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Complete List of Authors:	Curtis, Andrew; University of Geneva Institute of Global Health, GeoHealth group; Universite de Geneve Institut des Sciences de l'Environnement Monet, Jean-Pierre; UNFPA, Technical Division Brun, Michel; UNFPA, Technical Division Bindaoudou, Kerim; National Institute of Statistics and Economic and Demographic Studies Daoudou, Idrissou; Ministry of Health of Togo Schaaf, Marta; Independent Consultant, Agbigbi, Yawo; UNFPA-Togo Ray, Nicolas; University of Geneva Institute of Global Health, GeoHealth group; Universite de Geneve Institut des Sciences de l'Environnement

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National optimization of geographical accessibility to emergency obstetric and neonatal care in Togo

Andrew Curtis[1,2], Jean-Pierre Monet[3], Michel Brun[3], Kérim Bindaoudou[4], Idrissou Daoudou[5], Marta Schaaf[6], Yawo Agbigbi[7], Nicolas Ray[1,2,*]

[1] GeoHealth group, Institute of Global Health, Faculty of Medicine, University of Geneva, Geneva, Switzerland
[2] Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland
[3] Technical division, United Nations Population Fund (UNFPA), New York, USA
[4] National Institute of Statistics and Economic and Demographic Studies (INSEED), Lomé, Togo
[5] Ministry of Health, Lome, Togo
[6] Independent Consultant, Brooklyn, USA
[7] United Nations Population Fund (UNFPA), Lomé, Togo

Corresponding author: Dr. Nicolas Ray, nicolas.ray@unige.ch, GeoHealth group, Institute of Global Health, Faculty of Medicine, Campus Biotech, Chemin des Mines 9, 1202 Geneva, Switzerland

Abstract

Introduction: Improving access to emergency obstetrical and neonatal care (EmONC) is a key strategy for reducing maternal and neonatal mortality. Access is shaped by several factors, including service availability and geographic accessibility. In 2013, the Ministry of Health of Togo used service availability and other criteria to designate particular facilities as EmONC facilities, facilitating efficient allocation of limited resources. In 2018, the MoH further revised and rationalized this health facility network by applying an innovative methodology to optimize timely access to EmONC services. This study compares the geographic accessibility of the network established in 2013 and the more limited network developed in 2018.

Methods: We used data regarding travel modes and speeds, geographic barriers, and topographic and urban constraints, to estimate travel times to the nearest EmONC facilities. We compared the EmONC network of 109 facilities established in 2013 with the one composed of 73 facilities established in 2018, using three travel scenarios (walking and motorized, motorcycle-taxi, and walking-only).

Results: When walking and motorized travel is considered, the 2013 EmONC network covers 81% and 96.7% of the population at the 1-hour and 2-hour limit, respectively. These figures are slightly higher when motorcycle-taxis are considered (82.8 % and 98%), and drop down to 34.7% and 52.3% for the walking-only scenario. The 2018 prioritized EmONC network covers 78.3% (1-hour) and 95.5% (2-hour) of the population for the walking and motorized scenario. Population coverage is found to be most sensitive to uncertainties on speeds of travel on roads.

Conclusion: By considering geographical accessibility, our EmONC prioritization approach decreased the designated number of EmONC facilities in Togo by about 30%, while still ensuring that a high proportion of the population has timely access to these services. However, there physical access to EmONC for women not able to afford motorized transport remains inequitable.

Keywords: maternal health, universal health coverage, geospatial modelling, physical accessibility, health system strengthening

Strengths and limitations of this study

- This is the first study presenting a national optimization of a network of EmONC facilities partly based on realistic physical accessibility modelling.
- Country-based experts estimated the modes and speeds of transport on the various road types and off-road landcover categories, and associated uncertainty was accounted for.
- The EmONC prioritization approach succeeded in prioritizing 73 out of the initial 109 EmONC facilities, with only a marginal drop of population coverage.
- Only the physical accessibility to nearest EmONC services was modelled, but potential financial barriers and the fact that some patients could bypass the nearest facility may also affect access to EmONC.
- Travel was modelled only for the dry season conditions, but degraded road conditions in certain parts of the countries during the wet season may affect our estimates of EmONC accessibility.

INTRODUCTION

The Sustainable Development Goal (SDG) on health (SDG3) aims at bettering health outcomes for different at-risk groups, including pregnant women (SDG3.1.) and children under 5 years of age (SDG3.2.). One of the primary strategies for reducing maternal and neonatal mortality and morbidity is ensuring timely access to quality emergency obstetric and neonatal care (EmONC)[1]. However, access to EmONC is still a challenge in many low-income countries, especially in sub-Saharan Africa[2].

Because the physical distance to facilities has long been recognized as an important component of timely access to care[3, 4], an adequate geographic distribution of EmONC facilities is a prerequisite to minimize travel times for women in need of EmONC. WHO recommends a benchmark of no more than 2 hours of travel time to reach the nearest EmONC facility[5], as after 2 hours an obstetric hemorrhage can be fatal.

Realistically modelling and measuring spatial accessibility to health services is therefore very important for adequate planning and improvement of access to quality healthcare for pregnant women and newborns[6]. Some studies have used simple distances[7] and time[8] metrics, as well as population-to-provider ratios (PPRs)[9]. These metrics have been popular for their ease of use and minimal need for the input of spatial data layers, i.e. data that both provide locations and describe characteristics of geographic features.

However, these methods are not appropriate for modelling geographic accessibility in complex terrains where different modes of transport are potentially used for a single trip, and when patients seeking care are facing an emergency, where every minute of travel time is consequential. In such cases, approaches based on least-cost path modelling (i.e., finding the fastest route between locations based on various travel constraints) have proved useful to estimate time and routing to reach the nearest care providers, and to model catchment areas of facilities. Applying this modelling approach, the AccessMod tool[10] helps estimate geographic accessibility by taking into consideration the modes of transport, their respective speeds of travel on roads and off-road on various landcover types, and the influence of the topography and other barriers to movement. Studies assessing the accessibility of a variety of health care destinations have used AccessMod in their analyses (see e.g.[11-18]). Specific to accessibility to EmONC, Ebener and colleagues[19] have recently formalized and proposed new indicators based on least-cost path modelling.

The main objective of this study was to realistically determine and compare the overall geographic accessibility of our target population (women with obstetrical complications in need of EmONC) to two EmONC facility networks: the first one designated by the Ministry of Health

(MoH) in 2013 and the second one in 2018 through a methodology using accessibility modelling. We defined and applied various travel scenarios based on inputs from national and sub-national stakeholders, including speed and transport modes and their associated uncertainties. Besides expanding knowledge on the underlying mechanisms of geographical access to EmONC facilities in Togo, we described a robust spatially-explicit methodology for quantifying the population covered by networks of EmONC health facilities that can be replicated in other countries.

DATA AND METHODS

Study site and context

Togo is one of the smallest African countries in terms of landmass (approximately 56'785 km^2), with a population of approximately 7.9 million in 2018[20], and it is bordered by Benin to the East, Ghana to the West and Burkina Faso to the North. More than 40% of the total population live in the Southern part of the country[21] (in the region of Maritime and in the capital city of Lomé), with 42% of this population living in urban areas[21]. The 2017 Multiple Indicator Cluster Survey (MICS 6) for Togo[22] determined that there is a strong correlation between poverty and maternal mortality and morbidity, with the probability of giving birth assisted by qualified personnel found to be highly correlated to socio-economic status (98% of women in the richest quintile are assisted at birth by skilled health personal, compared to only 52% of the poorest quintile) and to place of residence (98% of women living in urban settings have skilled birth attendance, as compared to 65% of women living in rural settings). Three quarters of maternal deaths were found to be due to direct obstetrical causes. This suggests that access to timely EmONC is essential for reducing maternal mortality in Togo.

The 2017-2022 national plan for the health sector development in Togo[23] highlights that morbidity and mortality rates for mothers and newborns are still very high, and notes that this is due to insufficient supply of obstetric and neonatal care and by barriers to service access, including financial barriers. Despite some progress over the last decades, maternal and newborn mortality are still high in Togo, respectively 396 (80% CI: 270-557) maternal deaths per 100,000 live births in 2017[23] and 25 neonatal deaths per 1,000 live births in 2018[2]. Improving access to quality EmONC services has been a priority for the government since the EmONC needs assessment of 2012. In 2013, the MoH used facility data to identify 109 priority health facilities designated to provide EmONC services, and launched a process to monitor them on a quarterly basis to assess and address gaps in availability and quality of care. EmONC facility functionality requires enough qualified providers for 24h/7d services and the availability of key equipment, consumables, and medication for performing the key medical interventions (or signal functions) that are used to treat the direct obstetric complications that cause the vast majority of maternal deaths.

While the focus on a limited number of health facilities led to some progress in the availability of services, for example the increase of the proportion of EmONC facilities applying vacuum extractions from 5% in 2014 to 47% in 2016, the MoH decided in 2018 to further focus their efforts and resource allocation by decreasing the number of priority facilities; the MoH ultimately selected 73 health facilities that should provide EmONC services in the country. This selection was guided by a methodology developed by UNFPA and formalized and described in UNFPA's EmONC Network Development Implementation Manual[24]. In brief, this methodology, based on WHO, UNFPA, and UNICEF recommendations[5], helps countries to identify a network of EmONC facilities by selecting a number of EmONC facilities that do not exceed the international norm of 5 EmONC facilities per 500,000 population, and, by prioritizing facilities that can most feasibly be supported to actually provide all the relevant EmONC signal functions 24h/7d (see Box 1) with quality care, during the next programmatic cycle of the MoH (i.e. in the next 3-4 years). The selection of health facilities is done by considering both health facility characteristics (e.g. number of deliveries, human resources, gaps in EmONC signal functions, infrastructure) and two spatially-explicit indicators[19]: the population living within 1 and/or 2-hour maximum travel time from the nearest EmONC facility (i.e. population coverage), and the quality of each referral linkage between Basic EmONC (BEmONC) health facilities and their closest Comprehensive EmONC (CEmONC) health facility. BEmONC health facilities should provide seven EmONC signal functions 24h/7d while CEmONC health facilities provide nine EmONC signal functions (see Box 1).

Box 1: Emergency obstetrical and neonatal care (EmONC) signal functions

Services available 24h/24 and 7d/7	
Basic EmONC (BEmONC) signal functions	**Comprehensive EmONC (CEmONC) signal functions**
1) Administer parenteral antibiotics 2) Administer uterotonic drugs 3) Administer parenteral anticonvulsants 4) Perform manual removal of the placenta, 5) Remove retained products 6) Perform assisted vaginal delivery 7) Perform basic neonatal resuscitation.	BEmONC signal functions (1-7) + 8) Perform blood transfusion 9) Perform Caesarean section.

Accessibility & population coverage modelling

We used AccessMod, a WHO stand-alone and open-source geospatial tool[10, 25], to analyze the physical accessibility to, and the population coverage of, the national networks of EmONC health facilities in Togo in 2013 and 2018. AccessMod is based on a least-cost path algorithm that computes the fastest route between any location and the nearest health service (for details, see [10]). It can consider several sequential modes of travel (e.g. walking to a road, where one catches a motorcycle-taxi), several types of barriers to movement, health facility capacity, and population, when determining catchment areas. Moreover, AccessMod considers the direction of movement by applying an anisotropic analysis, i.e. considering the slope of the terrain to accurately model bicycling and walking speeds. Contrary to many accessibility modelling approaches that are based on a perfectly routable road data set (such as Nichols et al[26]), AccessMod can consider off-road travel in addition to road travel. On- and off-road travel speeds and modes of transport are user-defined in a travel scenario that assigns these travel constraints to each land cover and/or road category found in the input data.

For the movements of our target population, we defined three distinct travel scenarios from home to the nearest EmONC facility: 1) a walking & motorized scenario, 2) a motorcycle-taxi scenario, and 3) a walking-only scenario. The first scenario assumes that patients walk to the nearest road and then use a motorized mode of transportation (private or public), immediately available, to continue their journey. In the second scenario, patients use motorcycle-taxis to travel on- and off-road, with different speeds depending on the land cover.

Finally, the third scenario assumes patients are walking or being carried (e.g. on stretchers, carts) at walking speed (or lower).

The choice for these three scenarios and their associated modes and speeds of travel were decided through an iterative process of two workshops in Togo over the period 2016-2018. A first 3-day workshop took place in May 2016 to strengthen national capacity to analyze the geographic accessibility of health facilities in Togo by using AccessMod. The thirty Togolese participants were technical experts from the MoH; the national Togolese Institute for Statistics, Economic and Demographic studies (INSEED); NGOs and UN agencies; and they discussed and agreed on the specifics of how women with obstetrical emergency typically travel when they need to reach an EmONC facility in Togo. Average speeds of travel on all road categories were estimated by consensus, with travel scenario 1 deemed to be the most frequent. During a second workshop in May 2018, health stakeholders from each of the 6 regions of Togo gathered to define which health facilities should comprise their EmONC facility regional network, using the prioritization methodology described above to select a number of EmONC facilities per region not exceeding the international norm of 5 EmONC facilities per 500,000 population. These participants further refined the travel scenarios, and agreed that bicycles and public transport were rarely used, with the exception of a public bus system operating in greater Lomé [27]. The final travel speeds chosen for the three scenarios are found in Supplement 1.

Road speeds in urban areas were adjusted in order to simulate slower motorized travel occurring in intra-urban contexts due to various factors such as stoplights, traffic, pedestrians, and other hazards. Specifically, for scenario 1, travel speeds on asphalted roads were lowered from 80 km/h in rural areas to 30 km/h in urban areas, on urban secondary roads the speeds were lowered from 40 km/h to 20 km/h, and on urban tracks the speeds were lowered from 15km/h to 10 km/h. For scenario 2, travel speeds on asphalted roads were lowered from 40 km/h to 30 km/h, urban secondary road speeds were lowered from 20 km/h to 15 km/h and track travel speeds in urban areas were lowered from 15 km/h to 10 km/h. The speed corrections were applied on all road segments falling within the extent of the urban areas informed by the Global Rural Urban Mapping Project[28] (see Figure 1C).

Uncertainty analysis

To account for uncertainty in travel speeds, we additionally ran each consensus travel scenario with 20% slower or 20% faster speeds compared to the consensus scenario, following the methodology developed in Ouma et al.[16] and in Stewart et al.[29]. This translated to lower and upper uncertainty bounds on the reported output statistics. To further disentangle the effects of uncertainties on the speeds on roads and off roads, we ran scenario 1 by keeping on-road speeds constant (at consensus values) and varying off-road speeds by the plus or minus 20%. Conversely, we ran this scenario keeping off-road speeds constant and varying on-road speeds. Finally, to test the model's sensitivity to the consideration of topography, we also ran each consensus travel speed scenario without considering slope correction (i.e., isotropic mode).

Two uncertainty indicators were produced: (1) lower and upper uncertainty bounds on the variation in percentage (per region and for the whole country) of the coverage of population living less than one and two hours away from the closest EmONC facility, and (2) a series of spatially-explicit uncertainty maps showing the differences (by subtraction) between the lower and upper bound travel time maps.

Input geospatial data

Various datasets were assembled and prepared to run the geospatial analyses in AccessMod (details of the preparation steps are found in Supplement 2). We obtained the names and geographic coordinates of the 109 EmONC facilities composing the initial national network of EmONC health facilities in 2013 from INSEED (Figure 1A). We further verified these names and coordinates with the help of the MoH. For the EmONC health facilities network of 2018, the 73 final designated set of facilities was obtained through the MoH[30].

We used the road network created by the *Direction de la Cartographie national et du cadastre* of Togo, classified in three hierarchical categories: asphalted roads, secondary roads, and tracks (Figure 1B). We considered barriers to terrestrial movements composed of quarries and bodies of water, such as rivers, lakes and damned areas. The barriers file was created by the Togolese Ministry of Agriculture, Livestock and Hydraulics (Figure 1A).

Administrative boundaries at the prefectural, regional and national levels were created and made available by INSEED using data collected during the 2010 general census (see Figure 1C). These data sets were used to determine the percentage of population coverage for each administrative unit.

We used the Digital Elevation Model (DEM) of Togo from NASA' Shuttle Radar Topography Mission[31] (Figure 1D). Slopes were derived from the DEM directly in AccessMod. Land cover information was provided by INSEED, with a land cover data set composed of twelve categories (Figure 1E).

Finally, we used the population density data set from the Worldpop project[32] (Worldpop, 2013) (Figure 1F), with UN-adjusted population count from 2013 and 2018. We assumed that the target population of women with obstetrical complications in need of EmONC is uniformly distributed across the overall population.

Patients and the public involvement

There was no patient or public involvement in this study. Health facility names and geographic coordinates, as well as administrative boundaries, were shared by INSEED. The road network was shared by the *Direction de la Cartographie national et du cadastre* of Togo. All other geospatial data were publicly available.

RESULTS

The accessibility maps for the walking and motorized scenario, and the Motorcycle-taxi scenario, and for the two time periods, are shown in Figure 2, with the respective maps for the walking-only scenario in Supplement 3. In 2013, physical access was highest under scenario 2 (motorcycle-taxi scenario), with 82.8% of the total population less than one hour away from the nearest EmONC health facility, and 98% less than two hours away from the nearest EmONC health facility. For scenario 1 (walking and motorized scenario), these figures are 81% at the 1-hour travel time limit and 96.7% at the 2-hour limit respectively. Using the 2018 network of 73 facilities, the results using the motorcycle-taxi scenario are 79.2% at the 1-hour travel time limit and of 96% at the 2-hour limit. With the walking & motorized scenario, the corresponding results are 78.3% at the 1-hour limit and 95.5% at the 2-hour limit. Despite a reduction of the number of EmONC health facilities by one third from 2013 to 2018, the population able to physically access the closest EmONC health facility within one or two hours is similar – with a difference of less than 4 percentage points in these two travel scenarios.

For both time periods, access in terms of population coverage at national scale is only marginally higher for the motorcycle-taxi travel scenario, even though this translates to a much larger extent of the surface under the 2-hour maximum travel time limit (green areas in Figure 2). This is explained by the fact that many areas where access is very low in scenario 1 are fairly unpopulated. We also see that accessibility is highly dependent on roads in scenario 1. This is the case for instance in parts of the Atacora mountains (large red areas in the central-western part of the country in Figure 2A), a region with a very low population density and no roads (according to our data). With scenario 2, travel is less dependent on roads than in scenario 1, but access tends nevertheless to be higher around the road network, even though travel speeds on roads are lower for motorcycle-taxis than for regular motorized transport. The results for the 2018 network at regional level are given in Table 1, and at prefectural level in Supplement 2.

Table 1: Percentage of population living less than one- or two-hour travel time to the nearest EmONC facility, in 2018, per region and for the country, with uncertainty intervals within brackets, and for the walking & motorized and the motorcycle-taxi scenarios.

	Walking & Motorized Scenario		**Motorcycle-taxi Scenario**	
Region	*<1-hour*	*<2-hour*	*<1-hour*	*<2-hour*
Plateaux	55.4 [44.4 - 65.1]	89.8 [80.7 - 95.2]	58.7 [49.2 - 66.3]	88.4 [78.5 - 94.6]
Kara	62.7 [52.3 - 71]	90.2 [82.8 - 94.1]	65.2 [56.7 - 72]	92.8 [84 - 97.7]
Maritime	94.4 [90.1 - 96.7]	99.4 [98.6 - 99.7]	96.9 [93.7 - 98.5]	99.9 [99.7 - 100]
Centrale	65.2 [53 - 74.7]	91.7 [86.6 - 93.9]	66.5 [56.1 - 75.7]	96.2 [90 - 98.5]
Savanes	80.7 [68.9 - 87.9]	98.9 [96 - 99.6]	72.5 [58.9 - 81.8]	97.9 [93.3 - 99.9]
Lomé Commune	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]
Country	**78.3 [70.5 - 84]**	**95.5 [91.6 - 97.5]**	**79.2 [72.2 - 84.3]**	**96 [91.6 - 98.4]**

The region of Lomé Commune has 100% population coverage for both time thresholds and both motorized scenarios, which is due to the combined effect of a very densely populated region of only 90 km^2 with 11 EmONC facilities in 2018, and a good road network that permits the Lomé population to access the closest EmONC in less than 1 hour travel time. In contrast, the rural region of Plateaux presents much more heterogeneous results, with large uncertainty intervals. The result at prefectural level are available in Supplement 4.

We illustrate in Figure 3 the uncertainty in travel time for the walking & motorized scenario on the 2018 facility dataset, separated for the effects of speed uncertainty on roads and landcover. In these maps, pixel values indicate the extent of the uncertainty of travel time to the nearest EmONC facility, obtained by subtracting the travel time grid resulting from the "- 20%" travel speeds scenario by the "+ 20%" travel speeds scenario. The maps show a spatially heterogeneous distribution of the uncertainties, especially in the case of the road speed uncertainty map with widespread uncertainties in all areas of the country, but with relatively low uncertainties along the asphalted road network. Similar maps for the uncertainty linked to the DEM are found in Supplement 5.

The landcover and road uncertainty maps show that uncertainty is strongest in areas with very little population density (see Figure 1F). The total uncertainty map, combining uncertainty from roads and landcover, further highlights the fact that uncertainty is quite low on roads close to facilities and increases in more rural areas.

Population coverage for the walking-only scenario is found in Supplement 5. They show the expected drop in national population coverage to 33.4% within 1-hour walking, and 50.8% within 2-hour walking. Large differences in coverage are found between regions.

DISCUSSION

The accessibility maps that were produced according to our three travel models illustrate the differences in accessibility in different parts of the country. This can help identify areas in the country where geographic accessibility to EmONC facilities is most difficult. These areas could be targeted for remedial efforts, such as mobile outreach, posting community health workers, the creation of maternity waiting homes in the EmONC health facilities of the region, or planning improvement of the road infrastructure.

The three alternative models used to obtain these maps reflect different socio-economic segments of the population. If patients can afford to take a motorized vehicle after having reached the closest road or use a taxi-moto from their home, then more than 78% of the population can reach the closest EmONC facility (as per the 2018 designation) in less than 1 hour. When considering 2-hour maximum travel time, this percentage is much higher, with 95% of the population able to reach the nearest facility within the time limit. For women obliged to walk or be carried by non-motorized means, accessibility to EmONC within one hour drastically decreases to about 33% of the population, and to 51% within the 2-hour threshold travel time limit. Thus, nearly half of the target population has low access to EmONC if they cannot afford to travel by motorized vehicle or motorcycle-taxi.

As anticipated, access to EmONC is greater for urban populations, even with travel speeds that are substantially decreased in urban areas. The relatively higher density of EmONC facilities within urban areas compared to rural areas, and the much denser urban road network explain this.

Though the 2018 prioritized EmONC network included 36 fewer facilities than the 2013 network, the 2018 network still achieves good overall geographic accessibility. It only drops marginally in terms of population coverage (between 1 and 3.6 percentage points depending on the scenario) when compared to the initial network of 109 designated EmONC facilities in 2013. However, from a planning perspective, prioritizing 73, rather than 109 facilities for EmONC functionality is a more feasible, achievable goal over the short term, i.e. the next programmatic cycle. The number of prioritized EmONC facilities is lower than the international norm that targets around 80 functional EmONC facilities for the 2018 population of Togo. However, the decision of the MoH to target this prioritized network was commensurate with available resources and the modelling results showing that this network can nevertheless ensure timely access to a large proportion of the population in case of obstetrical complications.

Our uncertainty analysis has shown that population coverage estimates are also most sensitive to uncertainties on the speeds on roads, as compared to the speeds off roads. This highlights the need for great caution when choosing travel speeds. A good representativeness of local experts, both in terms of knowledge about the specific travel behaviors of the target population and in terms of possible regional specificities for travel is vitally important. Other sources of information on effective travel speeds (e.g. using speed tracker onboard vehicles or mobile phones) could be very useful if available in the future. Furthermore, spatially displaying the uncertainty regarding travel times highlights the regions where this uncertainty is the highest, and that could be given high priority for future improvements of model parametrization (e.g. ensuring that all roads are well captured, or incorporating possible region-specific alternative means of transport).

Limitations

Although our study has produced the first high-resolution model of geographic accessibility to EmONC facilities in Togo, several limitations should be noted. First, our models only consider physical accessibility of the national network of EmONC health facilities. Although the three alternative transport models captured potential financial barriers linked to transport, we have not considered in this study other possible financial accessibility issues such as health care related expenditures. Acceptability (i.e. "the match between how responsive health service providers are to the social and cultural expectations of individual users and communities", see Peters et al.[33]) was also not considered. Immediate availability of motorized transport was also assumed in our models, which could over-estimate accessibility in cases where delays for findings transport are significant. Variable quality of interpersonal and clinical care in facilities can also affect which facility patients chose; they may not chose the closest facility in terms of travel time[34], possibly bypassing BEmONC health facilities in certain cases. We also assumed no delay in the decision to seek care. Clearly, further research on how to incorporate these other facets of accessibility could improve our models and our understanding of the spatial variability of effective access to EmONC.

Second, although we decided to model travel during the dry season conditions, we could not capture degraded road conditions in certain parts of the countries during the wet season, and these are known to heavily affect travel time. A more balanced view of regional accessibility to EmONC could be achieved by factoring in these seasonal specificities.

Third, our analyses were built on a uniform uncertainty range (± 20%) on all roads and landcover categories. This could be improved by applying parameter-specific uncertainty ranges, notably on the different road types. This could be captured by a dedicated workshop, with experts representing specific regions providing more realistic uncertainty ranges on motorized and walking speeds, possibly complemented by field observations or facility-based surveys. Lowering uncertainties on the travel scenario, and therefore on population coverage estimates, would improve decision making for prioritized resource allocation.

Finally, we analyze the coverage to the closest designated EmONC health facilities, which includes both functioning and non-functioning EmONC health facilities. Non-functionality is here defined as when at least one EmONC signal function has not been performed in the previous 3 months. As the aim for faster maternal mortality reduction is a national network of functional EmONC health facilities, quarterly monitoring of the national network of EmONC health facilities in Togo started in 2015, included in 2020 in the health management information system (DHIS2), providing up-to-date information on the functionality of EmONC health facilities. Applying the same modeling approach described here to only functioning EmONC health facilities would provide up-do-date population coverage indicators at national and subnational level that can inform decision makers regarding the remaining gaps in order to optimize resource allocation. These results will be described in an upcoming dedicated publication.

CONCLUSION

The physical accessibility mapping of the national network of EmONC health facilities in Togo proved to be very useful in understanding the potential of the revised network to provide quality EmONC services to a large proportion of the population, while pointing to those areas with less accessibility. Using realistic modelling based on travel times, the accessibility analyses provided key information to the 2018 EmONC prioritization exercise, which aimed at finding a balance between designating a smaller number of facilities as EmONC to channel needed resources to these priority sites for improving quality of care, and ensuring good coverage of the population within 1 hour of travel time to the closest designated EmONC health facility.

The application of this methodology in Togo can be replicated in other countries thanks to the current good availability of key high-resolution geospatial data sets. This is of particular importance where mapping of physical accessibility is a crucial component for bettering health outcomes for women and newborns.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA SHARING STATEMENT

Data available upon reasonable request.

AUTHOR CONTRIBUTION

Andrew Curtis: conceptualization, methodology, formal analysis, writing, editing, visualization, validation. **Jean-Pierre Monet:** methodology, writing, editing, validation. **Michel Brun**: methodology, writing, editing, validation, supervision. **Kérim Bindaoudou:** data sharing, editing, validation. **Idrissou Daoudou:** data sharing, editing, validation**. Marta Schaaf:** methodology, writing, editing, validation**. Yawo Agbigbi:** data sharing, editing, validation**. Nicolas Ray:** conceptualization, methodology, writing, editing, validation, supervision.

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Figure legends:

Figure 1 - Vector and raster data sets used. (A) Barriers to movement (rivers, waterbodies, lakes); (B) Road network; (C) Digital Elevation Model (DEM); (D) 2013 Population density raster; (E) 2018 Population density raster; (F) Landcover raster; (G) 2013 EmONC facilities; (H) 2018 EmONC facilities; (I) Administrative boundaries (prefectures, regions and GRUMP urban extents) with region names.

Figure 2 - Maps of the travel time to the nearest EmONC facility using either the walking & motorized travel scenario or the motorcycle-taxi travel scenario, for both time periods (2013 and 2018).

Figure 3 - Uncertainty maps of the travel times to the nearest facility for the walking & motorized scenario on the 2018 EmONC facility network using (A) Road uncertainty, (B) Landcover uncertainty, and (C) Total uncertainty.

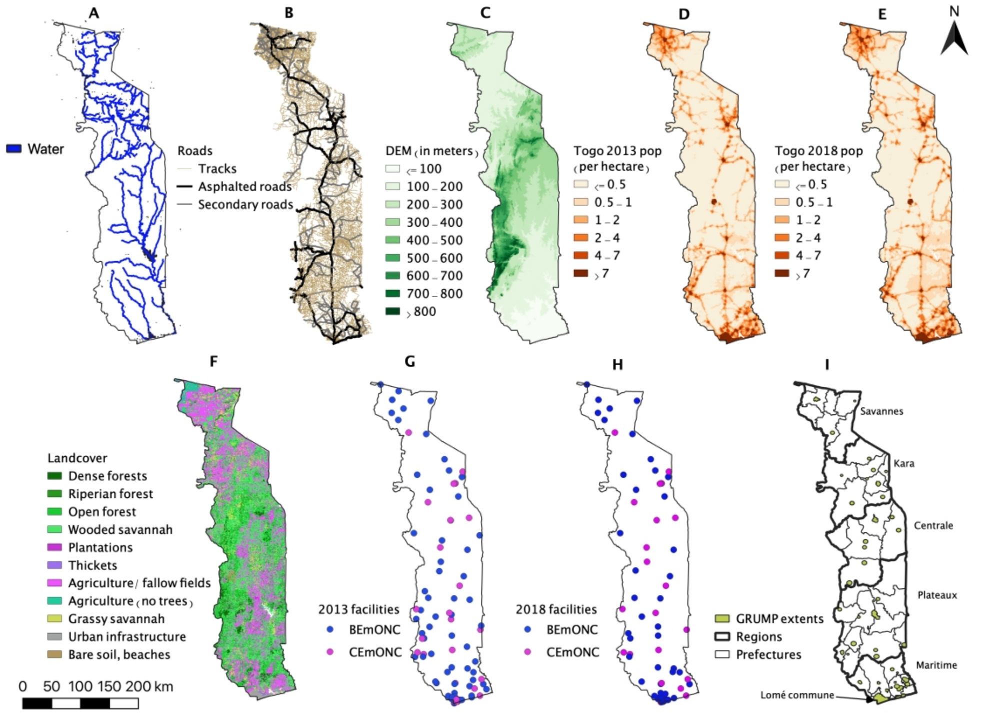


Figure 1 - Vector and raster data sets used. (A) Barriers to movement (rivers, waterbodies, lakes); (B) Road network; (C) Digital Elevation Model (DEM); (D) 2013 Population density raster; (E) 2018 Population density raster; (F) Landcover raster; (G) 2013 EmONC facilities; (H) 2018 EmONC facilities; (I) Administrative boundaries (prefectures, regions and GRUMP urban extents) with region names.

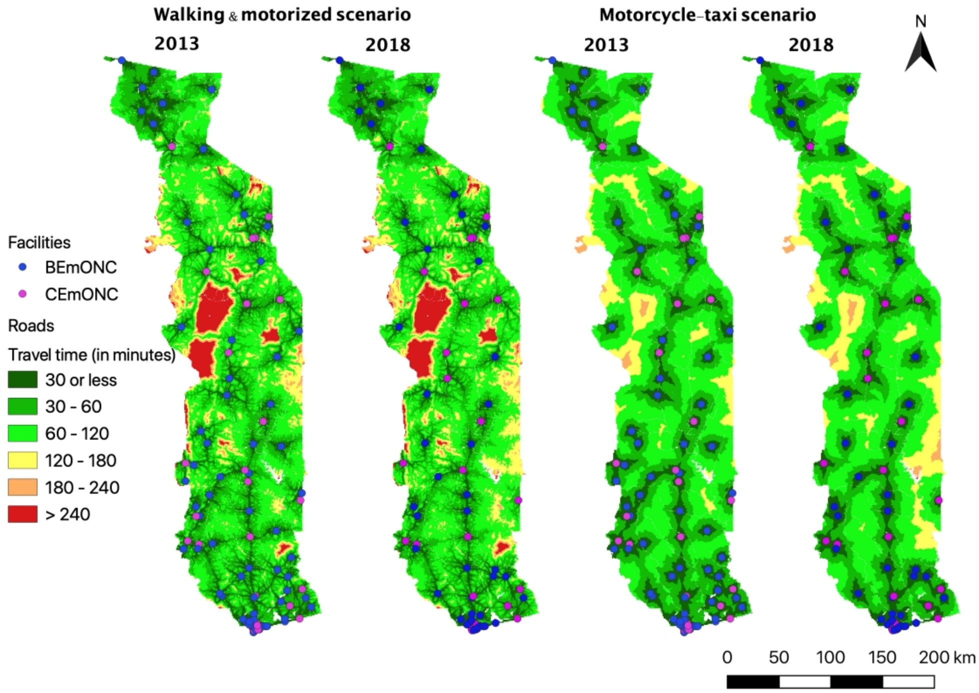


Figure 2 - Maps of the travel time to the nearest EmONC facility using either the walking & motorized travel scenario or the motorcycle-taxi travel scenario, for both time periods (2013 and 2018).

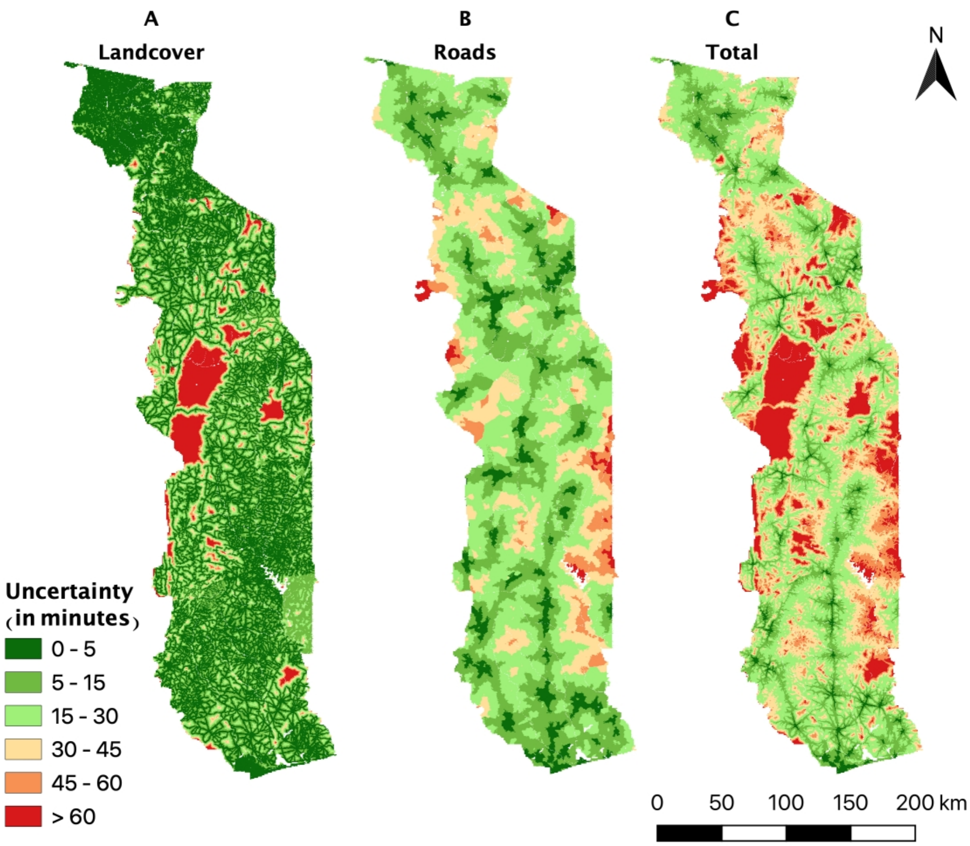


Figure 3 - Uncertainty maps of the travel times to the nearest facility for the walking & motorized scenario on the 2018 EmONC facility network using (A) Road uncertainty, (B) Landcover uncertainty, and (C) Total uncertainty.

SUPLEMENTARY MATERIAL

Supplement 1: travel scenario tables

Walking & Motorized scenario

class	label	Speed (km/h)	mode
11	Forets denses	1.5	WALKING
12	Forets riveraines	1.5	WALKING
13	Forets claires, savanes boisées	1.5	WALKING
14	Savane arborée, arbustive	1.5	WALKING
16	Plantations	3	WALKING
17	Fourrées	3	WALKING
21	Cultures et Jachères	3	WALKING
22	Cultures sans arbres	3	WALKING
32	Savanes herbeuses	3	WALKING
41	Agglomérations et infra, plantations urbaines	3	WALKING
61	Sols nus, roches, carrières, plage	3	WALKING
1000	Pistes rurales	15	MOTORIZED
1002	Routes bitumées rurales	80	MOTORIZED
1003	Routes secondaires rurales	40	MOTORIZED
1004	Pistes urbaines	10	MOTORIZED
1005	Routes bitumées urbaines	30	MOTORIZED
1006	Routes secondaires urbaines	20	MOTORIZED

Motorcycle-taxi scenario

class	label	Speed (km/h)	mode
11	Forets denses	8	MOTORIZED
12	Forets riveraines	8	MOTORIZED
13	Forets claires, savanes boisées	8	MOTORIZED
14	Savane arborée, arbustive	8	MOTORIZED
16	Plantations	10	MOTORIZED
17	Fourrées	8	MOTORIZED
21	Cultures et Jachères	10	MOTORIZED

22	Cultures sans arbres	10	MOTORIZED
32	Savanes herbeuses	12	MOTORIZED
41	Agglomérations et infra, plantations urbaines	7	MOTORIZED
61	Sols nus, roches, carrières, plage	7	MOTORIZED
1000	Pistes	15	MOTORIZED
1002	Routes bitumées	40	MOTORIZED
1003	Routes secondaires	20	MOTORIZED
1004	Pistes urbaines	10	MOTORIZED
1005	Routes bitumées urbaines	30	MOTORIZED
1006	Routes secondaires urbaines	15	MOTORIZED

Walking scenario

class	**label**	**Speed (km/h)**	**mode**
11	Forets denses	1.5	WALKING
12	Forets riveraines	1.5	WALKING
13	Forets claires, savanes boisées	1.5	WALKING
14	Savane arborée, arbustive	1.5	WALKING
16	Plantations	3	WALKING
17	Fourrées	3	WALKING
21	Cultures et Jachères	3	WALKING
22	Cultures sans arbres	3	WALKING
32	Savanes herbeuses	3	WALKING
41	Agglomérations et infra, plantations urbaines	3	WALKING
61	Sols nus, roches, carrières, plage	3	WALKING
1000	Pistes	4	WALKING
1002	Routes bitumées	4	WALKING
1003	Routes secondaires	4	WALKING
1004	Pistes urbaines	4	WALKING
1005	Routes bitumées urbaines	4	WALKING
1006	Routes secondaires urbaines	4	WALKING

Supplement 2: Preparation of input geospatial data

All following geospatial data sets were prepared using QGIS ver. 3.2.0. After finalization, each of them was changed to raster format (if needed), resampled to 100m resolution, and projected in the WGS84 Universal Transverse Mercator (zone 31N) coordinate reference sytem.

Road network

We used the road network created by the *Direction de la Cartographie national et du cadastre* of Togo. In 2015, GIS experts from the national Togolese Institute for Statistics, Economic and Demographic studies (INSEED), in collaboration with technicians from the National Ministry of Public Works and Transportation, re-categorized this road data set into three hierarchical categories: asphalted roads, secondary roads, and tracks (see figure 1B).

Barriers to movement

Water bodies were considered as barriers to terrestrial movements, unless a road segment crosses over, which is assumed to be a bridge. Rivers were recoded into two categories by the INSEED GIS experts, distinguishing permanent and seasonal rivers. We used both categories as barriers to movement in our accessibility models, reflecting our conservative approach of considering a maximum of potential barriers.

Land cover

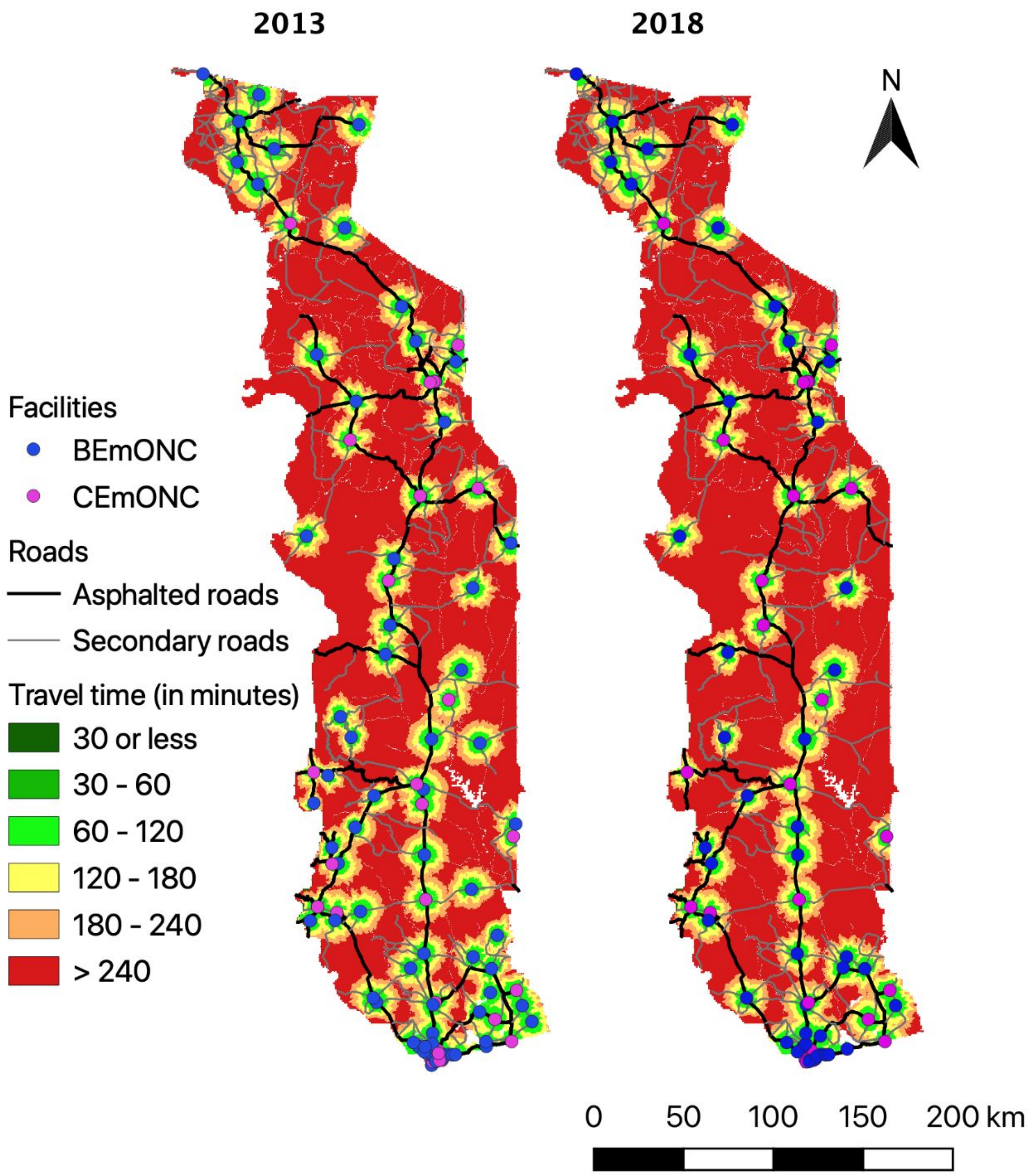
The land cover data set was provided by INSEED. We assumed that different land cover categories can influence travel speed (e.g., travel is slower in a dense forest than in an open area), each of these land cover categories can be given a distinct travel speed in the travel scenario. The landcover category representing bodies of water was extracted from the landcover and used as an additional barrier to movement. Using the "Merge land cover" tool in AccessMod, the land cover raster was merged with the road network and the various barriers to movement, in order to obtain the final "merged land cover" on which travel models are applied. For the merging process, roads were stacked above the barriers, so that any existing road passing over a barrier was considered passable.

Population density

Population densities were derived from the Worldpop data set[1]. This data set is at 3-arc second resolution (90m at the equator) and is appropriate for our analyses as the modelling technique to obtain it uses a detailed settlement mapping and links these settlements with gazetteer population numbers, considering that the vast majority of people live within a settlement. The remaining unaccounted-for population is then distributed using a weighted landcover grid in function of the probability of being populated, and the total population estimates are adjusted to UN estimates[2]. We used the UN-adjusted 2013 and 2018 Worldpop data sets for Togo.

A final correction step consisted in correcting for the population falling in pixels that were assigned a barrier status in the merged landcover data set, because this population is not considered by the accessibility analysis and is left unaccounted for. To correct for that, we extracted the population in each barrier pixel and dispatched it uniformly within the surface of the prefecture area the pixel belongs to. This way the population in each prefecture was correctly represented, even if a large number of barrier pixels are found. This step was done in AccessMod using the « Adjust population distribution” module.

Supplement 3: Travel time maps for the walking-only model



Supplement 4: Table of percentage of population living within 2-hour travel time to the nearest EmONC facility, per prefecture, with uncertainty intervals within brackets, and for the walking & motorized and the motorcycle-taxi scenarios

	Walking & Motorized scenario		**Motorcycle-taxi scenario**	
Prefectures	*1-hour*	*2-hour*	*1-hour*	*2-hour*
Agoenyive	100 [99.6 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]
Agou	73.4 [59.9 - 83.5]	99.7 [96.3 - 99.9]	69.3 [57.8 - 78.7]	99.9 [94.4 - 100]
Akebou	46.7 [31.7 - 61.5]	93.4 [84.3 - 96.3]	42.9 [23.7 - 55.9]	92.3 [75.3 - 100]
Amou	67.3 [55.3 - 76.3]	92.2 [86.5 - 95.4]	74.4 [64.9 - 83.5]	99.3 [94.4 - 100]
Anie	41.5 [35.5 - 48]	74 [61.2 - 88.3]	41.6 [37.2 - 44.7]	61.6 [52.3 - 71.3]
Assoli	56.5 [41.2 - 67.3]	90.5 [82.2 - 94.7]	77.7 [65.1 - 85.3]	99.6 [95.5 - 100]
Ave	76.3 [66.8 - 82.5]	94.8 [89.9 - 97.3]	85.2 [75.6 - 93.3]	100 [99.9 - 100]
Bas-Mono	88.3 [82.2 - 92]	98.6 [96.4 - 99.4]	98.9 [94.9 - 99.6]	99.6 [99.6 - 99.6]
Bassar	57.5 [46.9 - 67.1]	87.2 [80.4 - 90.8]	64.5 [54.2 - 71.7]	92.8 [84.4 - 97]
Binah	85.9 [77.3 - 91.6]	97.9 [96.6 - 98.6]	85.4 [77.7 - 90.5]	100 [97.3 - 100]
Blitta	81.4 [72.7 - 87.5]	97.1 [94.4 - 98.2]	84.3 [78.8 - 89.8]	98.3 [95 - 99.9]
Cinkasse	99.3 [93.5 - 99.6]	99.9 [99.9 - 99.9]	94.5 [67.9 - 100]	100 [100 - 100]
Dankpen	48.3 [37.2 - 57.4]	83.3 [71.7 - 90.5]	42.2 [32.7 - 52]	83.3 [69.1 - 93.4]
Danyi	76.8 [64.9 - 85.9]	98.1 [94.8 - 99.2]	92.5 [81.1 - 97.2]	100 [100 - 100]
Doufelgou	53.3 [44.3 - 61.8]	88 [77.7 - 93]	62.4 [51.1 - 71.3]	95.6 [84.4 - 99.8]
Est-Mono	37.3 [26.9 - 45.4]	75 [62.8 - 86.6]	38.9 [28 - 46.8]	78.5 [61.6 - 94.1]
Golfe	100 [99.5 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]
Haho	50 [38 - 61.4]	89.7 [78.8 - 94.9]	49.7 [41 - 58.4]	85.1 [74 - 94]
Keran	42 [29.5 - 54.9]	87.8 [74.9 - 93.3]	34.4 [26.3 - 42.7]	86 [64.7 - 97.7]
Kloto	85.5 [76.7 - 91.9]	99.4 [98 - 99.7]	97.2 [90.5 - 99.8]	100 [100 - 100]
Kozah	85.2 [76.6 - 90.3]	97.1 [95.1 - 98.1]	92.9 [87.6 - 95.9]	100 [99.8 - 100]
Kpele	71.8 [62.3 - 80.1]	98.2 [91.3 - 99.7]	78.4 [71.8 - 84.3]	99.6 [94.2 - 100]
Kpendjal	64.2 [47.9 - 76.5]	98.7 [92.9 - 99.8]	59.7 [38.6 - 74.8]	99.5 [92.8 - 100]
Lacs	94.9 [91.1 - 97.1]	99.7 [99 - 100]	95.4 [91.5 - 97.8]	100 [99.9 - 100]
Lomé Commune	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]
Moyen-Mono	39.6 [25.9 - 50.9]	94 [79.8 - 98.2]	42.6 [34.4 - 50.6]	90.7 [66.3 - 99.3]
Naki-Ouest	77.5 [60.5 - 89.8]	99.7 [98.5 - 100]	64.3 [49.3 - 77.9]	100 [97.8 - 100]
Ogou	54.9 [44.2 - 66.3]	95.9 [85.7 - 99.2]	54.9 [46.7 - 62.9]	93.2 [79.1 - 99.9]
Oti	79.3 [68.4 - 86.2]	97.7 [93.5 - 98.8]	78.4 [67.6 - 86.4]	98 [96.1 - 99.4]
Oti-Sud	47.8 [33.5 - 58.5]	95.3 [83.1 - 98.6]	36.7 [23.6 - 49.8]	87.4 [69.7 - 99.4]
Plaine de Mo	33.8 [21.1 - 45.9]	72.8 [62.8 - 78.8]	37.3 [24 - 52.7]	87.3 [75.7 - 94.1]
Sotouboua	42.4 [31.5 - 52.7]	75.2 [67.8 - 77.9]	49.9 [40.1 - 57.8]	82.2 [70.4 - 89.6]
Tandjoare	85.6 [76.7 - 91.2]	99.8 [98.3 - 100]	76.2 [65.5 - 84.7]	98.6 [92.9 - 100]
Tchamba	54.9 [37.3 - 67.9]	90.2 [83.7 - 93.4]	45.9 [33.4 - 60.9]	96.5 [88.8 - 99.2]
Tchaoudjo	65 [53.3 - 74.8]	93.4 [88 - 95.7]	71.8 [57.6 - 80.1]	98.5 [92.4 - 99.5]
Tone	91.8 [80.5 - 97.4]	100 [99.9 - 100]	82.4 [71.9 - 89.2]	99.9 [98.5 - 100]
Vo	85.6 [70.3 - 93.2]	99.4 [98.3 - 99.8]	95.5 [83.9 - 99.5]	100 [100 - 100]

Wawa	51.6 [36 - 65]	93 [83.2 - 96.8]	67.7 [45.3 - 82.3]	100 [97.5 - 100]
Yoto	82.2 [71.7 - 88.2]	95.9 [93.3 - 97.5]	87 [78.9 - 92]	98.9 [97.2 - 99.6]
Zio	87.9 [77.4 - 93.9]	99.7 [98.5 - 99.9]	93.1 [85.3 - 96.4]	100 [99.5 - 100]
Country	**78.3 [70.5 - 84]**	**95.5 [91.6 - 97.5]**	**79.2 [72.2 - 84.3]**	**96 [91.6 - 98.4]**

Supplement 5: Effects of considering slopes to correct for walking speeds

When walking is used in a travel scenario, AccessMod computes the slope between adjacent raster cells using the Digital Elevation Model. Walking speeds are then corrected using the slope value, following the Tobler (1993) formula[3]:

$$V = V_F * \ e^{-3.5 * |S + 0.05|},$$

where V is the corrected walking speed in kilometers per hour (Km/h), V_F is the walking speed on a flat surface (given by the user-defined travel scenario), and S is the slope in hundredth of percent.

These corrections applied when walking off-road in the "Walking & Motorized scenario", and everywhere in the "Walking scenario". In the table below, the first figure is with considering the slope correction, the second figure is without considering the slope correction.

	Walking & Motorized Scenario				**Walking Scenario**			
	2013		**2018**		**2013**		**2018**	
Regions	***1-hour***	***2-hour***	***1-hour***	***2-hour***	***1-hour***	***2-hour***	***1-hour***	***2-hour***
Plateaux	66.2/67.7	95.1/95.6	55.4/56.6	89.8/90.3	15.5/16.2	30.2/31.4	10.9/11.4	22.6/23.5
Kara	63.3/64.3	90.4/90.9	62.7/63.6	90.2/90.7	14.5/15	29.7/30.2	14.5/14.9	29.3/29.8
Maritime	94.7/94.8	99.5/99.5	94.4/94.5	99.4/99.4	47.9/48.2	74.8/75.1	47.7/48	76.4/76.5
Centrale	70.2/70.6	92.3/92.6	65.2/65.6	91.7/91.9	22/22.3	41.3/41.5	18.1/18.5	35.7/35.9
Savanes	81.7/81.9	98.9/99	80.7/80.9	98.9/99	12.1/12.4	26.5/27.2	11.4/11.6	24.2/24.9
Lomé Commune	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
Country	81/81.5	96.7/98	78.3/78.8	95.5/95.7	34.7/35.1	52.3/52.8	33.4/33.7	50.8/51.2

Supplementary References

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National optimization of accessibility to emergency obstetric and neonatal care in Togo: a geospatial analysis

Andrew Curtis[1,2], Jean-Pierre Monet[3], Michel Brun[3], Issa Abdou-Kérim Bindaoudou[4], Idrissou Daoudou[5], Marta Schaaf[6], Yawo Agbigbi[7], Nicolas Ray[1,2,*]

[1] GeoHealth Group, Institute of Global Health, Faculty of Medicine, University of Geneva, Geneva, Switzerland
[2] Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland
[3] Technical Division, United Nations Population Fund (UNFPA), New York City, USA
[4] National Institute of Statistics and Economic and Demographic Studies (INSEED), Lomé, Togo
[5] Ministry of Health, Lomé, Togo
[6] Independent Consultant, New York City, USA
[7] United Nations Population Fund (UNFPA), Lomé, Togo

Corresponding author: Prof. Nicolas Ray, nicolas.ray@unige.ch, GeoHealth group, Institute of Global Health, Faculty of Medicine, Campus Biotech, Chemin des Mines 9, 1202 Geneva, Switzerland

Abstract

Objectives: Improving access to emergency obstetrical and neonatal care (EmONC) is a key strategy for reducing maternal and neonatal mortality. Access is shaped by several factors, including service availability and geographic accessibility. In 2013, the Ministry of Health (MoH) of Togo used service availability and other criteria to designate particular facilities as EmONC facilities, facilitating efficient allocation of limited resources. In 2018, the MoH further revised and rationalized this health facility network by applying an innovative methodology using health facility characteristics and geographical accessibility modelling to optimize timely access to EmONC services. This study compares the geographic accessibility of the network established in 2013 and the smaller network developed in 2018.

Design: We used data regarding travel modes and speeds, geographic barriers, and topographic and urban constraints, to estimate travel times to the nearest EmONC facilities. We compared the EmONC network of 109 facilities established in 2013 with the one composed of 73 facilities established in 2018, using three travel scenarios (walking and motorized, motorcycle-taxi, and walking-only).

Results: When walking and motorized travel is considered, the 2013 EmONC network covers 81.0% and 96.6% of the population at the 1-hour and 2-hour limit, respectively. These figures are slightly higher when motorcycle-taxis are considered (82.8% and 98.0%), and decrease to 34.7% and 52.3% for the walking-only scenario. The 2018 prioritized EmONC network covers 78.3% (1-hour) and 95.5% (2-hour) of the population for the walking and motorized scenario.

Conclusions: By factoring in geographical accessibility modeling to our iterative EmONC prioritization process, the MoH was able to decrease the designated number of EmONC facilities in Togo by about 30%, while still ensuring that a high proportion of the population has timely access to these services. However, the physical access to EmONC for women unable to afford motorized transport remains inequitable.

Keywords: maternal health, universal health coverage, geospatial modelling, physical accessibility, health system strengthening

Strengths and limitations of this study

- This is the first study presenting an improvement of a network of EmONC facilities, based on the characteristics of these facilities and on realistic physical accessibility modelling.
- Country-based experts estimated the modes and speeds of transport on the various road types and off-road landcover categories, and associated uncertainty analyses assessing relative effect of travel speeds were performed.
- The EmONC prioritization approach succeeded in prioritizing 73 out of the initial 109 EmONC facilities, with only a marginal drop of population coverage. This will enable efficient use of limited resources.
- Only the physical accessibility to nearest designated EmONC services was modelled, but potential financial barriers and the fact that some patients could opt to bypass the nearest facility may also affect access to EmONC.
- Travel was modelled only for the dry season conditions, but degraded road conditions in certain parts of the country during the wet season may affect our estimates of EmONC accessibility.

INTRODUCTION

The Sustainable Development Goal 3 (SDG3) aims to better health outcomes for different at-risk groups, including pregnant women (SDG3.1) and children under 5 years of age (SDG3.2). One of the primary strategies for reducing maternal and neonatal mortality and morbidity is ensuring timely access to quality emergency obstetric and neonatal care (EmONC)[1]. However, access to EmONC is still a challenge in many low-income countries, especially in sub-Saharan Africa[2].

Because the physical distance to facilities has long been recognized as an important component of timely access to care[3, 4], an adequate geographic distribution of EmONC facilities is a prerequisite to minimize travel times for women in need of EmONC. The World Health Organization (WHO) recommends a benchmark of no more than 2 hours of travel time to reach the nearest EmONC facility[5], as after 2 hours, an obstetric hemorrhage can be fatal.

Realistically modelling and measuring spatial accessibility to health services is therefore very important for adequate planning and improvement of access to quality healthcare for pregnant women and newborns[6]. Some studies have used simple distances[7] and time[8] metrics, as well as population-to-provider ratios (PPRs)[9]. These metrics have been popular for their ease of use and minimal need for the input of spatial data layers, i.e. data that both provide locations and describe characteristics of geographic features[10].

However, these methods are not appropriate for modelling geographic accessibility in complex terrains where different modes of transport are potentially used for a single trip, and when patients seeking care are facing an emergency, where every minute of travel time is consequential. In such cases, approaches based on least-cost path modelling (i.e., finding the fastest route between locations based on various travel constraints) have proved useful to estimate time and routing to reach the nearest care providers, and to model catchment areas of facilities[10]. Applying this modelling approach, the AccessMod tool[11] helps estimate geographic accessibility by taking into consideration the modes of transport, their respective speeds of travel on roads and off-road on various landcover types, and the influence of the topography and other barriers to movement. Studies assessing the accessibility of a variety of health care destinations have used AccessMod in their analyses[12-19]. Specific to accessibility to EmONC, Ebener and colleagues[20] have recently formalized and proposed new indicators based on least-cost path modelling.

The main objective of this study was to realistically determine and compare the overall geographic accessibility of our target population (women with obstetrical complications in need of EmONC) to two EmONC facility networks: the first one designated by the Ministry of Health

(MoH) in 2013 and the second one in 2018 through a methodology using accessibility modelling. The comparison of the two networks in terms of physical accessibility and population coverage is very useful in Togo, a country where (i) the probability of being attended at birth by qualified personnel is strongly linked to socio-economic status and where (ii) three-quarters of maternal deaths are due to direct obstetrical complications, which could for the most part be avoided if those experiencing complications have access to quality EmONC in less than two hours. We defined and applied various travel scenarios based on inputs from national and sub-national stakeholders, including speed and transport modes and their associated uncertainties. Besides expanding knowledge on the underlying mechanisms of geographical access to EmONC facilities in Togo, we described a robust spatially-explicit methodology for quantifying the population covered by networks of EmONC health facilities that can be replicated in other countries.

DATA AND METHODS

Study site and context

Togo is one of the smallest African countries in terms of landmass (approximately 56,785 km^2), with a population of approximately 7.9 million in 2018[21], and it is bordered by Benin to the east, Ghana to the west and Burkina Faso to the north. More than 40% of the total population live in the southern part of the country (in the region of Maritime and in the capital city of Lomé), with 42% of this population living in urban areas[22]. The 2017 Multiple Indicator Cluster Survey (MICS 6) for Togo[23] determined that there is a strong correlation between poverty and maternal mortality and morbidity. Indeed, the probability of giving birth assisted by qualified personnel is found to be highly correlated to socio-economic status and to place of residence. The aforementioned survey determined that 98% of women in the richest quintile are assisted at birth by skilled health personal, compared to only 52% of the poorest quintile. It also highlighted the fact that 98% of women living in urban settings receive skilled birth attendance, as compared to 65% of women living in rural settings. Three quarters of maternal deaths were found to be due to direct obstetrical causes. This suggests that access to timely EmONC is essential for reducing maternal mortality in Togo.

The 2017-2022 national plan for health sector development in Togo[24] highlights that morbidity and mortality rates for mothers and newborns are still very high, and notes that this is due to insufficient supply of obstetric and neonatal care and by barriers to service access, including financial barriers. Despite some progress over the last decades, maternal and newborn mortality are still high in Togo respectively, with 396 (80% CI: 270-557) maternal deaths per 100,000 live births in 2017[24] and 25 neonatal deaths per 1,000 live births in 2018[2]. Improving access to quality EmONC services has been a priority for the government since the EmONC needs assessment of 2012. In 2013, the MoH used facility data to identify 109 priority health facilities designated to provide EmONC services, and launched a process to monitor them on a quarterly basis to assess and address gaps in availability and quality of care. This national network encompassed both government and NGO facilities, and its selection was done considering several pieces of information on each facility: obstetric activity (i.e., favoring those with more than 30 deliveries/month), qualified human resources, capacity to organize referrals, gaps in EmONC signal functions and adequate geographic distribution. EmONC facility functionality requires enough qualified providers for 24h/7d services and the availability of key equipment, consumables, and medication for performing the key medical interventions (or signal functions) that are used to treat the direct obstetric complications that cause the vast majority of maternal deaths.

While the focus on a prioritized set of health facilities led to some progress in the availability of services, for example the increase of the proportion of EmONC facilities applying vacuum extractions from 24% in 2014 to 43% in 2016, the MoH decided in 2018 to further focus their efforts and resource allocation by further decreasing the number of priority facilities; the MoH ultimately selected 73 health facilities that should provide EmONC services in the country. This selection was guided by a methodology developed by UNFPA and formalized and described in UNFPA's EmONC Network Development Implementation Manual[25]. In brief, this methodology, based on WHO, UNFPA, and UNICEF recommendations[5], helps countries to identify a network of EmONC facilities by selecting a number of EmONC facilities that do not exceed the international norm of 5 EmONC facilities per 500,000 population, and, by prioritizing facilities that can most feasibly be supported to actually provide all the relevant EmONC signal functions 24h/7d (see Box 1) with quality care, during the next programmatic cycle of the MoH (i.e. in the next 3-4 years). The selection of health facilities is done by considering both health facility characteristics (e.g. number of deliveries, human resources, gaps in EmONC signal functions, infrastructure) and two spatially-explicit indicators[20]: the population living within 1 and/or 2-hour maximum travel time from the nearest EmONC facility (i.e. population coverage), and the quality of each referral linkage between Basic EmONC (BEmONC) health facilities and their closest Comprehensive EmONC (CEmONC) health facility. BEmONC health facilities should provide seven EmONC signal functions 24h/7d while CEmONC health facilities provide nine EmONC signal functions (see Box 1). An EmONC facility is considered as functioning when it provides services 24h/7d, and when it has performed all seven (BEmONC) or all nine (CEmONC) signal functions in the three months prior to data collection[5]. A non-functioning EmONC facility has failed to provide one or more EmONC signal function during that same period.

Box 1: Emergency obstetrical and neonatal care (EmONC) signal functions

Services available 24h/24 and 7d/7	
Basic EmONC (BEmONC) signal functions	**Comprehensive EmONC (CEmONC) signal functions**
1) Administer parenteral antibiotics 2) Administer uterotonic drugs 3) Administer parenteral anticonvulsants 4) Perform manual removal of the placenta, 5) Remove retained products 6) Perform assisted vaginal delivery 7) Perform basic neonatal resuscitation.	BEmONC signal functions (1-7) + 8) Perform blood transfusion 9) Perform Caesarean section.

Accessibility & population coverage modelling

We used AccessMod, a WHO stand-alone and open-source geospatial tool[11, 26], to analyze the physical accessibility to, and the population coverage of, the national networks of EmONC health facilities in Togo in 2013 and 2018. AccessMod is based on a least-cost path algorithm that computes the fastest route between any location and the nearest health service (for details, see [11]). It can consider several sequential modes of travel (e.g. walking to a road, where one catches a motorized vehicle), several types of barriers to movement, health facility capacity, and population, when determining catchment areas. Moreover, AccessMod considers the direction of movement by applying an anisotropic analysis, i.e. considering the slope of the terrain to accurately model bicycling and walking speeds. Contrary to many accessibility modelling approaches that are based on a perfectly routable road data set (such as Nichols et al[27]), AccessMod can consider off-road travel in addition to road travel. On- and off-road travel speeds and modes of transport are user-defined in a travel scenario that assigns these travel constraints to each land cover and/or road category found in the input data.

For the movements of our target population, we defined three distinct travel scenarios from home to the nearest EmONC facility: 1) a walking & motorized scenario, 2) a motorcycle-taxi scenario, and 3) a walking-only scenario. The first scenario assumes that patients walk to the nearest road and then use a motorized mode of transportation (car, minibus or other motorized vehicle, either private or public), immediately available, to continue their journey. In the second scenario, patients use only a motorcycle-taxi to travel on- and off-road, with different speeds depending on the land cover. Finally, the third scenario assumes patients are walking or being carried (e.g. on stretchers, carts) at walking speed (or lower).

The choice for these three scenarios and their associated modes and speeds of travel were decided through an iterative process of two workshops in Togo in 2016-2018. A first 3-day workshop took place in May 2016 to strengthen national capacity to analyze the geographic accessibility of health facilities in Togo by using AccessMod. The thirty Togolese participants were technical experts from the MoH, the national Togolese Institute for Statistics, Economic and Demographic studies (INSEED), NGOs and UN agencies, and other key stakeholders (e.g., regional health director, monitoring expert) from all regions of Togo. The pool of experts discussed and agreed on the specifics of how women with obstetrical emergency typically travel when they need to reach an EmONC facility in Togo. Average speeds of travel on all road categories were estimated by consensus, with the walking & motorized scenario deemed to be the most frequent. During a second workshop in May 2018, health stakeholders from each of the 6 regions of Togo gathered to define which health facilities should comprise their EmONC facility regional network, using the prioritization methodology described above to select a number of EmONC facilities per region not exceeding the international norm of 5 EmONC facilities per 500,000 population. These participants further refined the travel scenarios, and agreed that bicycles and public transport were rarely used, with the exception of a public bus system operating in greater Lomé [28]. In both workshops, participants recognized that during the wet season the speeds of travel generally decrease in many areas. However, they decided to use only a dry season scenario to guide planning as this is the longest season in Togo (around 8 months). The final travel speeds chosen for the three scenarios are found in Supplement 1.

Road speeds in urban areas were adjusted in order to simulate slower motorized travel occurring in intra-urban contexts due to various factors such as stoplights, traffic, pedestrians, and other hazards. For the walking & motorized scenario, we lowered travel speeds on asphalted roads, secondary roads and tracks to 40km/h, 30km/h and 10 km/h, respectively. For the motorcycle-taxi scenario, these average travel speeds were lowered to 30 km/h, 15 km/h and

10 km/h. These speed corrections were applied on all road segments falling within the extent of the urban areas informed by the Global Rural Urban Mapping Project[29].

Uncertainty analysis

To account for uncertainty in travel speeds, we additionally ran each consensus travel scenario with 20% slower or 20% faster speeds compared to the consensus scenario, following the methodology developed in Ouma et al.[17] and in Stewart et al.[30]. This translated to lower and upper uncertainty bounds on the reported output statistics. To further disentangle the effects of uncertainties on the speeds on roads and off roads, we ran scenario 1 by keeping on-road speeds constant (at consensus values) and varying off-road speeds by the plus or minus 20%. Conversely, we ran this scenario keeping off-road speeds constant and varying on-road speeds. Finally, to test the model's sensitivity to the consideration of topography, we also ran each consensus travel speed scenario without considering slope correction (i.e., isotropic mode).

Two uncertainty indicators were produced: (1) lower and upper uncertainty bounds on the variation in percentage (per region and for the whole country) of the coverage of population living less than one and less than two hours away from the closest EmONC facility, and (2) a series of spatially-explicit uncertainty maps. In these uncertainty maps, pixel values indicate the extent of the uncertainty of travel time to the nearest EmONC facility, obtained by subtracting the travel time grid resulting from the "- 20%" travel speeds scenario by the one resulting from the "+ 20%" travel speeds scenario. This highlights the areas in the country where the travel time results are the most uncertain.

Input geospatial data

Various datasets were assembled and prepared to run the geospatial analyses in AccessMod (details of the preparation steps are found in Supplement 2). We considered barriers to terrestrial movements composed of quarries and bodies of water, such as rivers, lakes and damned areas. The barriers file was created by the Togolese Ministry of Agriculture, Livestock and Hydraulics[31] (figure 1A). We used the road network created by the *Direction de la Cartographie nationale et du cadastre* of Togo, classified in three hierarchical categories: asphalted roads, secondary roads, and tracks[32] (figure 1B). We obtained the Digital Elevation Model (DEM) of Togo from NASA' Shuttle Radar Topography Mission[33] (figure 1C). Slopes were derived from the DEM directly in AccessMod.

We used the population density data set from the Worldpop project[34], provided with UN-adjusted population count from 2013 (figure 1D) and 2018 (figure 1E). We assumed that the target population of women with obstetrical complications is uniformly distributed across the overall population. Land cover information was provided by INSEED, with a land cover data set composed of twelve categories (figure 1F). We obtained the names and geographic coordinates of the 109 EmONC facilities composing the initial national network of EmONC health facilities in 2013 from INSEED (figure 1G). We further verified these names and coordinates with the help of the MoH. For the EmONC health facilities network of 2018 (figure 1H), the 73 final designated set of facilities was obtained through the MoH[35]. Finally, the most recent administrative boundaries at the prefectural, regional and national levels were created and made available by INSEED using data collected during the 2010 general census[36] (see figure 1I). These datasets were used to determine the percentage of population coverage for each administrative unit.

Patients and the public involvement

There was no patient or public involvement in this study. Health facility names and geographic coordinates, as well as administrative boundaries, were shared by INSEED. The road network was shared by the *Direction de la Cartographie nationale et du cadastre* of Togo. The barriers to movement datasets were provided by the *Ministère de l'agriculture, de la production animale et halieutique.* All other geospatial data were publicly available.

RESULTS

The accessibility maps for the walking & motorized scenario, and the motorcycle-taxi scenario, and for the two time periods, are shown in figure 2, with the respective maps for the walking-only scenario in Supplement 3. In 2013, estimated physical access was highest under scenario 2 (motorcycle-taxi scenario), with 82.8% of the total population less than one hour away from the nearest EmONC health facility, and 98% less than two hours away from the nearest EmONC health facility. For the walking & motorized scenario, these estimations are 81% at the 1-hour travel time limit and 96.7% at the 2-hour limit respectively.

Using the 2018 network of 73 facilities, population coverages using the motorcycle-taxi scenario are 79.2% at the 1-hour travel time limit and of 96% at the 2-hour limit. Compared to the 2013 network, these population coverages are lower by 3.6% (of the total population) at the

1-hour threshold and by 2% at the 2-hour limit. With the walking & motorized scenario, the corresponding results are 78.3% at the 1-hour limit and 95.5% at the 2-hour limit. Compared to the initial estimations for the 2013 network, population coverage for that scenario has only dropped by 2.7% and 1.2% respectively. Despite a reduction of the number of EmONC health facilities by one-third from 2013 to 2018, the population able to physically access the closest EmONC health facility within one or two hours is only marginally lower with the 2018 prioritized network.

For both time periods, population coverage at national scale is only marginally higher for the motorcycle-taxi travel scenario when comparing to the walking & motorized scenario, even though this translates to a much larger extent of the country's surface under the 2-hour maximum travel time limit (green areas in figure 2). We also see that accessibility is highly dependent on roads in scenario 1. This is the case for instance in parts of the Atacora mountains (large red areas in the central-western part of the country in figure 2), a region with a very low population density and almost no roads (according to our data). With scenario 2, travel is less dependent on roads than in scenario 1, but access tends nevertheless to be higher around the road network, even though travel speeds on roads are lower for the motorcycle-taxi scenario than for the walking & motorized scenario. The results for the 2018 network at regional level are given in Table 1, and at prefectural level in Supplement 2.

Table 1: Percentage of population living less than one- or two-hour travel time to the nearest EmONC facility, in 2018, per region and for the country, with uncertainty intervals within brackets.

	Walking & motorized scenario		**Motorcycle-taxi scenario**		**Walking-only scenario**	
Region	*1-hour*	*2-hour*	*1-hour*	*2-hour*	*1-hour*	*2-hour*
Plateaux	55.4 [44.4 - 65.1]	89.8 [80.7 - 95.2]	58.7 [49.2 - 66.3]	88.4 [78.5 - 94.6]	10.9 [8.3 -13.3]	22.6 [18.1 -27.2]
Kara	62.7 [52.3 - 71.0]	90.2 [82.8 - 94.1]	65.2 [56.7 - 72.0]	92.8 [84 - 97.7]	14.5 [11.0 -17.8]	29.3 [23.9 -34.7]
Maritime	94.4 [90.1 - 96.7]	99.4 [98.6 - 99.7]	96.9 [93.7 - 98.5]	99.9 [99.7 - 100]	47.7 [36.7 -57.0]	76.4 [70.2 -80.9]
Centrale	65.2 [53.0 - 74.7]	91.7 [86.6 - 93.9]	66.5 [56.1 - 75.7]	96.2 [90.0 - 98.5]	18.1 [12.6 -23.4]	35.7 [31.3 -38.7]
Savanes	80.7 [68.9 - 87.9]	98.9 [96.0 - 99.6]	72.5 [58.9 - 81.8]	97.9 [93.3 - 99.9]	11.4 [8.4 -14.2]	24.2 [19.1 -30.0]
Lomé Commune	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [93.9 -100]	100 [100 -100]
Country	**78.3 [70.5 - 84.0]**	**95.5 [91.6 - 97.5]**	**79.2 [72.2 - 84.3]**	**96.0 [91.6 - 98.4]**	**33.4 [27.1 - 38.4]**	**50.8 [46.0 - 55.0]**

The region of Lomé Commune has 100% population coverage for both time thresholds and both motorized scenarios, which is due to the combined effect of a very densely populated region of only 90 km^2 with 11 EmONC facilities in 2018, and a good road network that permits the Lomé population to access the closest EmONC in less than 1 hour travel time. In contrast, the rural region of Plateaux presents much more heterogeneous results, with large uncertainty intervals. The results at prefectural level are available in Supplement 3.

We illustrate in figure 3 the uncertainty in travel time for the walking & motorized scenario on the 2018 facility dataset, separated for the effects of speed uncertainty on roads and landcover. The maps show a spatially heterogeneous distribution of the uncertainties, especially in the case of the road speed uncertainty map with widespread uncertainties in all areas of the country, but with relatively low uncertainties along the asphalted road network. Similar maps for the uncertainty linked to the DEM are found in Supplement 4.

The landcover and road uncertainty maps show that uncertainty is strongest in areas with very little population density (see figure 1E). The total uncertainty map, combining uncertainty from roads and landcover, further highlights the fact that uncertainty is quite low on roads close to facilities and increases in more rural areas.

As expected for the walking-only scenario, national population coverage of the 2018 network drops strongly to 33.4% within 1-hour walking, and 50.8% within 2-hour walking. Large differences in coverage are found between regions, with the southern more urban regions of Lomé and Maritime achieving higher accessibility results than the more rural areas of the country. Indeed, while the two aforementioned regions reach coverage percentages of 100% and 76.4% respectively at the two-hour threshold, the coverage percentages do not exceed 40% in all the other regions modelled.

DISCUSSION

The accessibility maps that were produced according to our three travel models illustrate the differences in accessibility in different parts of the country. This can help identify areas in the country where geographic accessibility to EmONC facilities is most difficult. These areas could be targeted for remedial efforts, such as mobile outreach, posting community health workers for reducing decision time to seek care, the creation of maternity waiting homes in the EmONC health facilities of the region, or planning improvement of the road infrastructure.

The three alternative models used to obtain these maps reflect different socio-economic segments of the population. If patients can afford to take a motorized vehicle after having reached the closest road or use a motorcycle-taxi from their home, then more than 78% of the population can reach the closest EmONC facility (as per the 2018 designation) in less than 1 hour. When considering 2-hour maximum travel time, this percentage is much higher, with 95% of the population able to reach the nearest facility within the time limit. We also note that the motorcycle-taxi scenario covers much larger areas of the country (green areas in Figure 2) in comparison to the walking & motorized scenario. Nevertheless, this does not result in a substantial increase in population coverage. This is explained by the fact that many areas where access is very low in scenario 1 are fairly unpopulated.

For women who have no access to motorized means of transport, accessibility to EmONC within one hour drastically decreases to about 33% of the population, and to 51% within the 2-hour threshold travel time limit. Thus, nearly half of the target population does not have access to EmONC in the maximum acceptable travel time if they cannot afford to travel by motorized means of transport. As anticipated, access to EmONC is greater for urban populations, even with substantially decreased travel speeds, due to a higher density of both EmONC facilities and road networks in urban areas.

Though the 2018 prioritized EmONC network included 36 fewer facilities than the 2013 network, the 2018 network still achieves high overall geographic accessibility, with all regions obtaining estimated coverage percentage of 90% and more. It only drops marginally in terms of population coverage (between 1 and 3.6 percentage points depending on the scenario) when compared to the initial network of 109 designated EmONC facilities in 2013. However, from a planning perspective, prioritizing 73, rather than 109 facilities for EmONC functionality is a more feasible, achievable goal over the short term, i.e. the next MoH programmatic cycle (i.e. 3-4 years). The number of prioritized EmONC facilities is lower than the international norm that targets around 80 functional EmONC facilities for the 2018 population of Togo. However, the decision of the MoH to target this prioritized network was commensurate with available resources and the modelling results showing that this network can nevertheless ensure timely access to a large proportion of the population in case of obstetrical complications.

Our uncertainty analysis has shown that population coverage estimates are also most sensitive to uncertainties on the speeds on roads, as compared to the speeds off roads. This highlights the need for great caution when choosing travel speeds. A good representativeness of local experts, both in terms of knowledge about the specific travel behaviors of the target population and in terms of possible regional specificities for travel is vitally important. Other sources of information on effective travel speeds (e.g. using speed tracker onboard vehicles or mobile phones) could be very useful if available in the future. Furthermore, spatially displaying the uncertainty regarding travel times highlights the regions where this uncertainty is the highest, and that could be given high priority for future improvements of model parametrization. These improvements can be achieved by ensuring that all roads are well captured, or incorporating possible region-specific alternative means of transport.

Limitations

Although our study has produced the first high-resolution model of geographic accessibility to EmONC facilities in Togo, several limitations should be noted. First, our models only consider physical accessibility of the national network of EmONC health facilities. Although the three alternative transport models were created to acknowledge that motorized travel is not financially possible for some, there are additional financial barriers – such as formal and informal expenditures for health care – that our models do not address. Acceptability (i.e. "the match between how responsive health service providers are to the social and cultural expectations of individual users and communities", see Peters et al.[37]) was also not considered. Immediate availability of motorized transport was also assumed in our models, which could over-estimate accessibility in cases where delays for finding transport are significant. Variable quality of interpersonal and clinical care in facilities can also affect which facility patients chose; they may not choose the closest facility in terms of travel time[38], possibly bypassing BEmONC health facilities in certain cases. We also assumed no delay in the decision to seek care. Clearly, further research on how to incorporate these other facets of accessibility could improve our models and our understanding of the spatial variability of effective access to EmONC.

Second, the workshop participants decided to model travel during the dry season conditions. The extent of the degradation of road conditions could not be captured in certain parts of the countries during the wet season, and this is known to heavily affect travel time. A more balanced view of regional accessibility to EmONC could be achieved by factoring in these seasonal specificities.

Third, our analyses were built on a uniform uncertainty range (± 20%) on all roads and landcover categories. This could be improved by applying parameter-specific uncertainty ranges, notably on the different road types. This could be captured by a dedicated workshop with regional experts having a thorough knowledge of the road network, providing more realistic uncertainty ranges on motorized and walking speeds, possibly complemented by field observations or facility-based surveys. Lowering uncertainties on the travel scenario, and therefore on population coverage estimates, would improve decision making for prioritized resource allocation.

Finally, we analyze the coverage to the closest designated EmONC health facilities, which includes facilities that are actually functioning (as per our definition of functioning), as well as those that are not. The quarterly monitoring of the national network of EmONC health facilities in Togo started in 2015, and was included in the health management information system (DHIS2) in 2020. This provides up-to-date information on the functionality of EmONC health facilities. The aim is to attain a network of functioning EmONC facilities, which is essential to help decrease maternal mortality/morbidity. Applying the same modeling approach described here to only functioning EmONC facilities would provide up-to-date population coverage indicators at national and subnational level that can inform decision makers regarding the remaining gaps in order to optimize resource allocation. This will be the subject of a forthcoming publication.

CONCLUSION

The physical accessibility mapping of the national network of EmONC health facilities in Togo proved to be very useful in understanding the potential of the revised network to provide quality EmONC services to a large proportion of the population, while pointing to those areas with less accessibility. Using realistic modelling based on travel times, the accessibility analyses provided key information to the 2018 EmONC prioritization exercise, which aimed at finding a balance between designating a smaller number of facilities as EmONC to channel needed resources to these priority sites for improving quality of care, and ensuring good coverage of the population within 1 hour of travel time to the closest designated EmONC health facility.

The application of this methodology in Togo can be replicated in other countries thanks to the current online availability of key high-resolution geospatial data sets. This is of particular importance where mapping of physical accessibility is a crucial component for bettering health outcomes for women and newborns.

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AUTHOR CONTRIBUTION

Andrew Curtis: conceptualization, methodology, formal analysis, writing, editing, visualization, validation. **Jean-Pierre Monet:** methodology, writing, editing, validation. **Michel Brun**: methodology, writing, editing, validation, supervision. **Issa Abdou-Kérim Bindaoudou:** data sharing, editing, validation. **Idrissou Daoudou:** data sharing, editing, validation**. Marta Schaaf:** methodology, writing, editing, validation**. Yawo Agbigbi:** data sharing, editing, validation**. Nicolas Ray:** conceptualization, methodology, writing, editing, validation, supervision.

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COMPETING INTERESTS

None declared.

PATIENT CONSENT FOR PUBLICATION

Not required.

DATA AVAILABILITY STATEMENT

Data are available on reasonable request. Most data used in this study are openly accessible through the indicated data sources in the "Input geospatial data" section. Health facility names and geographic coordinates, as well as administrative boundaries are available on request to INSEED. Road data are available on request to the *Direction de la Cartographie nationale et du cadastre* of Togo. Data on barriers to movement are available on request to the the *Ministère de l'agriculture, de la production animale et halieutique* of Togo.

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Figure legends

Figure 1 - Vector and raster data sets used. (A) Barriers to movement (rivers, waterbodies, lakes); (B) Road network; (C) Digital Elevation Model (DEM); (D) 2013 Population density raster; (E) 2018 Population density raster; (F) Landcover raster; (G) 2013 EmONC facilities; (H) 2018 EmONC facilities; (I) Administrative boundaries (prefectures, regions and Global Rural-Urban Mapping Project (GRUMP) urban extents) with region names.

Figure 2 - Maps of the travel time to the nearest EmONC facility using either the walking & motorized scenario, the motorcycle-taxi scenario and the walking-only scenario, for both time periods (2013 and 2018).

Figure 3 - Uncertainty maps of the travel times to the nearest facility for the walking & motorized scenario on the 2018 EmONC facility network using (A) Road uncertainty, (B) Landcover (off-road) uncertainty, and (C) Total uncertainty.

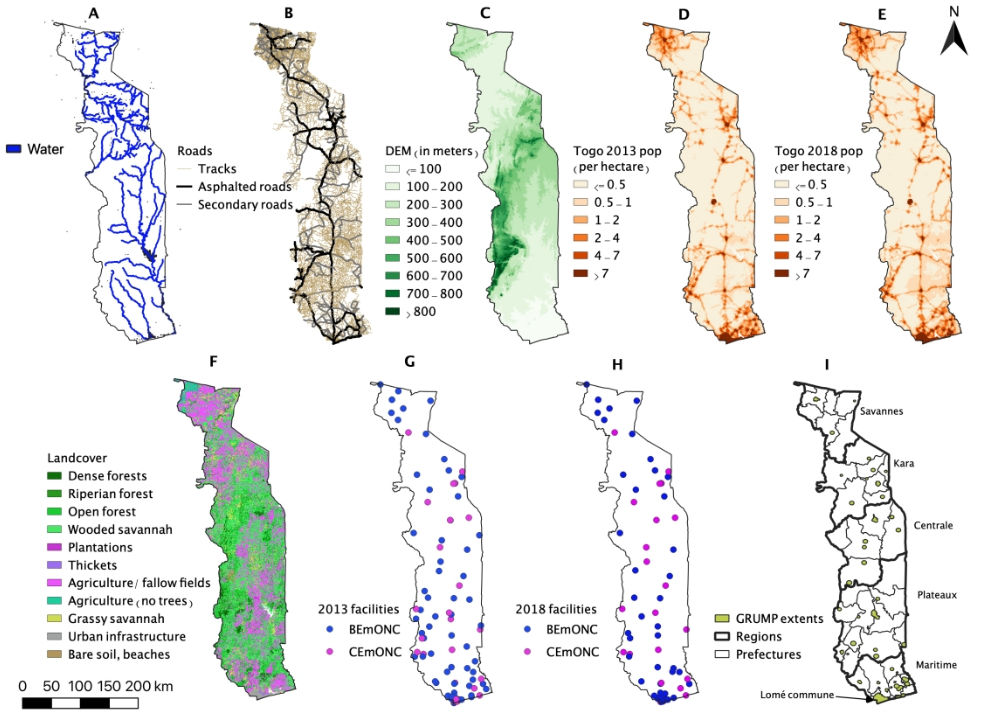

Figure 1 - Vector and raster data sets used. (A) Barriers to movement (rivers, waterbodies, lakes); (B) Road network; (C) Digital Elevation Model (DEM); (D) 2013 Population density raster; (E) 2018 Population density raster; (F) Landcover raster; (G) 2013 EmONC facilities; (H) 2018 EmONC facilities; (I) Administrative boundaries (prefectures, regions and Global Rural-Urban Mapping Project (GRUMP) urban extents) with region names.

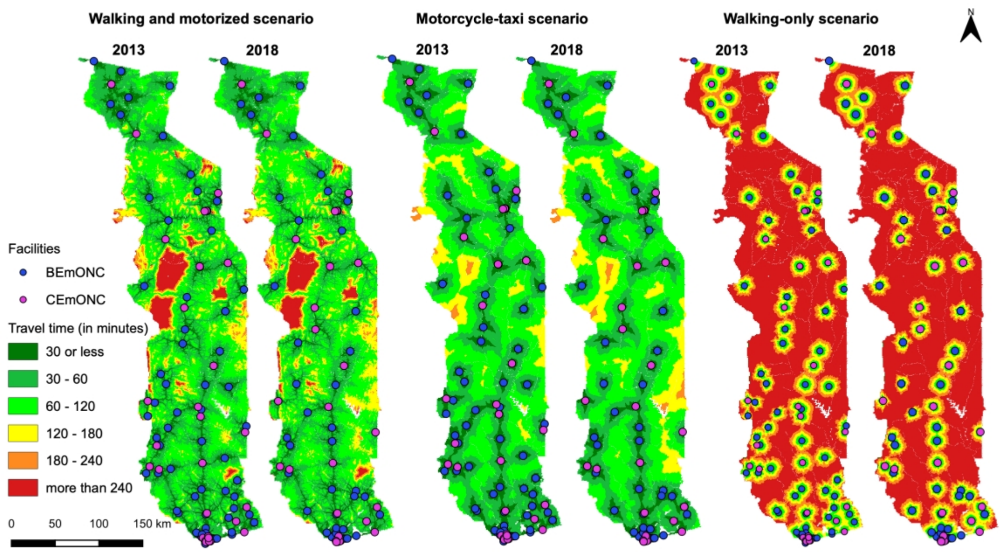

Figure 2 - Maps of the travel time to the nearest EmONC facility using either the walking & motorized scenario, the motorcycle-taxi scenario and the walking-only scenario, for both time periods (2013 and 2018).

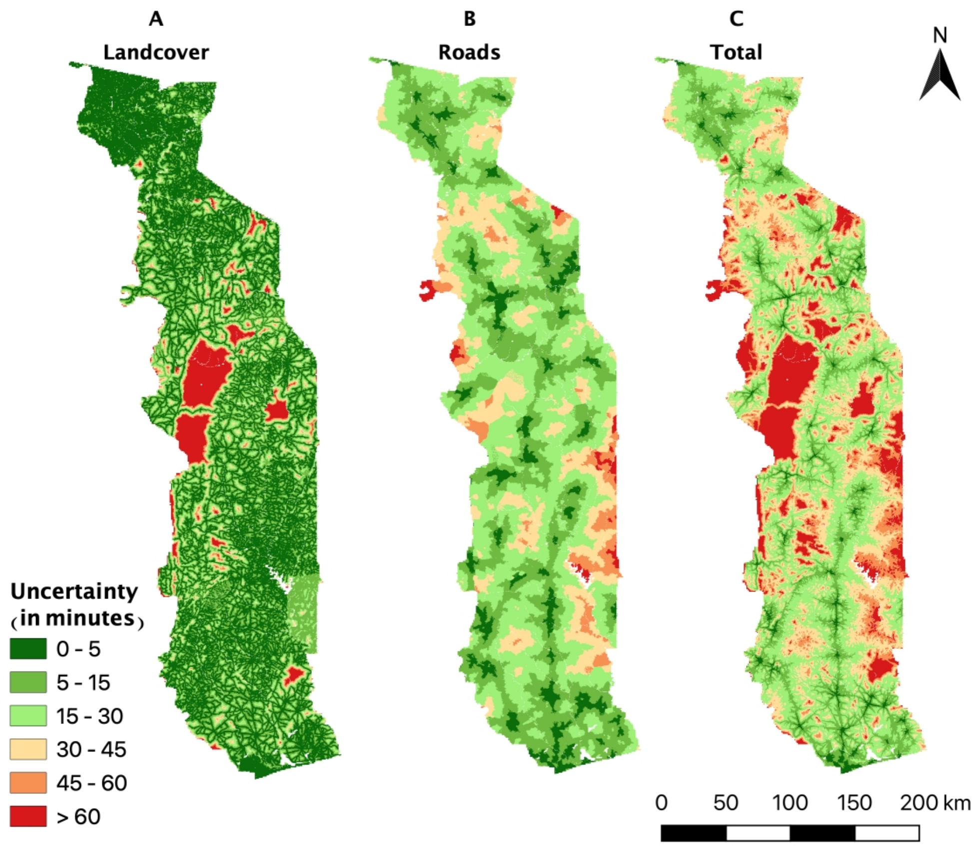

Figure 3 - Uncertainty maps of the travel times to the nearest facility for the walking & motorized scenario on the 2018 EmONC facility network using (A) Road uncertainty, (B) Landcover (off-road) uncertainty, and (C) Total uncertainty.

SUPLEMENTARY MATERIAL

Supplement 1: travel scenario tables

Walking & Motorized scenario

Class	Label	Label (English)	Speed (km/h)	Mode
11	Forets denses	Dense forest	1.5	WALKING
12	Forets riveraines	Riparian forest	1.5	WALKING
13	Forets claires, savanes boisées	Open forest, wooded savannah	1.5	WALKING
14	Savane arborée, arbustive	Sparsely wooded savannah	1.5	WALKING
16	Plantations	Plantations	3	WALKING
17	Fourrées	Thickets	3	WALKING
21	Cultures et Jachères	Cultivated and fallow lands	3	WALKING
22	Cultures sans arbres	Cultivated lands without trees	3	WALKING
32	Savanes herbeuses	Grassy savannah	3	WALKING
41	Agglomérations et infra, plantations urbaines	Agglomerations and infrastructure, urban plantations	3	WALKING
61	Sols nus, roches, carrières, plage	Open soil, rocky terrain, quarries, beach	3	WALKING
1000	Pistes rurales	Rural tracks	15	MOTORIZED
1002	Routes bitumées rurales	Primary rural asphalted roads	80	MOTORIZED
1003	Routes secondaires rurales	Secondary rural roads	40	MOTORIZED
1004	Pistes urbaines	Urban tracks	10	MOTORIZED
1005	Routes bitumées urbaines	Primary urban asphalted roads	30	MOTORIZED
1006	Routes secondaires urbaines	Secondary urban roads	20	MOTORIZED

Motorcycle-taxi scenario

class	label	Label (English)	Speed (km/h)	mode
11	Forets denses	Dense forest	8	MOTORIZED
12	Forets riveraines	Riparian forest	8	MOTORIZED
13	Forets claires, savanes boisées	Open forest, wooded savannah	8	MOTORIZED
14	Savane arborée, arbustive	Sparsely wooded savannah	8	MOTORIZED
16	Plantations	Plantations	10	MOTORIZED
17	Fourrées	Thickets	8	MOTORIZED

21	Cultures et Jachères	Cultivated and fallow lands	10	MOTORIZED
22	Cultures sans arbres	Cultivated lands without trees	10	MOTORIZED
32	Savanes herbeuses	Grassy savannah	12	MOTORIZED
41	Agglomérations et infra, plantations urbaines	Agglomerations and infrastructure, urban plantations	7	MOTORIZED
61	Sols nus, roches, carrières, plage	Open soil, rocky terrain, quarries, beach	7	MOTORIZED
1000	Pistes	Rural tracks	15	MOTORIZED
1002	Routes bitumées	Primary rural asphalted roads	40	MOTORIZED
1003	Routes secondaires	Secondary rural roads	20	MOTORIZED
1004	Pistes urbaines	Urban tracks	10	MOTORIZED
1005	Routes bitumées urbaines	Primary urban asphalted roads	30	MOTORIZED
1006	Routes secondaires urbaines	Secondary urban roads	15	MOTORIZED

Walking scenario

class	label	Label (English)	Speed (km/h)	mode
11	Forets denses	Dense forest	1.5	WALKING
12	Forets riveraines	Riparian forest	1.5	WALKING
13	Forets claires, savanes boisées	Open forest, wooded savannah	1.5	WALKING
14	Savane arborée, arbustive	Sparsely wooded savannah	1.5	WALKING
16	Plantations	Plantations	3	WALKING
17	Fourrées	Thickets	3	WALKING
21	Cultures et Jachères	Cultivated and fallow lands	3	WALKING
22	Cultures sans arbres	Cultivated lands without trees	3	WALKING
32	Savanes herbeuses	Grassy savannah	3	WALKING
41	Agglomérations et infra, plantations urbaines	Agglomerations and infrastructure, urban plantations	3	WALKING
61	Sols nus, roches, carrières, plage	Open soil, rocky terrain, quarries, beache	3	WALKING
1000	Pistes	Rural tracks	4	WALKING
1002	Routes bitumées	Primary rural asphalted roads	4	WALKING

1003	Routes secondaires	Secondary rural roads	4	WALKING
1004	Pistes urbaines	Urban tracks	4	WALKING
1005	Routes bitumées urbaines	Primary urban asphalted roads	4	WALKING
1006	Routes secondaires urbaines	Secondary urban roads	4	WALKING

Supplement 2: Preparation of input geospatial data

All following geospatial data sets were prepared using QGIS ver. 3.2.0. After finalization, each of them was changed to raster format (if needed) at 100m resolution, and projected in the WGS84 Universal Transverse Mercator (zone 31N) coordinate reference system.

Road network (vector)
We used the road network created by the *Direction de la Cartographie nationale et du cadastre* of Togo. In 2015, GIS experts from the national Togolese Institute for Statistics, Economic and Demographic studies (INSEED), in collaboration with technicians from the National Ministry of Public Works and Transportation, re-categorized this road data set into three hierarchical categories: asphalted roads, secondary roads, and tracks (see figure 1B).

Barriers to movement (vector)
Water bodies were considered as barriers to terrestrial movements, unless a road segment crosses over, which is assumed to be a bridge. Rivers were recoded into two categories by the INSEED GIS experts, distinguishing permanent and seasonal rivers. We used both categories as barriers to movement in our accessibility models, reflecting our conservative approach of considering a maximum of potential barriers.

Land cover (raster)
The land cover data set at 100m resolution was provided by INSEED. We assumed that different land cover categories can influence travel speed (e.g., travel is slower in a dense forest than in an open area), each of these land cover categories can be given a distinct travel speed in the travel scenario. The landcover category representing bodies of water was extracted from the landcover and used as an additional barrier to movement. Using the "Merge land cover" tool in AccessMod, the land cover raster was merged with the road network and the various barriers to movement, in order to obtain the final "merged land cover" on which travel models are applied. For the merging process, roads were stacked above the barriers, so that any existing road passing over a barrier was considered passable.

Population density (raster)
Population densities were derived from the Worldpop data set[1]. This data set is at 3-arc second resolution (90m at the equator) and is appropriate for our analyses as the modelling technique to obtain it uses a detailed settlement mapping and links these settlements with gazetteer population numbers, considering that the vast majority of people live within a settlement. The remaining unaccounted-for population is then distributed using a weighted landcover grid in function of the probability of being populated, and the total population estimates are adjusted to UN estimates[2]. We used the UN-adjusted 2013 and 2018 Worldpop data sets for Togo. The data set was aggregated to 100m resolution.

A final correction step consisted in correcting for the population falling in pixels that were assigned a barrier status in the merged landcover data set, because this population is not considered by the accessibility analysis and is left unaccounted for. To correct for that, we extracted the population in each barrier pixel and dispatched it uniformly within the surface of the prefecture area the pixel belongs to. This way the population in each prefecture was correctly represented, even if a large number of barrier pixels are found. This step was done in AccessMod using the « Adjust population distribution" module.

Supplement 3: Table of percentage of population living within 2-hour travel time to the nearest EmONC facility, per prefecture, with uncertainty intervals within brackets, and for the walking & motorized and the motorcycle-taxi scenarios

	Walking & Motorized Scenario		Motorized only Scenario		Walking only Scenario	
Prefectures	*1-hour*	*2-hour*	*1-hour*	*2-hour*	*1-hour*	*2-hour*
Agoenyive	100 [99.6 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	68.4 [53.2 - 80.3]	99.6 [95.5 - 99.9]
Agou	73.4 [59.9 - 83.5]	99.7 [96.3 - 99.9]	69.3 [57.8 - 78.7]	99.9 [94.4 - 100]	13.0 [9.9 - 15.9]	27.9 [21.9 - 34.1]
Akebou	46.7 [31.7 - 61.5]	93.4 [84.3 - 96.3]	42.9 [23.7 - 55.9]	92.3 [75.3 - 100]	0.9 [0.6 - 1.4]	4.8 [2.7 - 6.9]
Amou	67.3 [55.3 - 76.3]	92.2 [86.5 - 95.4]	74.4 [64.9 - 83.5]	99.3 [94.4 - 100]	8.8 [6 - 12.2]	26.9 [19.6 - 34.4]
Anie	41.5 [35.5 - 48.0]	74.0 [61.2 - 88.3]	41.6 [37.2 - 44.7]	61.6 [52.3 - 71.3]	15.4 [11.8 - 18.6]	27.8 [23.9 - 31.5]
Assoli	56.5 [41.2 - 67.3]	90.5 [82.2 - 94.7]	77.7 [65.1 - 85.3]	99.6 [95.5 - 100]	9.8 [6.6 - 13.2]	25.5 [19.8 - 31.2]
Ave	76.3 [66.8 - 82.5]	94.8 [89.9 - 97.3]	85.2 [75.6 - 93.3]	100 [99.9 - 100]	17.5 [12.8 - 21.6]	37.8 [29.4 - 45.4]
Bas-Mono	88.3 [82.2 - 92.0]	98.6 [96.4 - 99.4]	98.9 [94.9 - 99.6]	99.6 [99.6 - 99.6]	45.3 [33.9 - 54.2]	78.8 [68.0 - 86.3]
Bassar	57.5 [46.9 - 67.1]	87.2 [80.4 - 90.8]	64.5 [54.2 - 71.7]	92.8 [84.4 - 97.0]	12.5 [9.0 - 15.8]	24.3 [20.1 - 28.9]
Binah	85.9 [77.3 - 91.6]	97.9 [96.6 - 98.6]	85.4 [77.7 - 90.5]	100 [97.3 - 100]	28 [20.6 - 36.6]	61.1 [53.2 - 66.8]
Blitta	81.4 [72.7 - 87.5]	97.1 [94.4 - 98.2]	84.3 [78.8 - 89.8]	98.3 [95.0 - 99.9]	31.7 [21.6 - 41.8]	64.1 [57.2 - 66.3]
Cinkasse	99.3 [93.5 - 99.6]	99.9 [99.9 - 99.9]	94.5 [67.9 - 100]	100 [100 - 100]	10.7 [9.1 - 12.2]	18.1 [15.2 - 21.6]
Dankpen	48.3 [37.2 - 57.4]	83.3 [71.7 - 90.5]	42.2 [32.7 - 52.0]	83.3 [69.1 - 93.4]	9.8 [7.6 - 11.5]	16.8 [14.2 - 19.8]
Danyi	76.8 [64.9 - 85.9]	98.1 [94.8 - 99.2]	92.5 [81.1 - 97.2]	100 [100 - 100]	8.8 [6.6 - 11.3]	23.5 [16.9 - 32.0]
Doufelgou	53.3 [44.3 - 61.8]	88.0 [77.7 - 93.0]	62.4 [51.1 - 71.3]	95.6 [84.4 - 99.8]	12.2 [8.6 - 15.3]	28.6 [21.8 - 35.4]
Est-Mono	37.3 [26.9 - 45.4]	75.0 [62.8 - 86.6]	38.9 [28.0 - 46.8]	78.5 [61.6 - 94.1]	5.1 [3.7 - 6.3]	12.2 [8.9 - 16.2]
Golfe	100 [99.5 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	67.1 [52.5 - 80]	99.9 [97.1 - 100]
Haho	50.0 [38.0 - 61.4]	89.7 [78.8 - 94.9]	49.7 [41.0 - 58.4]	85.1 [74.0 - 94.0]	11.4 [8.8 - 13.3]	20.4 [16.9 - 24.3]
Keran	42.0 [29.5 - 54.9]	87.8 [74.9 - 93.3]	34.4 [26.3 - 42.7]	86.0 [64.7 - 97.7]	4.3 [3.0 - 5.7]	12.6 [9.3 - 15.3]
Kloto	85.5 [76.7 - 91.9]	99.4 [98.0 - 99.7]	97.2 [90.5 - 99.8]	100 [100 - 100]	22.7 [18.3 - 27]	40.7 [34.7 - 45.6]
Kozah	85.2 [76.6 - 90.3]	97.1 [95.1 - 98.1]	92.9 [87.6 - 95.9]	100 [99.8 - 100]	22.1 [17.6 - 26.3]	42.3 [33.8 - 50.8]
Kpele	71.8 [62.3 - 80.1]	98.2 [91.3 - 99.7]	78.4 [71.8 - 84.3]	99.6 [94.2 - 100]	16.8 [12.2 - 20.2]	29.6 [25.3 - 34.3]
Kpendjal	64.2 [47.9 - 76.5]	98.7 [92.9 - 99.8]	59.7 [38.6 - 74.8]	99.5 [92.8 - 100]	3.7 [2.7 - 4.7]	10.3 [7.0 - 13.6]
Lacs	94.9 [91.1 - 97.1]	99.7 [99.0 - 100]	95.4 [91.5 - 97.8]	100 [99.9 - 100]	22.2 [15.9 - 28.8]	51.8 [40.1 - 64.2]
Lomé Commune	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [93.9 - 100]	100 [100 - 100]
Moyen-Mono	39.6 [25.9 - 50.9]	94.0 [79.8 - 98.2]	42.6 [34.4 - 50.6]	90.7 [66.3 - 99.3]	3.4 [2.2 - 4.5]	12.6 [7.8 - 19.2]
Naki-Ouest	77.5 [60.5 - 89.8]	99.7 [98.5 - 100]	64.3 [49.3 - 77.9]	100 [97.8 - 100]	11.4 [8 - 15.2]	26.3 [21.6 - 30.8]
Ogou	54.9 [44.2 - 66.3]	95.9 [85.7 - 99.2]	54.9 [46.7 - 62.9]	93.2 [79.1 - 99.9]	10.1 [7.4 - 13]	26.0 [19.5 - 30.9]
Oti	79.3 [68.4 - 86.2]	97.7 [93.5 - 98.8]	78.4 [67.6 - 86.4]	98.0 [96.1 - 99.4]	20.6 [15.5 - 24.7]	37.1 [30.7 - 44.7]
Oti-Sud	47.8 [33.5 - 58.5]	95.3 [83.1 - 98.6]	36.7 [23.6 - 49.8]	87.4 [69.7 - 99.4]	5.5 [3.7 - 6.7]	11.5 [8.9 - 13.6]
Plaine de Mo	33.8 [21.1 - 45.9]	72.8 [62.8 - 78.8]	37.3 [24.0 - 52.7]	87.3 [75.7 - 94.1]	1.7 [1.1 - 2.5]	7.3 [4.5 - 11.2]
Sotouboua	42.4 [31.5 - 52.7]	75.2 [67.8 - 77.9]	49.9 [40.1 - 57.8]	82.2 [70.4 - 89.6]	3.9 [2.9 - 4.9]	9.0 [6.9 - 11.6]
Tandjoare	85.6 [76.7 - 91.2]	99.8 [98.3 - 100]	76.2 [65.5 - 84.7]	98.6 [92.9 - 100]	8.8 [6.3 - 11.7]	27.5 [18.9 - 37.0]
Tchamba	54.9 [37.3 - 67.9]	90.2 [83.7 - 93.4]	45.9 [33.4 - 60.9]	96.5 [88.8 - 99.2]	8.2 [6.4 - 9.9]	15.7 [12.9 - 18.3]
Tchaoudjo	65.0 [53.3 - 74.8]	93.4 [88.0 - 95.7]	71.8 [57.6 - 80.1]	98.5 [92.4 - 99.5]	16.7 [11.7 - 21.2]	30.4 [26.5 - 34.8]
Tone	91.8 [80.5 - 97.4]	100 [99.9 - 100]	82.4 [71.9 - 89.2]	99.9 [98.5 - 100]	13.9 [10.1 - 17.3]	28.1 [22.7 - 34.6]

Vo	85.6 [70.3 - 93.2]	99.4 [98.3 - 99.8]	95.5 [83.9 - 99.5]	100 [100 - 100]	10.9 [7.0 - 15.4]	31.6 [23.3 - 43.4]
Wawa	51.6 [36.0 - 65.0]	93.0 [83.2 - 96.8]	67.7 [45.3 - 82.3]	100 [97.5 - 100]	2.7 [2.1 - 3.4]	6.5 [4.8 - 8.6]
Yoto	82.2 [71.7 - 88.2]	95.9 [93.3 - 97.5]	87.0 [78.9 - 92]	98.9 [97.2 - 99.6]	24.3 [18.0 - 29.0]	46.1 [37.8 - 55.4]
Zio	87.9 [77.4 - 93.9]	99.7 [98.5 - 99.9]	93.1 [85.3 - 96.4]	100 [99.5 - 100]	16.4 [11.9 - 21.2]	39.5 [29.4 - 49.7]
Country	78.3 [70.5 - 84.0]	95.5 [91.6 - 97.5]	79.2 [72.2 - 84.3]	96.0 [91.6 - 98.4]	33.4 [27.1 - 38.4]	50.8 [46.0 - 55.0]

Supplement 4: Effects of considering slopes to correct for walking speeds

When walking is used in a travel scenario, AccessMod computes the slope between adjacent raster cells using the Digital Elevation Model. Walking speeds are then corrected using the slope value, following the Tobler (1993) formula[3]:

$$V = V_F * e^{-3.5*|S+0.05|},$$

where V is the corrected walking speed in kilometers per hour (Km/h), V_F is the walking speed on a flat surface (given by the user-defined travel scenario), and S is the slope in hundredth of percent.

These corrections applied when walking off-road in the "Walking & Motorized scenario", and everywhere in the "Walking scenario". In the table below, each cell is composed of two results. The first figure takes slope correction into consideration, while the second figure does not take into account the slope correction.

	Walking & Motorized Scenario				**Walking Scenario**			
	2013		**2018**		**2013**		**2018**	
Regions	***1-hour***	***2-hour***	***1-hour***	***2-hour***	***1-hour***	***2-hour***	***1-hour***	***2-hour***
Plateaux	66.2/67.7	95.1/95.6	55.4/56.6	89.8/90.3	15.5/16.2	30.2/31.4	10.9/11.4	22.6/23.5
Kara	63.3/64.3	90.4/90.9	62.7/63.6	90.2/90.7	14.5/15.0	29.7/30.2	14.5/14.9	29.3/29.8
Maritime	94.7/94.8	99.5/99.5	94.4/94.5	99.4/99.4	47.9/48.2	74.8/75.1	47.7/48.0	76.4/76.5
Centrale	70.2/70.6	92.3/92.6	65.2/65.6	91.7/91.9	22.0/22.3	41.3/41.5	18.1/18.5	35.7/35.9
Savanes	81.7/81.9	98.9/99.0	80.7/80.9	98.9/99.0	12.1/12.4	26.5/27.2	11.4/11.6	24.2/24.9
Lomé Commune	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
Country	81.0/81.5	96.7/98.0	78.3/78.8	95.5/95.7	34.7/35.1	52.3/52.8	33.4/33.7	50.8/51.2

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National optimization of accessibility to emergency obstetric and neonatal care in Togo: a geospatial analysis

Andrew Curtis[1,2], Jean-Pierre Monet[3], Michel Brun[3], Issa Abdou-Kérim Bindaoudou[4], Idrissou Daoudou[5], Marta Schaaf[6], Yawo Agbigbi[7], Nicolas Ray[1,2,*]

[1] GeoHealth Group, Institute of Global Health, Faculty of Medicine, University of Geneva, Geneva, Switzerland
[2] Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland
[3] Technical Division, United Nations Population Fund (UNFPA), New York City, USA
[4] National Institute of Statistics and Economic and Demographic Studies (INSEED), Lomé, Togo
[5] Ministry of Health, Lomé, Togo
[6] Independent Consultant, New York City, USA
[7] United Nations Population Fund (UNFPA), Lomé, Togo

Corresponding author: Prof. Nicolas Ray, nicolas.ray@unige.ch, GeoHealth group, Institute of Global Health, Faculty of Medicine, Campus Biotech, Chemin des Mines 9, 1202 Geneva, Switzerland

Abstract

Objectives: Improving access to emergency obstetrical and neonatal care (EmONC) is a key strategy for reducing maternal and neonatal mortality. Access is shaped by several factors, including service availability and geographic accessibility. In 2013, the Ministry of Health (MoH) of Togo used service availability and other criteria to designate particular facilities as EmONC facilities, facilitating efficient allocation of limited resources. In 2018, the MoH further revised and rationalized this health facility network by applying an innovative methodology using health facility characteristics and geographical accessibility modelling to optimize timely access to EmONC services. This study compares the geographic accessibility of the network established in 2013 and the smaller network developed in 2018.

Design: We used data regarding travel modes and speeds, geographic barriers, and topographic and urban constraints, to estimate travel times to the nearest EmONC facilities. We compared the EmONC network of 109 facilities established in 2013 with the one composed of 73 facilities established in 2018, using three travel scenarios (walking and motorized, motorcycle-taxi, and walking-only).

Results: When walking and motorized travel is considered, the 2013 EmONC network covers 81.0% and 96.6% of the population at the 1-hour and 2-hour limit, respectively. These figures are slightly higher when motorcycle-taxis are considered (82.8% and 98.0%), and decrease to 34.7% and 52.3% for the walking-only scenario. The 2018 prioritized EmONC network covers 78.3% (1-hour) and 95.5% (2-hour) of the population for the walking and motorized scenario.

Conclusions: By factoring in geographical accessibility modeling to our iterative EmONC prioritization process, the MoH was able to decrease the designated number of EmONC facilities in Togo by about 30%, while still ensuring that a high proportion of the population has timely access to these services. However, the physical access to EmONC for women unable to afford motorized transport remains inequitable.

Keywords: maternal health, universal health coverage, geospatial modelling, physical accessibility, health system strengthening

Strengths and limitations of this study

- This is the first study presenting an improvement of a network of EmONC facilities, based on the characteristics of these facilities and on realistic physical accessibility modelling.
- Country-based experts estimated the modes and speeds of transport on the various road types and off-road landcover categories, and associated uncertainty analyses assessing relative effect of travel speeds were performed.
- The EmONC prioritization approach succeeded in prioritizing 73 out of the initial 109 EmONC facilities, with only a marginal drop of population coverage. This will enable efficient use of limited resources.
- Only the physical accessibility to nearest designated EmONC services was modelled, but potential financial barriers and the fact that some patients could opt to bypass the nearest facility may also affect access to EmONC.
- Travel was modelled only for the dry season conditions, but degraded road conditions in certain parts of the country during the wet season may affect our estimates of EmONC accessibility.

INTRODUCTION

The Sustainable Development Goal 3 (SDG3) aims to better health outcomes for different at-risk groups, including pregnant women (SDG3.1) and children under 5 years of age (SDG3.2). One of the primary strategies for reducing maternal and neonatal mortality and morbidity is ensuring timely access to quality emergency obstetric and neonatal care (EmONC)[1]. However, access to EmONC is still a challenge in many low-income countries, especially in sub-Saharan Africa[2].

Because the physical distance to facilities has long been recognized as an important component of timely access to care[3, 4], an adequate geographic distribution of EmONC facilities is a prerequisite to minimize travel times for women in need of EmONC. The World Health Organization (WHO) recommends a benchmark of no more than 2 hours of travel time to reach the nearest EmONC facility[5], as after 2 hours, an obstetric hemorrhage can be fatal.

Realistically modelling and measuring spatial accessibility to health services is therefore very important for adequate planning and improvement of access to quality healthcare for pregnant women and newborns[6]. Some studies have used simple distances[7] and time[8] metrics, as well as population-to-provider ratios (PPRs)[9]. These metrics have been popular for their ease of use and minimal need for the input of spatial data layers, i.e. data that both provide locations and describe characteristics of geographic features[10].

However, these methods are not appropriate for modelling geographic accessibility in complex terrains where different modes of transport are potentially used for a single trip, and when patients seeking care are facing an emergency, where every minute of travel time is consequential. In such cases, approaches based on least-cost path modelling (i.e., finding the fastest route between locations based on various travel constraints) have proved useful to estimate time and routing to reach the nearest care providers, and to model catchment areas of facilities[10]. Applying this modelling approach, the AccessMod tool[11] helps estimate geographic accessibility by taking into consideration the modes of transport, their respective speeds of travel on roads and off-road on various landcover types, and the influence of the topography and other barriers to movement. Studies assessing the accessibility of a variety of health care destinations have used AccessMod in their analyses[12-19]. Specific to accessibility to EmONC, Ebener and colleagues[20] have recently formalized and proposed new indicators based on least-cost path modelling.

The main objective of this study was to realistically determine and compare the overall geographic accessibility of our target population (women with obstetrical complications in need of EmONC) to two EmONC facility networks: the first one designated by the Ministry of Health

(MoH) in 2013 and the second one in 2018 through a methodology using accessibility modelling. The comparison of the two networks in terms of physical accessibility and population coverage is very useful in Togo, a country where (i) the probability of being attended at birth by qualified personnel is strongly linked to socio-economic status and where (ii) three-quarters of maternal deaths are due to direct obstetrical complications[21], which could for the most part be avoided if those experiencing complications have access to quality EmONC in less than two hours. We defined and applied various travel scenarios based on inputs from national and sub-national stakeholders, including speed and transport modes and their associated uncertainties. Besides expanding knowledge on the underlying mechanisms of geographical access to EmONC facilities in Togo, we described a robust spatially-explicit methodology for quantifying the population covered by networks of EmONC health facilities that can be replicated in other countries.

DATA AND METHODS

Study site and context

Togo is one of the smallest African countries in terms of landmass (approximately 56,785 km^2), with a population of approximately 7.9 million in 2018[22], and it is bordered by Benin to the east, Ghana to the west and Burkina Faso to the north. More than 40% of the total population live in the southern part of the country (in the region of Maritime and in the capital city of Lomé), with 42% of this population living in urban areas[23]. The 2017 Multiple Indicator Cluster Survey (MICS 6) for Togo[24] determined that there is a strong correlation between poverty and maternal mortality and morbidity. Indeed, the probability of giving birth assisted by qualified personnel is found to be highly correlated to socio-economic status and to place of residence. The aforementioned survey determined that 98% of women in the richest quintile are assisted at birth by skilled health personal, compared to only 52% of the poorest quintile. It also highlighted the fact that 98% of women living in urban settings receive skilled birth attendance, as compared to 65% of women living in rural settings. Three quarters of maternal deaths were found to be due to direct obstetrical causes. This suggests that access to timely EmONC is essential for reducing maternal mortality in Togo.

The 2017-2022 national plan for health sector development in Togo[25] highlights that morbidity and mortality rates for mothers and newborns are still very high, and notes that this is due to insufficient supply of obstetric and neonatal care and by barriers to service access, including financial barriers. Despite some progress over the last decades, maternal and newborn mortality are still high in Togo respectively, with 396 (80% CI: 270-557) maternal deaths per 100,000 live births in 2017[25] and 25 neonatal deaths per 1,000 live births in 2018[2]. Improving access to quality EmONC services has been a priority for the government since the EmONC needs assessment of 2012. In 2013, the MoH used facility data to identify 109 priority health facilities designated to provide EmONC services, and launched a process to monitor them on a quarterly basis to assess and address gaps in availability and quality of care. This national network encompassed both government and NGO facilities, and its selection was done by considering several pieces of information on each facility: high obstetric activity (i.e., favoring those with more than 30 deliveries/month), qualified human resources, capacity to organize referrals, gaps in EmONC signal functions and adequate geographic distribution. EmONC facility functionality requires enough qualified providers for 24h/7d services and the availability of key equipment, consumables, and medication for performing the key medical interventions (or signal functions) that are used to treat the direct obstetric complications that cause the vast majority of maternal deaths.

While the focus on a prioritized set of health facilities led to some progress in the availability of services, for example the increase of the proportion of EmONC facilities applying vacuum extractions from 24% in 2014 to 43% in 2016, the MoH decided in 2018 to further focus their efforts and resource allocation by further decreasing the number of priority facilities; the MoH ultimately selected 73 health facilities that should provide EmONC services in the country. This selection was guided by a methodology developed by UNFPA and formalized and described in UNFPA's EmONC Network Development Implementation Manual[26]. In brief, this methodology, based on WHO, UNFPA, and UNICEF recommendations[5], helps countries to identify a network of EmONC facilities by selecting a number of EmONC facilities that do not exceed the international norm of 5 EmONC facilities per 500,000 population, and, by prioritizing facilities that can most feasibly be supported to actually provide all the relevant EmONC signal functions 24h/7d (see Box 1) with quality care, during the next programmatic cycle of the MoH (i.e. in the next 3-4 years). The selection of health facilities is done by considering both health facility characteristics (e.g. number of deliveries, human resources, gaps in EmONC signal functions, infrastructure) and two spatially-explicit indicators[20]: the population living within 1 and/or 2-hour maximum travel time from the nearest EmONC facility (i.e. population coverage), and the quality of each referral linkage between Basic EmONC (BEmONC) health facilities and their closest Comprehensive EmONC (CEmONC) health facility. BEmONC health facilities should provide seven EmONC signal functions 24h/7d while CEmONC health facilities provide nine EmONC signal functions (see Box 1). An EmONC facility is considered as functioning when it provides services 24h/7d, and when it has performed all seven (BEmONC) or all nine (CEmONC) signal functions in the three months prior to data collection[5]. A non-functioning EmONC facility has failed to provide one or more EmONC signal functions during that same period.

Box 1: Emergency obstetrical and neonatal care (EmONC) signal functions

Services available 24h/24 and 7d/7	
Basic EmONC (BEmONC) signal functions	**Comprehensive EmONC (CEmONC) signal functions**
1) Administer parenteral antibiotics 2) Administer uterotonic drugs 3) Administer parenteral anticonvulsants 4) Perform manual removal of the placenta, 5) Remove retained products 6) Perform assisted vaginal delivery 7) Perform basic neonatal resuscitation.	BEmONC signal functions (1-7) + 8) Perform blood transfusion 9) Perform Caesarean section.

Accessibility & population coverage modelling

We used AccessMod, a WHO stand-alone and open-source geospatial tool[11, 27], to analyze the physical accessibility to, and the population coverage of, the national networks of EmONC health facilities in Togo in 2013 and 2018. AccessMod is based on a least-cost path algorithm that computes the fastest route between any location and the nearest health service (for details, see [11]). It can consider several sequential modes of travel (e.g. walking to a road, where one catches a motorized vehicle), several types of barriers to movement, health facility capacity, and population, when determining catchment areas. Moreover, AccessMod considers the direction of movement by applying an anisotropic analysis (i.e. considering the slope of the terrain to accurately model bicycling and walking speeds). Contrary to many accessibility modelling approaches that are based on a perfectly routable road data set (such as Nichols et al[28]), AccessMod can consider off-road travel in addition to road travel. On- and off-road travel speeds and modes of transport are user-defined in a travel scenario that assigns these travel constraints to each land cover and/or road category found in the input data.

For the movements of our target population, we defined three distinct travel scenarios from home to the nearest EmONC facility: 1) a walking & motorized scenario, 2) a motorcycle-taxi scenario, and 3) a walking-only scenario. The first scenario assumes that patients walk to the nearest road and then use a motorized mode of transportation (car, minibus or other motorized vehicle, either private or public), immediately available, to continue their journey. In the second scenario, patients use only a motorcycle-taxi to travel on- and off-road, with different speeds depending on the land cover. Finally, the third scenario assumes patients are walking or being carried (e.g. on stretchers, carts) at walking speed (or lower).

The choice for these three scenarios and their associated modes and speeds of travel were decided through an iterative process of two workshops in Togo in 2016-2018. A first 3-day workshop took place in May 2016 to strengthen national capacity to analyze the geographic accessibility of health facilities in Togo by using AccessMod. The thirty Togolese participants were technical experts from the MoH, the national Togolese Institute for Statistics, Economic and Demographic studies (INSEED), NGOs and UN agencies, and other key stakeholders (e.g., regional health director, monitoring expert) from all regions of Togo. The pool of experts discussed and agreed on the specifics of how women with obstetrical emergency typically travel when they need to reach an EmONC facility in Togo. Average speeds of travel on all road categories were estimated by consensus, with the walking & motorized scenario deemed to be the most frequent. During a second workshop in May 2018, health stakeholders from each of the 6 regions of Togo gathered to define which health facilities should comprise their EmONC facility regional network, using the prioritization methodology described above to select a number of EmONC facilities per region not exceeding the international norm of 5 EmONC facilities per 500,000 population. These participants further refined the travel scenarios, and agreed that bicycles and public transport were rarely used, with the exception of a public bus system operating in greater Lomé [29]. In both workshops, participants recognized that during the wet season the speeds of travel generally decrease in many areas. However, they decided to use only a dry season scenario to guide planning as this is the longest season in Togo, around 8 months. The final travel speeds chosen for the three scenarios are found in Supplement 1.

Road speeds in urban areas were adjusted in order to simulate slower motorized travel occurring in intra-urban contexts due to various factors such as stoplights, traffic, pedestrians, and other hazards. For the walking & motorized scenario, we lowered travel speeds on asphalted roads, secondary roads and tracks to 40 km/h, 30 km/h and 10 km/h, respectively. For the motorcycle-taxi scenario, these average travel speeds were lowered to 30 km/h, 15 km/h and

10 km/h. These speed corrections were applied on all road segments falling within the extent of the urban areas informed by the Global Rural Urban Mapping Project[30].

Uncertainty analysis

To account for uncertainty in travel speeds, we additionally ran each consensus travel scenario with 20% slower or 20% faster speeds compared to the consensus scenario, following the methodology developed in Ouma et al.[17] and in Stewart et al.[31]. This translated to lower and upper uncertainty bounds on the reported output statistics. To further disentangle the effects of uncertainties on the speeds on roads and off roads, we ran scenario 1 by keeping on-road speeds constant (at consensus values) and varying off-road speeds by the plus or minus 20%. Conversely, we ran this scenario keeping off-road speeds constant and varying on-road speeds. Finally, to test the model's sensitivity to the consideration of topography, we also ran each consensus travel speed scenario without considering slope correction (i.e., isotropic mode).

Two uncertainty indicators were produced: (1) lower and upper uncertainty bounds on the variation in percentage (per region and for the whole country) of the coverage of population living less than one and less than two hours away from the closest EmONC facility, and (2) a series of spatially-explicit uncertainty maps. In these uncertainty maps, pixel values indicate the extent of the uncertainty of travel time to the nearest EmONC facility, obtained by subtracting the travel time grid resulting from the "- 20%" travel speeds scenario by the one resulting from the "+ 20%" travel speeds scenario. This highlights the areas in the country where the travel time estimates have the most uncertainty.

Input geospatial data

Various datasets were assembled and prepared to run the geospatial analyses in AccessMod. Details of the preparation steps are found in Supplement 2. We considered barriers to terrestrial movements composed of quarries and bodies of water, such as rivers, lakes and damned areas. The barriers file was created by the Togolese Ministry of Agriculture, Livestock and Hydraulics[32] (figure 1A). We used the road network created by the *Direction de la Cartographie nationale et du cadastre* of Togo, classified in three hierarchical categories: asphalted roads, secondary roads, and tracks[33] (figure 1B). We obtained the Digital Elevation Model (DEM) of Togo from NASA' Shuttle Radar Topography Mission[34] (figure 1C). Slopes were derived from the DEM directly in AccessMod.

We used the population density data set from the Worldpop project[35], provided with UN-adjusted population count from 2013 (figure 1D) and 2018 (figure 1E). We assumed that the target population of women with obstetrical complications is uniformly distributed across the overall population. Land cover information was provided by INSEED, with a land cover data set composed of twelve categories (figure 1F). We obtained the names and geographic coordinates of the 109 EmONC facilities composing the initial national network of EmONC health facilities in 2013 from INSEED (figure 1G). We further verified these names and coordinates with the help of the MoH. For the EmONC health facilities network of 2018 (figure 1H), the 73 final designated set of facilities was obtained through the MoH[36]. Finally, the most recent administrative boundaries at the prefectural, regional and national levels were created and made available by INSEED using data collected during the 2010 general census[37] (see figure 1I). These datasets were used to determine the percentage of population coverage for each administrative unit.

Patients and the public involvement

There was no patient or public involvement in this study. Health facility names and geographic coordinates, as well as administrative boundaries, were shared by INSEED. The road network was shared by the *Direction de la Cartographie nationale et du cadastre* of Togo. The barriers to movement datasets were provided by the *Ministère de l'agriculture, de la production animale et halieutique.* All other geospatial data were publicly available.

RESULTS

The accessibility maps for the walking & motorized scenario, and the motorcycle-taxi scenario, and for the two time periods, are shown in figure 2, with the respective maps for the walking-only scenario in Supplement 3. In 2013, estimated physical access was highest under scenario 2 (motorcycle-taxi scenario), with 82.8% of the total population less than one hour away from the nearest EmONC health facility, and 98% less than two hours away from the nearest EmONC health facility. For the walking & motorized scenario, these estimations are 81% at the 1-hour travel time limit and 96.7% at the 2-hour limit respectively.

Using the 2018 network of 73 facilities, population coverages using the motorcycle-taxi scenario are 79.2% at the 1-hour travel time limit and of 96% at the 2-hour limit. Compared to the 2013 network, these population coverages are lower by 3.6% (of the total population) at the

1-hour threshold and by 2% at the 2-hour limit. With the walking & motorized scenario, the corresponding results are 78.3% at the 1-hour limit and 95.5% at the 2-hour limit. Compared to the initial estimations for the 2013 network, population coverage for that scenario has only dropped by 2.7% and 1.2% respectively. Despite a reduction of the number of EmONC health facilities by one-third from 2013 to 2018, the population able to physically access the closest EmONC health facility within one or two hours is only marginally lower compared to the 2018 prioritized network.

For both time periods, population coverage at national scale is only marginally higher for the motorcycle-taxi travel scenario when comparing to the walking & motorized scenario, even though this translates to a much larger extent of the country's surface under the 2-hour maximum travel time limit (green areas in figure 2). We also see that accessibility is highly dependent on roads in scenario 1. This is the case for instance in parts of the Atacora mountains (large red areas in the central-western part of the country in figure 2), a region with a very low population density and almost no roads (according to our data). With scenario 2, travel is less dependent on roads than in scenario 1, but access tends nevertheless to be higher around the road network, even though travel speeds on roads are lower for the motorcycle-taxi scenario than for the walking & motorized scenario. The results for the 2018 network at regional level are given in Table 1, and at prefectural level in Supplement 2.

Table 1: Percentage of population living less than one- or two-hour travel time to the nearest EmONC facility, in 2018, per region and for the country, with uncertainty intervals within brackets.

	Walking & motorized scenario		**Motorcycle-taxi scenario**		**Walking-only scenario**	
Region	*1-hour*	*2-hour*	*1-hour*	*2-hour*	*1-hour*	*2-hour*
Plateaux	55.4 [44.4 - 65.1]	89.8 [80.7 - 95.2]	58.7 [49.2 - 66.3]	88.4 [78.5 - 94.6]	10.9 [8.3 -13.3]	22.6 [18.1 -27.2]
Kara	62.7 [52.3 - 71.0]	90.2 [82.8 - 94.1]	65.2 [56.7 - 72.0]	92.8 [84 - 97.7]	14.5 [11.0 -17.8]	29.3 [23.9 -34.7]
Maritime	94.4 [90.1 - 96.7]	99.4 [98.6 - 99.7]	96.9 [93.7 - 98.5]	99.9 [99.7 - 100]	47.7 [36.7 -57.0]	76.4 [70.2 -80.9]
Centrale	65.2 [53.0 - 74.7]	91.7 [86.6 - 93.9]	66.5 [56.1 - 75.7]	96.2 [90.0 - 98.5]	18.1 [12.6 -23.4]	35.7 [31.3 -38.7]
Savanes	80.7 [68.9 - 87.9]	98.9 [96.0 - 99.6]	72.5 [58.9 - 81.8]	97.9 [93.3 - 99.9]	11.4 [8.4 -14.2]	24.2 [19.1 -30.0]
Lomé Commune	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [93.9 -100]	100 [100 -100]
Country	**78.3 [70.5 - 84.0]**	**95.5 [91.6 - 97.5]**	**79.2 [72.2 - 84.3]**	**96.0 [91.6 - 98.4]**	**33.4 [27.1 - 38.4]**	**50.8 [46.0 - 55.0]**

The region of Lomé Commune has 100% population coverage for both time thresholds and both motorized scenarios, which is due to the combined effect of a very densely populated region of only 90 km^2 with 11 EmONC facilities in 2018, and a good road network that permits the Lomé population to access the closest EmONC in less than 1 hour travel time. In contrast, the rural region of Plateaux presents much more heterogeneous results, with large uncertainty intervals. The results at prefectural level are available in Supplement 3.

We illustrate in figure 3 the uncertainty in travel time for the walking & motorized scenario on the 2018 facility dataset, separated for the effects of speed uncertainty on roads and landcover. The maps show a spatially heterogeneous distribution of the uncertainties, especially in the case of the road speed uncertainty map with widespread uncertainties in all areas of the country, but with relatively low uncertainties along the asphalted road network. Similar maps for the uncertainty linked to the DEM are found in Supplement 4.

The landcover and road uncertainty maps show that uncertainty is strongest in areas with very little population density (see figure 1E). The total uncertainty map, combining uncertainty from roads and landcover, further highlights the fact that uncertainty is quite low on roads close to facilities and increases in more rural areas.

As expected for the walking-only scenario, national population coverage of the 2018 network notably drops to 33.4% within 1-hour walking, and 50.8% within 2-hour walking. Large differences in coverage are found between regions, with the southern more urban regions of Lomé and Maritime achieving higher accessibility results than the more rural areas of the country. Indeed, while the two aforementioned regions reach coverage percentages of 100% and 76.4% respectively at the two-hour threshold, the coverage percentages do not exceed 40% for all the other modelled regions.

DISCUSSION

The accessibility maps that were produced according to our three travel models illustrate the differences in accessibility in different parts of the country. This can help identify areas in the country where geographic accessibility to EmONC facilities is most difficult. These areas could be targeted for remedial efforts, such as mobile outreach, posting community health workers for reducing decision time to seek care, the creation of maternity waiting homes in the EmONC health facilities of the region, or planning improvement of the road infrastructure.

The three alternative models used to obtain these maps reflect different socio-economic segments of the population. If patients can afford to take a motorized vehicle after having reached the closest road or use a motorcycle-taxi from their home, then more than 78% of the population can reach the closest EmONC facility (as per the 2018 designation) in less than 1 hour. When considering 2-hour maximum travel time, this percentage is much higher, with 95% of the population able to reach the nearest facility within the time limit. We also note that the motorcycle-taxi scenario covers much larger areas of the country (green areas in Figure 2) in comparison to the walking & motorized scenario. Nevertheless, this does not result in a substantial increase in population coverage. This is explained by the fact that many areas where access is very low in scenario 1 are fairly unpopulated.

For women who have no access to motorized means of transport, accessibility to EmONC within one hour drastically decreases to about 33% of the population, and to 51% within the 2-hour threshold travel time limit. Thus, nearly half of the target population does not have access to EmONC in the maximum acceptable travel time if they cannot afford to travel by motorized means of transport. As anticipated, access to EmONC is greater for urban populations, even with substantially decreased travel speeds, due to a higher density of both EmONC facilities and road networks in urban areas.

Though the 2018 prioritized EmONC network included 36 fewer facilities than the 2013 network, the 2018 network still achieves high overall geographic accessibility, with all regions obtaining estimated coverage percentage of 90% and more. It only drops marginally in terms of population coverage (between 1 and 3.6 percentage points depending on the scenario) when compared to the initial network of 109 designated EmONC facilities in 2013. However, from a planning perspective, prioritizing the EmONC functionality of 73, rather than 109, facilities is a more feasible, achievable goal for the next MoH programmatic cycle (i.e. 3-4 years). The number of prioritized EmONC facilities is lower than the international norm that targets around 80 functional EmONC facilities for the 2018 population of Togo. However, the decision of the MoH to target this prioritized network was commensurate with available resources and the modelling results showing that this network can nevertheless ensure timely access to a large proportion of the population in case of obstetrical complications.

Our uncertainty analysis has shown that population coverage estimates are also most sensitive to uncertainties on the speeds on roads, as compared to the speeds off roads. This highlights the need for great caution when choosing travel speeds. A good representativeness of local experts, both in terms of knowledge about the specific travel behaviors of the target population and in terms of possible regional specificities for travel is vitally important. Other sources of information on effective travel speeds (e.g. using speed tracker onboard vehicles or mobile phones) could be very useful if available in the future. Furthermore, spatially displaying the uncertainty regarding travel times highlights the regions where this uncertainty is the highest, and that could be given high priority for future improvements of model parametrization. These improvements can be achieved by ensuring that all roads are well captured, or incorporating possible region-specific alternative means of transport.

Limitations

Although our study has produced the first high-resolution model of geographic accessibility to EmONC facilities in Togo, several limitations should be noted. First, our models only consider physical accessibility of the national network of EmONC health facilities. Although the three alternative transport models were created to acknowledge that motorized travel is not financially possible for some, there are additional financial barriers – such as formal and informal expenditures for health care – that our models do not address. Acceptability (i.e. "the match between how responsive health service providers are to the social and cultural expectations of individual users and communities", as mentioned in Peters et al.[38]) was also not considered. Immediate availability of motorized transport was also assumed in our models, which could over-estimate accessibility in cases where delays for finding transport are significant. Variable quality of interpersonal and clinical care in facilities can also affect which facility patients chose; they may not choose the closest facility in terms of travel time[39], possibly bypassing BEmONC health facilities in certain cases. We also assumed no delay in the decision to seek care. Clearly, further research on how to incorporate these other facets of accessibility could improve our models and our understanding of the spatial variability of effective access to EmONC.

Second, the workshop participants decided to model travel during the dry season conditions. The extent of the degradation of road conditions could not be captured in certain parts of the countries during the wet season, and this is known to heavily affect travel time. A more balanced view of regional accessibility to EmONC could be achieved by factoring in these seasonal specificities.

Third, our analyses were built on a uniform uncertainty range (± 20%) on all roads and landcover categories. This could be improved by applying parameter-specific uncertainty ranges, notably on the different road types. This could be captured by a dedicated workshop with regional experts having a thorough knowledge of the road network, providing more realistic uncertainty ranges on motorized and walking speeds, possibly complemented by field observations or facility-based surveys. Lowering uncertainties on the travel scenario, and therefore on population coverage estimates, would improve decision making for prioritized resource allocation.

Finally, we analyze the coverage to the closest designated EmONC health facilities, which includes facilities that are actually functioning (as per our definition of functioning), as well as those that are not. The quarterly monitoring of the national network of EmONC health facilities in Togo started in 2015, and was included in the health management information system in 2020. This provides up-to-date information on the functionality of EmONC health facilities. The aim is to attain a network of functioning EmONC facilities, which is essential to help decrease maternal mortality/morbidity. Applying the same modeling approach described here to only functioning EmONC facilities would provide up-to-date population coverage indicators at national and subnational level that can inform decision makers regarding the remaining gaps in order to optimize resource allocation. This will be the subject of a forthcoming publication.

CONCLUSION

The physical accessibility mapping of the national network of EmONC health facilities in Togo proved to be very useful in understanding the potential of the revised network to provide quality EmONC services to a large proportion of the population, while pointing to those areas with less accessibility. Using realistic modelling based on travel times, the accessibility analyses provided key information to the 2018 EmONC prioritization exercise, which aimed at finding a balance between designating a smaller number of facilities as EmONC to channel needed resources to these priority sites for improving quality of care, and ensuring good coverage of the population within 1 hour of travel time to the closest designated EmONC health facility.

The application of this methodology in Togo can be replicated in other countries thanks to the current online availability of key high-resolution geospatial data sets. This is of particular importance where mapping of physical accessibility is a crucial component for bettering health outcomes for women and newborns.

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AUTHOR CONTRIBUTION

Andrew Curtis: conceptualization, methodology, formal analysis, writing, editing, visualization, validation. **Jean-Pierre Monet:** methodology, writing, editing, validation. **Michel Brun**: methodology, writing, editing, validation, supervision. **Issa Abdou-Kérim Bindaoudou:** data sharing, editing, validation. **Idrissou Daoudou:** data sharing, editing, validation**. Marta Schaaf:** methodology, writing, editing, validation**. Yawo Agbigbi:** data sharing, editing, validation**. Nicolas Ray:** conceptualization, methodology, writing, editing, validation, supervision.

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COMPETING INTERESTS

None declared.

DATA AVAILABILITY STATEMENT

Data are available on reasonable request. Most data used in this study are openly accessible through the indicated data sources in the "Input geospatial data" section. Health facility names and geographic coordinates, as well as administrative boundaries are available on request to INSEED. Road data are available on request to the *Direction de la Cartographie nationale et du cadastre* of Togo. Data on barriers to movement are available on request to the *Ministère de l'agriculture, de la production animale et halieutique* of Togo.

ETHICS STATEMENT

Patient consent for publication

Not required.

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Figure legends

Figure 1 - Vector and raster data sets used. (A) Barriers to movement (rivers, waterbodies, lakes); (B) Road network; (C) Digital Elevation Model (DEM); (D) 2013 Population density raster; (E) 2018 Population density raster; (F) Landcover raster; (G) 2013 EmONC facilities; (H) 2018 EmONC facilities; (I) Administrative boundaries (prefectures, regions and Global Rural-Urban Mapping Project (GRUMP) urban extents) with region names.

Figure 2 - Maps of the travel time to the nearest EmONC facility using either the walking & motorized scenario, the motorcycle-taxi scenario and the walking-only scenario, for both time periods (2013 and 2018).

Figure 3 - Uncertainty maps of the travel times to the nearest facility for the walking & motorized scenario on the 2018 EmONC facility network using (A) Road uncertainty, (B) Landcover (off-road) uncertainty, and (C) Total uncertainty.

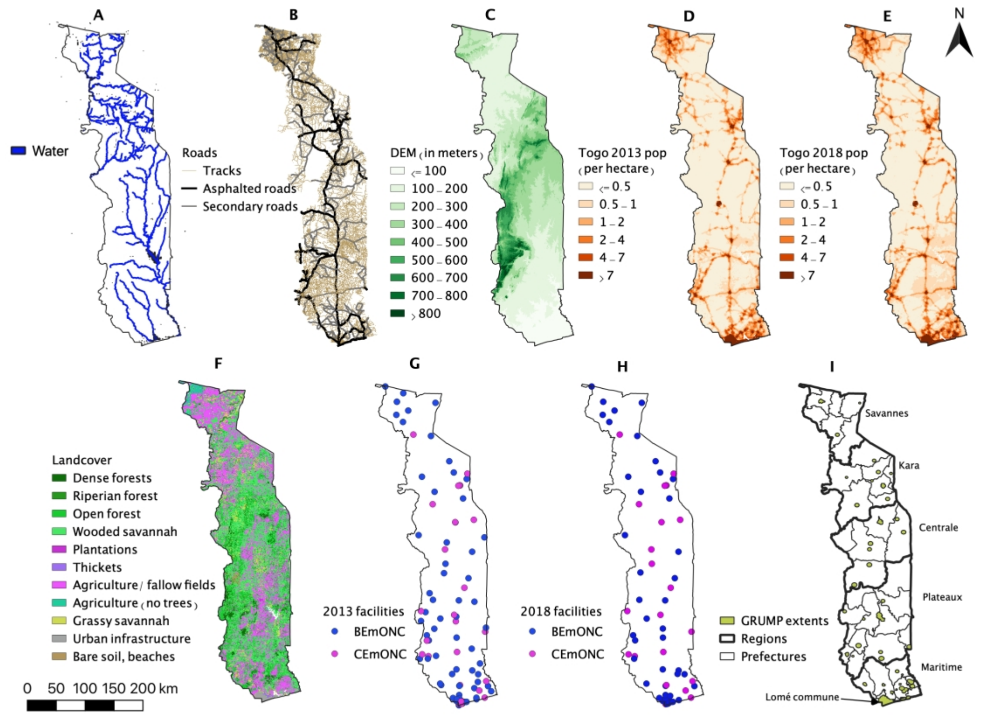

Figure 1 - Vector and raster data sets used. (A) Barriers to movement (rivers, waterbodies, lakes); (B) Road network; (C) Digital Elevation Model (DEM); (D) 2013 Population density raster; (E) 2018 Population density raster; (F) Landcover raster; (G) 2013 EmONC facilities; (H) 2018 EmONC facilities; (I) Administrative boundaries (prefectures, regions and Global Rural-Urban Mapping Project (GRUMP) urban extents) with region names.

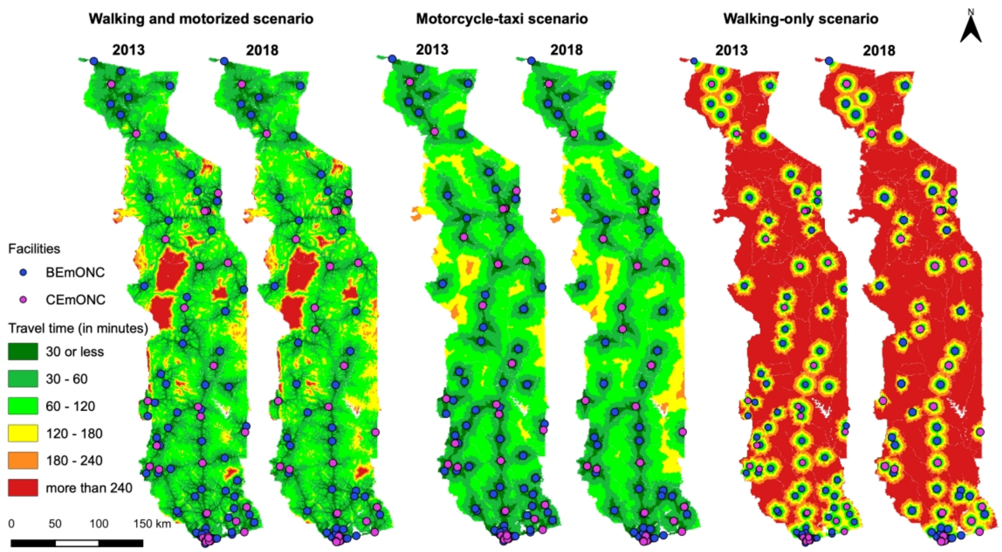

Figure 2 - Maps of the travel time to the nearest EmONC facility using either the walking & motorized scenario, the motorcycle-taxi scenario and the walking-only scenario, for both time periods (2013 and 2018).

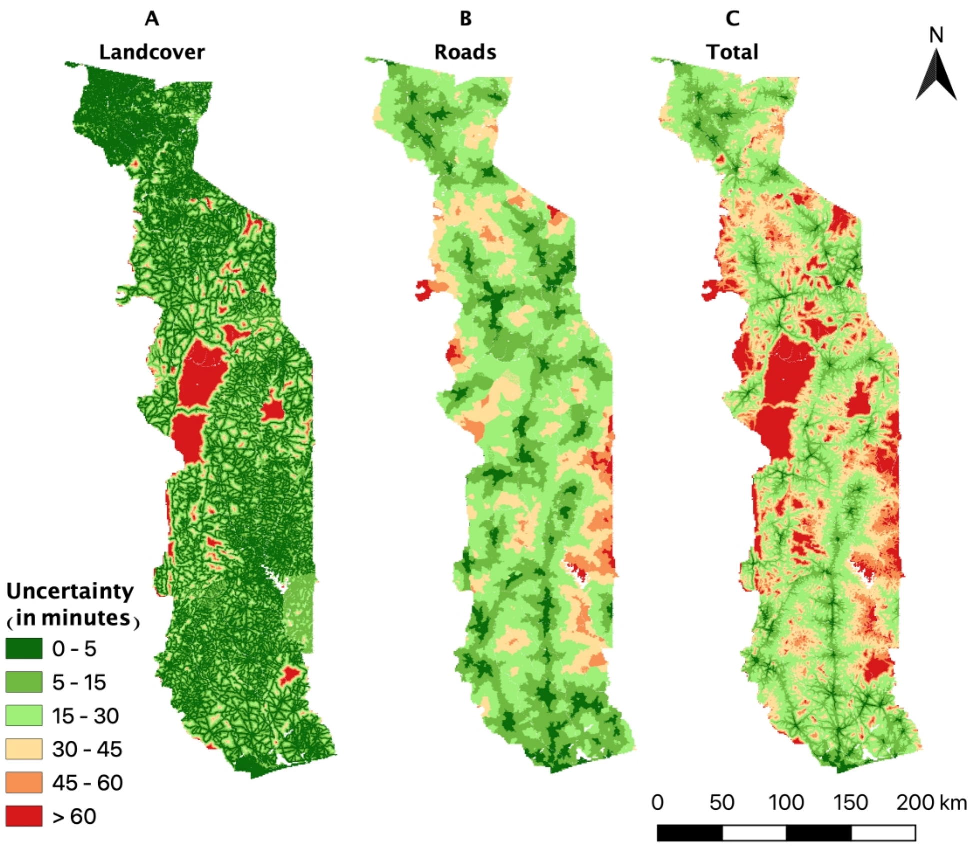

Figure 3 - Uncertainty maps of the travel times to the nearest facility for the walking & motorized scenario on the 2018 EmONC facility network using (A) Road uncertainty, (B) Landcover (off-road) uncertainty, and (C) Total uncertainty.

SUPLEMENTARY MATERIAL

Supplement 1: travel scenario tables

Walking & Motorized scenario

Class	Label	Label (English)	Speed (km/h)	Mode
11	Forets denses	Dense forest	1.5	WALKING
12	Forets riveraines	Riparian forest	1.5	WALKING
13	Forets claires, savanes boisées	Open forest, wooded savannah	1.5	WALKING
14	Savane arborée, arbustive	Sparsely wooded savannah	1.5	WALKING
16	Plantations	Plantations	3	WALKING
17	Fourrées	Thickets	3	WALKING
21	Cultures et Jachères	Cultivated and fallow lands	3	WALKING
22	Cultures sans arbres	Cultivated lands without trees	3	WALKING
32	Savanes herbeuses	Grassy savannah	3	WALKING
41	Agglomérations et infra, plantations urbaines	Agglomerations and infrastructure, urban plantations	3	WALKING
61	Sols nus, roches, carrières, plage	Open soil, rocky terrain, quarries, beach	3	WALKING
1000	Pistes rurales	Rural tracks	15	MOTORIZED
1002	Routes bitumées rurales	Primary rural asphalted roads	80	MOTORIZED
1003	Routes secondaires rurales	Secondary rural roads	40	MOTORIZED
1004	Pistes urbaines	Urban tracks	10	MOTORIZED
1005	Routes bitumées urbaines	Primary urban asphalted roads	30	MOTORIZED
1006	Routes secondaires urbaines	Secondary urban roads	20	MOTORIZED

Motorcycle-taxi scenario

class	label	Label (English)	Speed (km/h)	mode
11	Forets denses	Dense forest	8	MOTORIZED
12	Forets riveraines	Riparian forest	8	MOTORIZED
13	Forets claires, savanes boisées	Open forest, wooded savannah	8	MOTORIZED
14	Savane arborée, arbustive	Sparsely wooded savannah	8	MOTORIZED
16	Plantations	Plantations	10	MOTORIZED
17	Fourrées	Thickets	8	MOTORIZED

21	Cultures et Jachères	Cultivated and fallow lands	10	MOTORIZED
22	Cultures sans arbres	Cultivated lands without trees	10	MOTORIZED
32	Savanes herbeuses	Grassy savannah	12	MOTORIZED
41	Agglomérations et infra, plantations urbaines	Agglomerations and infrastructure, urban plantations	7	MOTORIZED
61	Sols nus, roches, carrières, plage	Open soil, rocky terrain, quarries, beach	7	MOTORIZED
1000	Pistes	Rural tracks	15	MOTORIZED
1002	Routes bitumées	Primary rural asphalted roads	40	MOTORIZED
1003	Routes secondaires	Secondary rural roads	20	MOTORIZED
1004	Pistes urbaines	Urban tracks	10	MOTORIZED
1005	Routes bitumées urbaines	Primary urban asphalted roads	30	MOTORIZED
1006	Routes secondaires urbaines	Secondary urban roads	15	MOTORIZED

Walking scenario

class	label	Label (English)	Speed (km/h)	mode
11	Forets denses	Dense forest	1.5	WALKING
12	Forets riveraines	Riparian forest	1.5	WALKING
13	Forets claires, savanes boisées	Open forest, wooded savannah	1.5	WALKING
14	Savane arborée, arbustive	Sparsely wooded savannah	1.5	WALKING
16	Plantations	Plantations	3	WALKING
17	Fourrées	Thickets	3	WALKING
21	Cultures et Jachères	Cultivated and fallow lands	3	WALKING
22	Cultures sans arbres	Cultivated lands without trees	3	WALKING
32	Savanes herbeuses	Grassy savannah	3	WALKING
41	Agglomérations et infra, plantations urbaines	Agglomerations and infrastructure, urban plantations	3	WALKING
61	Sols nus, roches, carrières, plage	Open soil, rocky terrain, quarries, beache	3	WALKING
1000	Pistes	Rural tracks	4	WALKING
1002	Routes bitumées	Primary rural asphalted roads	4	WALKING

1003	Routes secondaires	Secondary rural roads	4	WALKING
1004	Pistes urbaines	Urban tracks	4	WALKING
1005	Routes bitumées urbaines	Primary urban asphalted roads	4	WALKING
1006	Routes secondaires urbaines	Secondary urban roads	4	WALKING

Supplement 2: Preparation of input geospatial data

All following geospatial data sets were prepared using QGIS ver. 3.2.0. After finalization, each of them was changed to raster format (if needed) at 100m resolution, and projected in the WGS84 Universal Transverse Mercator (zone 31N) coordinate reference system.

Road network (vector)
We used the road network created by the *Direction de la Cartographie nationale et du cadastre* of Togo. In 2015, GIS experts from the national Togolese Institute for Statistics, Economic and Demographic studies (INSEED), in collaboration with technicians from the National Ministry of Public Works and Transportation, re-categorized this road data set into three hierarchical categories: asphalted roads, secondary roads, and tracks (see figure 1B).

Barriers to movement (vector)
Water bodies were considered as barriers to terrestrial movements, unless a road segment crosses over, which is assumed to be a bridge. Rivers were recoded into two categories by the INSEED GIS experts, distinguishing permanent and seasonal rivers. We used both categories as barriers to movement in our accessibility models, reflecting our conservative approach of considering a maximum of potential barriers.

Land cover (raster)
The land cover data set at 100m resolution was provided by INSEED. We assumed that different land cover categories can influence travel speed (e.g., travel is slower in a dense forest than in an open area), each of these land cover categories can be given a distinct travel speed in the travel scenario. The landcover category representing bodies of water was extracted from the landcover and used as an additional barrier to movement. Using the "Merge land cover" tool in AccessMod, the land cover raster was merged with the road network and the various barriers to movement, in order to obtain the final "merged land cover" on which travel models are applied. For the merging process, roads were stacked above the barriers, so that any existing road passing over a barrier was considered passable.

Population density (raster)
Population densities were derived from the Worldpop data set[1]. This data set is at 3-arc second resolution (90m at the equator) and is appropriate for our analyses as the modelling technique to obtain it uses a detailed settlement mapping and links these settlements with gazetteer population numbers, considering that the vast majority of people live within a settlement. The remaining unaccounted-for population is then distributed using a weighted landcover grid in function of the probability of being populated, and the total population estimates are adjusted to UN estimates[2]. We used the UN-adjusted 2013 and 2018 Worldpop data sets for Togo. The data set was aggregated to 100m resolution.

A final correction step consisted in correcting for the population falling in pixels that were assigned a barrier status in the merged landcover data set, because this population is not considered by the accessibility analysis and is left unaccounted for. To correct for that, we extracted the population in each barrier pixel and dispatched it uniformly within the surface of the prefecture area the pixel belongs to. This way the population in each prefecture was correctly represented, even if a large number of barrier pixels are found. This step was done in AccessMod using the « Adjust population distribution" module.

Supplement 3: Table of percentage of population living within 2-hour travel time to the nearest EmONC facility, per prefecture, with uncertainty intervals within brackets, and for the walking & motorized and the motorcycle-taxi scenarios

	Walking & Motorized Scenario		Motorized only Scenario		Walking only Scenario	
Prefectures	*1-hour*	*2-hour*	*1-hour*	*2-hour*	*1-hour*	*2-hour*
Agoenyive	100 [99.6 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	68.4 [53.2 - 80.3]	99.6 [95.5 - 99.9]
Agou	73.4 [59.9 - 83.5]	99.7 [96.3 - 99.9]	69.3 [57.8 - 78.7]	99.9 [94.4 - 100]	13.0 [9.9 - 15.9]	27.9 [21.9 - 34.1]
Akebou	46.7 [31.7 - 61.5]	93.4 [84.3 - 96.3]	42.9 [23.7 - 55.9]	92.3 [75.3 - 100]	0.9 [0.6 - 1.4]	4.8 [2.7 - 6.9]
Amou	67.3 [55.3 - 76.3]	92.2 [86.5 - 95.4]	74.4 [64.9 - 83.5]	99.3 [94.4 - 100]	8.8 [6 - 12.2]	26.9 [19.6 - 34.4]
Anie	41.5 [35.5 - 48.0]	74.0 [61.2 - 88.3]	41.6 [37.2 - 44.7]	61.6 [52.3 - 71.3]	15.4 [11.8 - 18.6]	27.8 [23.9 - 31.5]
Assoli	56.5 [41.2 - 67.3]	90.5 [82.2 - 94.7]	77.7 [65.1 - 85.3]	99.6 [95.5 - 100]	9.8 [6.6 - 13.2]	25.5 [19.8 - 31.2]
Ave	76.3 [66.8 - 82.5]	94.8 [89.9 - 97.3]	85.2 [75.6 - 93.3]	100 [99.9 - 100]	17.5 [12.8 - 21.6]	37.8 [29.4 - 45.4]
Bas-Mono	88.3 [82.2 - 92.0]	98.6 [96.4 - 99.4]	98.9 [94.9 - 99.6]	99.6 [99.6 - 99.6]	45.3 [33.9 - 54.2]	78.8 [68.0 - 86.3]
Bassar	57.5 [46.9 - 67.1]	87.2 [80.4 - 90.8]	64.5 [54.2 - 71.7]	92.8 [84.4 - 97.0]	12.5 [9.0 - 15.8]	24.3 [20.1 - 28.9]
Binah	85.9 [77.3 - 91.6]	97.9 [96.6 - 98.6]	85.4 [77.7 - 90.5]	100 [97.3 - 100]	28 [20.6 - 36.6]	61.1 [53.2 - 66.8]
Blitta	81.4 [72.7 - 87.5]	97.1 [94.4 - 98.2]	84.3 [78.8 - 89.8]	98.3 [95.0 - 99.9]	31.7 [21.6 - 41.8]	64.1 [57.2 - 66.3]
Cinkasse	99.3 [93.5 - 99.6]	99.9 [99.9 - 99.9]	94.5 [67.9 - 100]	100 [100 - 100]	10.7 [9.1 - 12.2]	18.1 [15.2 - 21.6]
Dankpen	48.3 [37.2 - 57.4]	83.3 [71.7 - 90.5]	42.2 [32.7 - 52.0]	83.3 [69.1 - 93.4]	9.8 [7.6 - 11.5]	16.8 [14.2 - 19.8]
Danyi	76.8 [64.9 - 85.9]	98.1 [94.8 - 99.2]	92.5 [81.1 - 97.2]	100 [100 - 100]	8.8 [6.6 - 11.3]	23.5 [16.9 - 32.0]
Doufelgou	53.3 [44.3 - 61.8]	88.0 [77.7 - 93.0]	62.4 [51.1 - 71.3]	95.6 [84.4 - 99.8]	12.2 [8.6 - 15.3]	28.6 [21.8 - 35.4]
Est-Mono	37.3 [26.9 - 45.4]	75.0 [62.8 - 86.6]	38.9 [28.0 - 46.8]	78.5 [61.6 - 94.1]	5.1 [3.7 - 6.3]	12.2 [8.9 - 16.2]
Golfe	100 [99.5 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	67.1 [52.5 - 80]	99.9 [97.1 - 100]
Haho	50.0 [38.0 - 61.4]	89.7 [78.8 - 94.9]	49.7 [41.0 - 58.4]	85.1 [74.0 - 94.0]	11.4 [8.8 - 13.3]	20.4 [16.9 - 24.3]
Keran	42.0 [29.5 - 54.9]	87.8 [74.9 - 93.3]	34.4 [26.3 - 42.7]	86.0 [64.7 - 97.7]	4.3 [3.0 - 5.7]	12.6 [9.3 - 15.3]
Kloto	85.5 [76.7 - 91.9]	99.4 [98.0 - 99.7]	97.2 [90.5 - 99.8]	100 [100 - 100]	22.7 [18.3 - 27]	40.7 [34.7 - 45.6]
Kozah	85.2 [76.6 - 90.3]	97.1 [95.1 - 98.1]	92.9 [87.6 - 95.9]	100 [99.8 - 100]	22.1 [17.6 - 26.3]	42.3 [33.8 - 50.8]
Kpele	71.8 [62.3 - 80.1]	98.2 [91.3 - 99.7]	78.4 [71.8 - 84.3]	99.6 [94.2 - 100]	16.8 [12.2 - 20.2]	29.6 [25.3 - 34.3]
Kpendjal	64.2 [47.9 - 76.5]	98.7 [92.9 - 99.8]	59.7 [38.6 - 74.8]	99.5 [92.8 - 100]	3.7 [2.7 - 4.7]	10.3 [7.0 - 13.6]
Lacs	94.9 [91.1 - 97.1]	99.7 [99.0 - 100]	95.4 [91.5 - 97.8]	100 [99.9 - 100]	22.2 [15.9 - 28.8]	51.8 [40.1 - 64.2]
Lomé Commune	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [100 - 100]	100 [93.9 - 100]	100 [100 - 100]
Moyen-Mono	39.6 [25.9 - 50.9]	94.0 [79.8 - 98.2]	42.6 [34.4 - 50.6]	90.7 [66.3 - 99.3]	3.4 [2.2 - 4.5]	12.6 [7.8 - 19.2]
Naki-Ouest	77.5 [60.5 - 89.8]	99.7 [98.5 - 100]	64.3 [49.3 - 77.9]	100 [97.8 - 100]	11.4 [8 - 15.2]	26.3 [21.6 - 30.8]
Ogou	54.9 [44.2 - 66.3]	95.9 [85.7 - 99.2]	54.9 [46.7 - 62.9]	93.2 [79.1 - 99.9]	10.1 [7.4 - 13]	26.0 [19.5 - 30.9]
Oti	79.3 [68.4 - 86.2]	97.7 [93.5 - 98.8]	78.4 [67.6 - 86.4]	98.0 [96.1 - 99.4]	20.6 [15.5 - 24.7]	37.1 [30.7 - 44.7]
Oti-Sud	47.8 [33.5 - 58.5]	95.3 [83.1 - 98.6]	36.7 [23.6 - 49.8]	87.4 [69.7 - 99.4]	5.5 [3.7 - 6.7]	11.5 [8.9 - 13.6]
Plaine de Mo	33.8 [21.1 - 45.9]	72.8 [62.8 - 78.8]	37.3 [24.0 - 52.7]	87.3 [75.7 - 94.1]	1.7 [1.1 - 2.5]	7.3 [4.5 - 11.2]
Sotouboua	42.4 [31.5 - 52.7]	75.2 [67.8 - 77.9]	49.9 [40.1 - 57.8]	82.2 [70.4 - 89.6]	3.9 [2.9 - 4.9]	9.0 [6.9 - 11.6]
Tandjoare	85.6 [76.7 - 91.2]	99.8 [98.3 - 100]	76.2 [65.5 - 84.7]	98.6 [92.9 - 100]	8.8 [6.3 - 11.7]	27.5 [18.9 - 37.0]
Tchamba	54.9 [37.3 - 67.9]	90.2 [83.7 - 93.4]	45.9 [33.4 - 60.9]	96.5 [88.8 - 99.2]	8.2 [6.4 - 9.9]	15.7 [12.9 - 18.3]
Tchaoudjo	65.0 [53.3 - 74.8]	93.4 [88.0 - 95.7]	71.8 [57.6 - 80.1]	98.5 [92.4 - 99.5]	16.7 [11.7 - 21.2]	30.4 [26.5 - 34.8]
Tone	91.8 [80.5 - 97.4]	100 [99.9 - 100]	82.4 [71.9 - 89.2]	99.9 [98.5 - 100]	13.9 [10.1 - 17.3]	28.1 [22.7 - 34.6]

Vo	85.6 [70.3 - 93.2]	99.4 [98.3 - 99.8]	95.5 [83.9 - 99.5]	100 [100 - 100]	10.9 [7.0 - 15.4]	31.6 [23.3 - 43.4]
Wawa	51.6 [36.0 - 65.0]	93.0 [83.2 - 96.8]	67.7 [45.3 - 82.3]	100 [97.5 - 100]	2.7 [2.1 - 3.4]	6.5 [4.8 - 8.6]
Yoto	82.2 [71.7 - 88.2]	95.9 [93.3 - 97.5]	87.0 [78.9 - 92]	98.9 [97.2 - 99.6]	24.3 [18.0 - 29.0]	46.1 [37.8 - 55.4]
Zio	87.9 [77.4 - 93.9]	99.7 [98.5 - 99.9]	93.1 [85.3 - 96.4]	100 [99.5 - 100]	16.4 [11.9 - 21.2]	39.5 [29.4 - 49.7]
Country	78.3 [70.5 - 84.0]	95.5 [91.6 - 97.5]	79.2 [72.2 - 84.3]	96.0 [91.6 - 98.4]	33.4 [27.1 - 38.4]	50.8 [46.0 - 55.0]

Supplement 4: Effects of considering slopes to correct for walking speeds

When walking is used in a travel scenario, AccessMod computes the slope between adjacent raster cells using the Digital Elevation Model. Walking speeds are then corrected using the slope value, following the Tobler (1993) formula[3]:

$$V = V_F * e^{-3.5*|S+0.05|},$$

where V is the corrected walking speed in kilometers per hour (Km/h), V_F is the walking speed on a flat surface (given by the user-defined travel scenario), and S is the slope in hundredth of percent.

These corrections applied when walking off-road in the "Walking & Motorized scenario", and everywhere in the "Walking scenario". In the table below, each cell is composed of two results. The first figure takes slope correction into consideration, while the second figure does not take into account the slope correction.

	Walking & Motorized Scenario				Walking Scenario			
	2013		2018		2013		2018	
Regions	*1-hour*	*2-hour*	*1-hour*	*2-hour*	*1-hour*	*2-hour*	*1-hour*	*2-hour*
Plateaux	66.2/67.7	95.1/95.6	55.4/56.6	89.8/90.3	15.5/16.2	30.2/31.4	10.9/11.4	22.6/23.5
Kara	63.3/64.3	90.4/90.9	62.7/63.6	90.2/90.7	14.5/15.0	29.7/30.2	14.5/14.9	29.3/29.8
Maritime	94.7/94.8	99.5/99.5	94.4/94.5	99.4/99.4	47.9/48.2	74.8/75.1	47.7/48.0	76.4/76.5
Centrale	70.2/70.6	92.3/92.6	65.2/65.6	91.7/91.9	22.0/22.3	41.3/41.5	18.1/18.5	35.7/35.9
Savanes	81.7/81.9	98.9/99.0	80.7/80.9	98.9/99.0	12.1/12.4	26.5/27.2	11.4/11.6	24.2/24.9
Lomé Commune	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
Country	81.0/81.5	96.7/98.0	78.3/78.8	95.5/95.7	34.7/35.1	52.3/52.8	33.4/33.7	50.8/51.2

Supplementary References

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