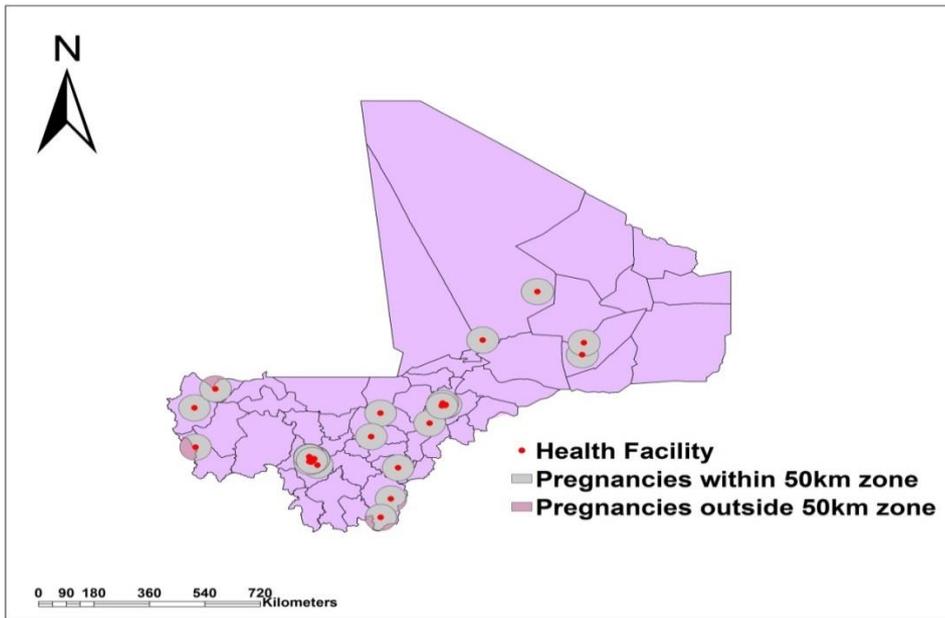
Number of pregnancies within and outside 50km of a health facility

(b)

Number of pregnancies within and outside 25km of a health facility

Figure 6: Proximity of pregnancies to health facilities in districts (cercles) of Mali

Results of the buffer analysis revealed disparities in health facility coverage and access in many districts of Mali. As shown in Table 2, all the pregnancies in Bamako were within 50km and 25km distance of a health facility indicating a high clustering of health facilities and adequate access. In contrast, almost all the pregnancies in Kidal region were outside 50km (and consequently also outside 25km) distance of a health facility, implying that pregnant women may have to travel about 2 hours to access healthcare services.
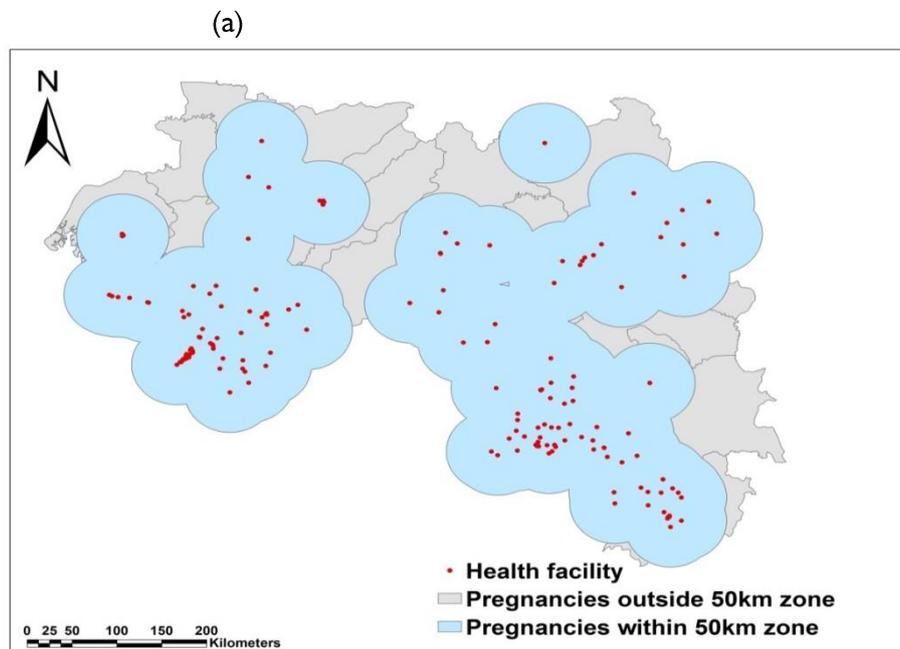
Table 2: Number of pregnancies (and percentage) outside 50 km and 25km of a health facility in Mali in 2015 by region

(a)　Regions	(b)　Total Number of Pregnancies*	(c)　Pregnancies outside 50km buffer zones (d)　N　　(%)	(e)　Pregnancies outside 25km buffer zones (f)　N　　(%)
(g)　Bamako	(h)　102551	(i)　0　　(0)	(j)　0　　(0)
(k)　Gao	(l)　43281	(m)　25136 (58.1)	(n)　29780 (68.8)
(o)　Timbuktu	(p)　60272	(q)　49744 (82.5)	(r)　54391 (90.2)
(s)　Segou	(t)　143013	(u)　81944 (57.3)	(v)　113612 (79.4)
(w)　Mopti	(x)　138333	(y)　99119 (71.6)	(z)　108718 (78.5)
(aa)　Kayes	(bb)　130906	(cc)　93117 (71.1)	(dd)　110791 (84.6)
(ee)　Sikasso	(ff)　185891	(gg)　100256 (53.9)	(hh)　143617 (77.2)
(ii)　Koulikoro	(jj)　162069	(kk)　99870 (61.6)	(ll)　118898 (73.4)
(mm)　Kidal	(nn)　5099	(oo)　5099 (100)	(pp)　5099 (100)

*Total number of pregnancies per region is the sum of pregnancies in all the districts in the region

Furthermore, results indicated considerable spatial variations in proximity to health facilities and access across the region of Mali. In Timbuktu the majority of pregnancies (83%), over two-thirds in Mopti (72%) and Kayes (71%), more than half in Koulikoro (62%) and Gao (54%) were outside 50km of a health facility. Similarly, more than three-quarter of pregnancies in the districts of Timbuktu (90%), Segou (79%), Mopti (79%), Kayes (85%) and Sikasso (77%) were outside 25km buffer zones, while over two-thirds of pregnancies in Gao (69%) were outside 25km buffer zones.

The visual maps (Figures 7a, b) and results from zonal statistics (Table 3) showed spatial variations in proximity of pregnancies to health facility across the various districts of Guinea. Estimates from the zonal statistics indicated that 100 percent of the estimated pregnancies in Conakry were within 25km of a health facility. Out of all the pregnancies outside 50km and 25km buffer zone, the highest percentages were observed in Mamou region (46% and 89%) and Labe (39% and 62%)

(a)

Number of pregnancies within and outside 50km of a health facility

(b)
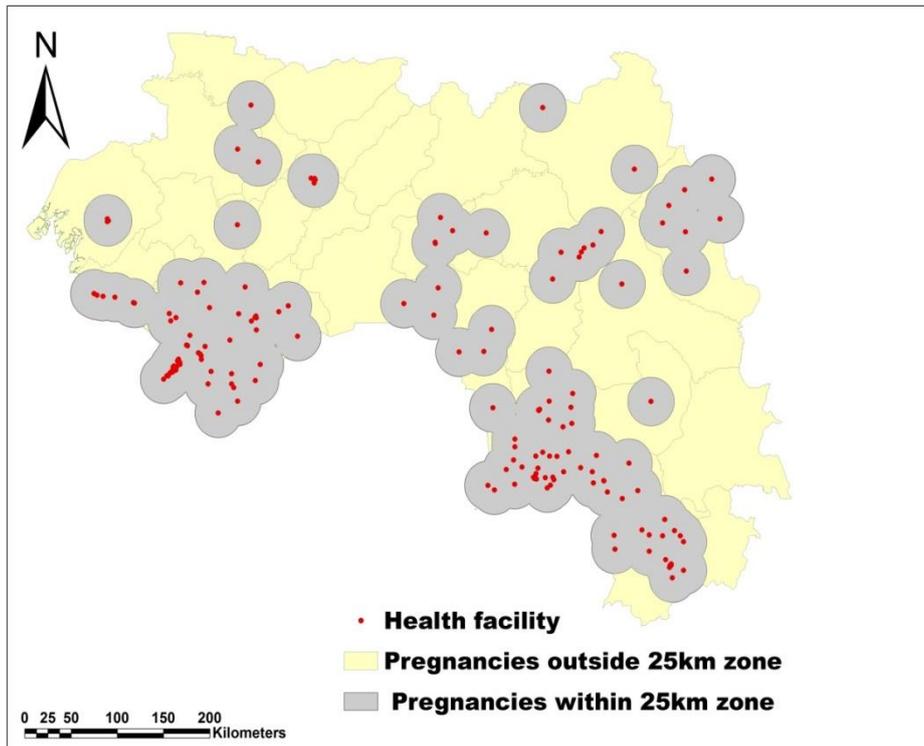
Number of pregnancies within and outside 25km of a health facility

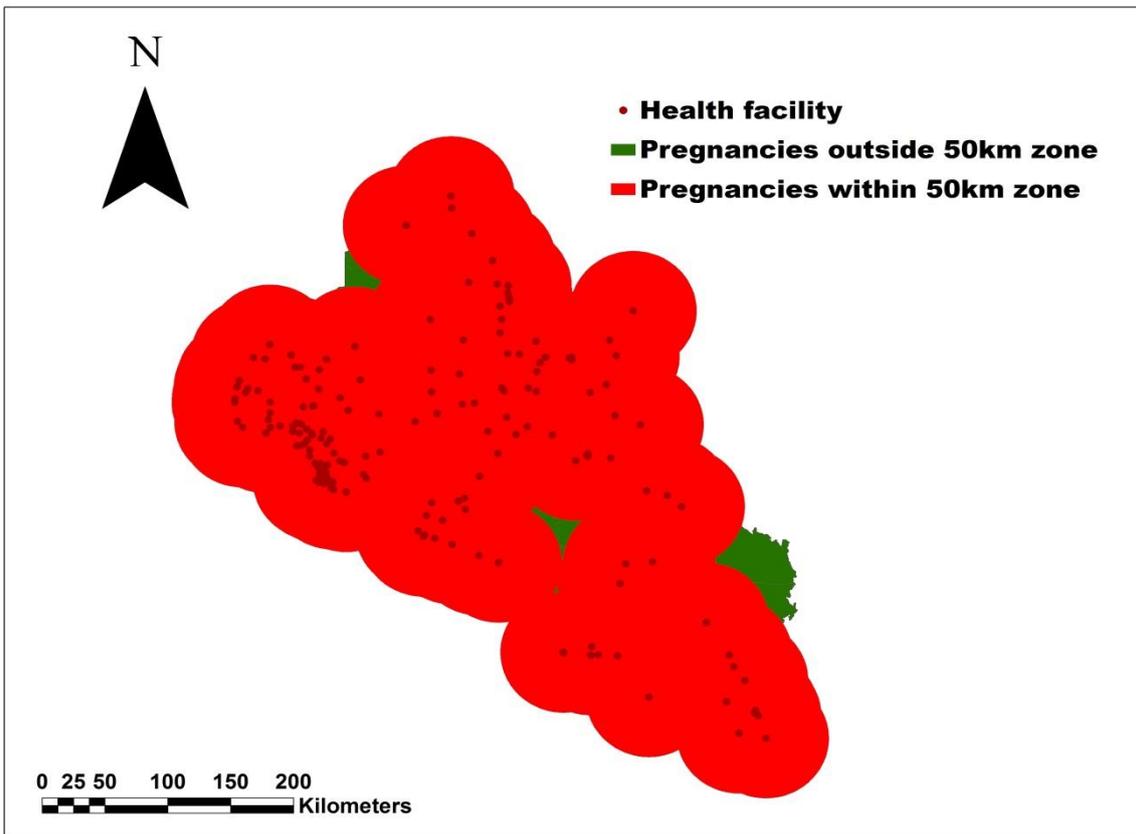**Figure 7: Proximity of pregnancies to health facilities in districts (prefectures) of Guinea**

Table 3: Number of pregnancies (and percentage) outside 50km and 25km of a health facility in Guinea in 2015 by regions

(qq) Region	(rr) Total number of pregnancies	(ss) Pregnancies outside 50km buffer zones		(uu) Pregnancies outside 25km buffer zones	
		(tt) N	(%)	(vv) N	(%)
(ww) Conakry	(xx) 75514	(yy) 0	(0)	(zz) 0	(0)
(aaa) Boke	(bbb) 60900	(ccc) 15187	(24.9)	(ddd) 35715	(58.6)
(eee) Farana	(fff) 46342	(ggg) 5442	(11.4)	(hhh) 14785	(31.9)
(iii) Mamou	(jjj) 38749	(kkk) 17896	(46.0)	(lll) 34572	(89.2)
(mmm) Kankan	(nnn) 102356	(ooo) 14776	(14.4)	(ppp) 51621	(50.4)
(qqq) Kindia	(rrr) 91915	(sss) 4397	(4.7)	(ttt) 11169	(12.2)
(uuu) Labe	(vvv) 46330	(www) 18256	(39.4)	(xxx) 28692	(61.9)
(yyy) Nzerekore	(zzz) 129521	(aaaa) 15792	(12.2)	(bbbb) 33205	(25.6)

Results also revealed that one out of every four pregnancies in Boke (25%) was not within 50km of a health facility and the lowest percentage (5%) was found in Kindia. For pregnancies out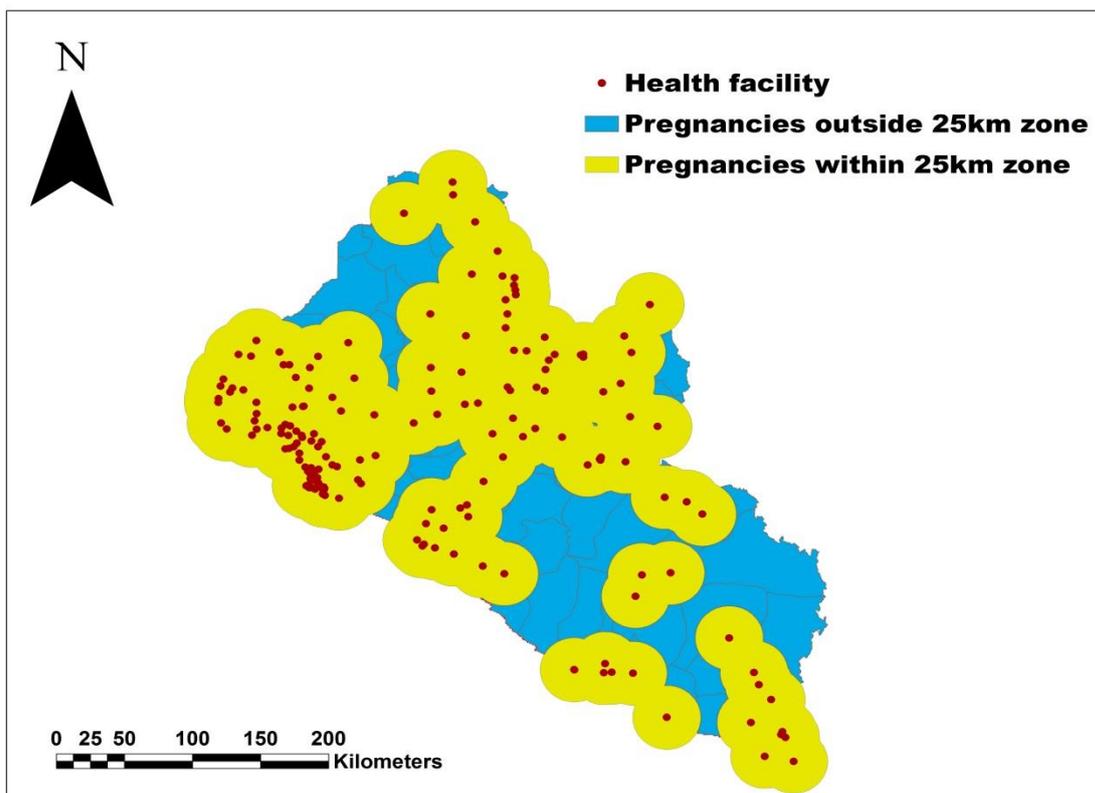side 25km buffer zone, about 3 out of 5 occurred in Labe (62%) and Boke (59%), half in Kanakan (50%), one third in Farana (32%) and 1 out of 4 in Nzerekore (26%).

(a)

Number of pregnancies within and outside 50km of a health facility

(b)

Number of pregnancies within and outside 25km of a health facility.

Figure 8: Proximity of pregnancies to health facilities in districts of Liberia

Table 4: Number of pregnancies (and percentage) outside 50km and 25km of a health facility in Liberia in 2015 by regions

(cccc) Regions*	(dddd) Total number of pregnancies	(eeee) Pregnancies outside 50km Buffer zones (ffff) N (%)	(gggg) Pregnancies outside 25km buffer zones (hhhh) N (%)
(iiii) Gbarpolu	(jjjj) 5264	(kkkk) 144 (2.7)	(llll) 1161 (22.1)
(mmmm) Grand Gedeh	(nnnn) 9627	(oooo) 1300 (13.5)	(pppp) 3821 (39.6)
(qqqq) Grand Kru	(rrrr) 4640	(ssss) 145 (3.1)	(tttt) 2398 (51.6)
(uuuu) Nimba	(vvvv) 30828	(wwww) 55 (0.2)	(xxxx) 3130 (10.2)
(yyyy) River Gee	(zzzz) 4595	(aaaaa) 172 (3.7)	(bbbbb)1606 (34.9)
(ccccc) Rivercess	(ddddd)4965	(eeeee) 83 (1.6)	(fffff) 2094 (42.2)
(ggggg) Sinoe	(hhhhh) 7241	(iiiii) 10 (0.1)	(jjjjj) 2840 (39.2)
(kkkkk) Bong	(lllll) 19639	(mmmmm) 0 (0)	(nnnnn)66 (0.3)
(ooooo) Lofa	(ppppp)14405	(qqqqq)0 (0)	(rrrrr) 3666 (25.4)
(sssss) Margibi	(ttttt) 17016	(uuuuu)0 (0)	(vvvvv) 258 (1.5)

Note: *Only regions with pregnancies outside 50km and/or 25km of a health facility are displayed

The percentage of estimated pregnancies outside 50km distance of a health facility in Liberia was highest in Grand Gedeh (14%) lowest in Sinoe. Meanwhile in Bong, Lofa and Margibi regions, all the pregnancies were within 50km radius. More than half (52%) in Grand Kru, roughly 2 out of 5 pregnancies in Rivercess (42%), Sinoe (39%) and Grand Gedeh (40%), and one-quarter in Lofa (25%) and slightly over one–third in River Gee (35%) and were outside 25km buffer zone. The lowest percentage (0.3%) was found in the Bong region.

Discussion

The aims of this study were to describe and visualize the spatial distribution of women of reproductive age, pregnancies and live births at subnational levels in Mali, Guinea and Liberia; and to quantify and identify pregnancies with 'inadequate access' to healthcare services (those that fell outside 50km and 25km of a health facility). The results revealed spatial heterogeneities in the distribution of women of reproductive age, births and pregnancies across the districts, and clustering of all the reproductive health outcomes in the urban and capital cities of the three countries: Bamako, Conakry and Monrovia. Buffer analysis also revealed that all the estimated pregnancies (100%) in the capital cities were within 50km and 25km of a health facility indicating adequate coverage and access. This could be due to environmental features and high concentration of health facilities in the capital cities. We will now discuss the country results one at a time: Mali, Guinea, then Liberia.

In Mali, the distribution of women of reproductive age, births and pregnancies per square km was highest in Bamako, Koulikoro, Kayes, Segou districts in southern Mali and Gao in the North. However, the clustering was lowest in districts of the Sahel regions: Timbuktu, and Kidal. For instance, the results showed that almost all the pregnancies in the districts of Kidal region, and more than 70 percent in Timbuktu, Mopti and Kayes regions were not within 50km and 25km distance of a health facility. This is not surprising because, the armed conflict that has been going on in the Sahel may have contributed to the difficulty in accessing healthcare for women and newborn living in the north.

According to International Committee of the Red Cross (ICRC) report, the conflict has affected the functioning of health facilities, hence it is very hard for many Malians, particularly young children and pregnant women, who are the most vulnerable segment of the population and also war casualties, to obtain adequate access to healthcare (International Committee of the Red Cross (ICRC) 2013). Apart from four community health centres in the Bourem district to the north of Gao and a referral health centre in Kidal, Gao's regional hospital remains the main medical facility in the north of the country. Our study corroborates the findings of this report, because almost all the pregnancies in the districts of Kidal were outside 50km distance of a health facility. This implied that pregnant women would have to travel over 50 kilometres (approximately over 2 hours) from other rural districts in order to access care in the Gao region. The ICRC report also confirmed that women in labour were often arriving too late from the rural areas with complications of bleeding thus leading to high rate of infant and maternal mortality at the hospital in Gao (International Committee of the Red Cross (ICRC), 2013). There is therefore, need for the provision of adequate primary healthcare and health professionals in the districts of northern Mali.

In Guinea, (as shown in Figures 3a and b; 4b and 5b) high clusters of women of reproductive age, live births and pregnancies were observed in the capital city of Conakry and most districts in southern regions of Guinea, for instance, Nzerekore, Labe and Farana. However, the lowest distribution of women of reproductive age, live births and pregnancies was found in the districts located in western, central and forested regions of the country, particularly Dinguiraye, Pita and Lelouma in Mamou region. Our study also revealed that 46% and 89% of pregnancies in Mamou in central Guinea were located outside 50km and 25km distance of a health facility respectively. This finding corroborates the report of 2012 Demographic and Health Survey (DHS) and Multiple Indicators Cluster Survey (MICS) which indicated that a higher proportion of women (84%) in Mamou did not receive maternal healthcare after childbirth which is crucial for the survival of the mother and newborn (MEASURE DHS and ICF International 2013-2014). This is an indication of lack of adequate access to maternal healthcare services.

Furthermore, according to WHO, report, about 57% of health facilities in Guinea were rated to be 'poor' and concentrated in urban areas where most health workers resided. For instance, 16% of the population live in the capital city of Conakry, and roughly half of all health professionals live there. This implied that, there is a major shortage of adequately trained health force, particularly in the rural areas. As a country largely affected by Ebola, and the first to have a recorded case, the health infrastructure must have been particularly affected by the disease. The first cases were recorded at Gueckedou, in Nzerekore region located in the south of the country. The region is near the borders of Liberia and Sierra Leone, and has been left impoverished by the civil unrest in Guinea, and the neighbouring countries. Another unintended consequence of Ebola was that health workers have borne the brunt of infections and were up to 32 times more likely to be infected (Shoman Karafillakis & Rawaf 2017; World Health Organisation 2014). In addition, the health infrastructure of the country has also been severely damaged and this could be the plausible explanation for the high percentage of pregnancies located outside 50km distance of a health facility.

From the maps of Liberia (Figures 3e and 3f, 4c and 5c), the distribution of women of reproductive age was high in most districts of Sinoe, Maryland and Grand Gedeh counties with the highest clustering found in Greater Monrovia. The results also showed that the maximum number of live births and pregnancies per square kilometer were lowest in the districts of Bokomu (Gbarpolu county), Butaw and Kpayan in Sinoe county, Morweh in Rivercess county;

Salayea and Sasstown in Lofa and Grand Kru counties respectively. In addition, the high percentage of pregnancies outside 50 km and 25 km of a health facility observed in the counties of Grand Gedeh, Grand Kru, River Cess, River Gee and Sinoe could indicate poor healthcare coverage and access exacerbated by the prolonged 14-year civil war in Liberia with its devastating effects on the country's healthcare system. Notably, Grand Kru, Rivercess and River Gee in south-eastern Liberia have been identified as the poorest counties in the country with poor social and health indicators (Yaya, Uthman, Bishwajit & Ekholuenetale, 2019). According to WHO situation health analysis, the number of nurses and certified midwives per health centre varies considerably across counties in Liberia, with the rural counties in the south-east more likely to have the lowest staffing levels (UNICEF 2014).

Furthermore, it has been observed that in many rural southeastern towns of Liberia most roads become impassable during the rainy season from April to October and pregnant women seeking medical care had to trek for hours to the nearest clinic (Kruk, Rockers, Williams, Varpilah, Macauley, Saydee & Galea, 2010). Following the outbreak of the Ebola virus, in 2014, the fragile healthcare system deteriorated and there was uneven distribution of health workers, with 60 percent of Liberia's health workers concentrated in Monrovia, where about 30 percent of the country's population lived (Streifel, 2015). Consequently, the people living in rural areas particularly were under-served; and as shown in our analysis, one such area is Lofa county, located on the border with Guinea, which happened to be where the first Liberian Ebola case was recorded.

Strengths and limitations of the study

Our study has admittedly some limitations, and highlights further areas of work. In the main, our analysis did not include an exhaustive listing of health facilities (this would have required an inordinate amount of time and resources to locate all primary, secondary and tertiary health facilities), due to unavailability of data on emergency obstetric and newborn care in all the countries. This lack of completeness prevents us to make inferences regarding the relationship between maternal mortality and healthcare access, and claims about the representativeness of study conclusions. In addition, calculation of standard or actual travel time is beyond the scope of this study; and since the choice of a 50km buffer zone did not fully represent the difficulty of travel between two locations, this would require impedance information that would reflect the most efficient route to the nearest health facility (Alegana et al. 2012). However, though there are uncertainties

in the health facility and travel times data used in this study due to unavailability of comprehensive health facility data, the linkage of pregnancy data to datasets with the location of health facilities clearly showed that there were localities where increasing numbers of pregnancies and births have not been matched by commensurate increases in the availability of appropriate health facilities. This finding was also highlighted by the WorldPop project team (Tatem et al. 2014). This therefore suggests that inadequate maternal healthcare services and distribution of healthcare providers is leading to poor maternal health in these countries.

Another limitation is the fact that the majority of births (60%) occur outside health facilities, and a significant proportion of these births are delivered with complications and assisted by unskilled birth attendants (Amoako Johnson 2016). For women who live farther from health facilities birth-related complications can often be fatal (Neal & Matthews 2013). Admittedly, some of these births may not have been captured in this study. Nonetheless, our study adds depth to the current knowledge from small area estimation of maternal and newborn outcomes by extending the work to subnational level (districts) in West Africa. Data generated would be useful for effective planning to promote safer pregnancies, births and healthier newborns and equitable distribution of human resources and infrastructure, thus bridging the gap in health inequity within and across the countries.

Conclusion
This study has revealed spatial variations in the distribution of women of reproductive age, pregnancies and live births, and linkage of pregnancies to healthcare services at district levels in Mali, Guinea and Liberia. This can be related to the numerous findings (Tatem 2014; Campbell et al. 2016; Bosomprah et al., 2016; Ebener et al. 2015) which have shown that proximity to health facilities is important in accessing maternal and newborn services. Our study found that in urban areas geographic distance does not appear to affect access to healthcare. However, in rural and remote areas, where transport infrastructure tend to be lacking and weak, there are geographic barriers and hence inadequate access to healthcare services. To bridge the gap in inequity in health care access and improve maternal and newborn health, there is need for equitable distribution of health facilities and health professionals in disadvantaged districts. Policy makers should prioritize allocation of resources and health infrastructure in these identified districts of the three countries particulaly districts in northern Mali,

northern and forest regions of Guinea and counties in south eastern Liberia.

Authors' contributions
Study Design and Analysis: DO. Results summary and manuscript development: DO, BB, AR. Manuscript review: DO, BB, AR. All authors read and approved the final manuscript.

Competing interests
All authors declare that they have no competing interests.

Ethics approval and consent to participate
The manuscript does not involve direct human subjects and hence does not need ethical approval. The data used are available in the public domain.

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