Geographical accessibility to functional emergency obstetric care facilities in urban Nigeria using closer-to-reality travel time estimates: a population-based spatial analysis

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Summary

Background Better accessibility for emergency obstetric care facilities can substantially reduce maternal and perinatal deaths. However, pregnant women and girls living in urban settings face additional complex challenges travelling to facilities. We aimed to assess the geographical accessibility of the three nearest functional public and private comprehensive emergency obstetric care facilities in the 15 largest Nigerian cities via a novel approach that uses closer-to-reality travel time estimates than traditional model-based approaches.

Methods In this population-based spatial analysis, we mapped city boundaries, verified and geocoded functional comprehensive emergency obstetric care facilities, and mapped the population distribution for girls and women aged 15–49 years (ie, of childbearing age). We used the Google Maps Platform's internal Directions Application Programming Interface to derive driving times to public and private facilities. Median travel time and the percentage of women aged 15–49 years able to reach care were summarised for eight traffic scenarios (peak and non-peak hours on weekdays and weekends) by city and within city under different travel time thresholds (≤15 min, ≤30 min, ≤60 min).

Findings As of 2022, there were 11·5 million girls and women aged 15–49 years living in the 15 studied cities, and we identified the location and functionality of 2020 comprehensive emergency obstetric care facilities. City-level median travel time to the nearest comprehensive emergency obstetric care facility ranged from 18 min in Maiduguri to 46 min in Kaduna. Median travel time varied by location within a city. The between-ward IQR of median travel time to the nearest public comprehensive emergency obstetric care varied from the narrowest in Maiduguri (10 min) to the widest in Benin City (41 min). Informal settlements and peripheral areas tended to be worse off compared to the inner city. The percentages of girls and women aged 15–49 years within 60 min of their nearest public comprehensive emergency obstetric care ranged from 83% in Aba to 100% in Maiduguri, while the percentage within 30 min ranged from 33% in Aba to over 95% in Ilorin and Maiduguri. During peak traffic times, the median number of public comprehensive emergency obstetric care facilities reachable by women aged 15–49 years under 30 min was zero in eight (53%) of 15 cities.

Interpretation Better access to comprehensive emergency obstetric care is needed in Nigerian cities and solutions need to be tailored to context. The innovative approach used in this study provides more context-specific, finer, and policy-relevant evidence to support targeted efforts aimed at improving comprehensive emergency obstetric care geographical accessibility in urban Africa.

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Introduction

Despite a 43% reduction in global maternal mortality since 2000, around 287 000 maternal deaths occurred in 2020 and about 70% of them were in Africa.[1] Similarly, 44% of the estimated 2 million stillbirths worldwide in 2019 occurred in Africa.[2] Of these global figures, Nigeria has the highest number of maternal deaths (82 000 [29%]) and the third highest number of stillbirths (171 428 [9%]).[1,2] Evidence shows that half of maternal deaths and three-quarters of intrapartum stillbirths are preventable with timely access to high-quality emergency obstetric care, meaning that delays increase the risk for poor pregnancy outcomes.[3]

Current guidelines from WHO recommend that comprehensive emergency obstetric care, including caesarean section and blood transfusion, be available within 2–3 h travel time.[4] Pregnant women in urban areas of Africa typically live closer to comprehensive emergency obstetric care facilities compared with their rural counterparts.[5] However, this so-called urban advantage is less apparent in some urban areas as travel can be long due to poor road infrastructure, haphazardly built

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Research in context

Evidence before this study

We systematically searched PubMed and Scopus on Sept 16, 2023, without language and date restrictions, for previously published articles that reported geographical accessibility to emergency obstetric care using the search string (“emergency obstetric care” OR “EmOC” OR “EmONC”) AND (“distance” OR “travel time” OR “access*” OR “geography*”). We also reviewed references from retrieved articles to identify any additional studies. We found 12 studies that used models to assess geographical accessibility to emergency obstetric care in Africa. All but one of the 12 studies only estimated travel to the nearest health facility in the public sector with no verification of facility functionality, despite established evidence that pregnant women might bypass the nearest health facility even in an emergency, particularly due to issues of trust in quality of care. In addition, all studies were conducted in rural areas or across an entire country without urban-specific estimates. However, concerns have been raised by experts that modelled approaches do not reflect the reality of travel that many pregnant women living in urban African settings undergo in accessing care. Evidence from a 2021 study that compared estimates from models (cost-friction surface approach and Open Source Routing Machine) and the navigation application, Google Maps, with actual replicated journeys that women would have taken to reach comprehensive emergency obstetric care showed that Google Maps offers closer-to-reality travel time estimates. In a separate study, when applied retrospectively to map journeys pregnant women took to care in Africa’s largest megacity, Lagos, Nigeria, the method led to highly policy-relevant insights. However, analysis prospectively accounting for choice of different facilities and variable travel conditions at different times of the day and days of the week had yet to be conducted.

Added value of this study

To the best of our knowledge, this study is the first to apply Google Maps at scale using close-to-reality travel time estimates to assess geographical accessibility to comprehensive emergency obstetric care. We assessed travel times to these facilities in the 15 most populated cities in Nigeria. We integrated the element of choice by incorporating hospitals from both public and private sectors, validated their functionality, and assessed driving time to the three nearest hospitals that provide comprehensive obstetric care. Estimates also accounted for the day of the week and time of day. We found that, even under peak travel conditions, the majority of pregnant women in all cities were within 45 min of the nearest public sector hospital. Geographical coverage was generally poorest during weekdays, between 1800 h and 2000 h, and best during the weekend, between 0100 h and 0300 h. This level of precision adds to existing evidence that highlights where inequities exist, to establishing when they are worse. In several cities women cannot reach more than one hospital within 1 h, especially if affordability limits them to the public sector. Within cities, geographical inequity of accessibility to care existed to various extents, with women in informal settlements and peripheral suburbs particularly affected. Such a granular report on geographical accessibility to emergency obstetric care has only been possible because of our innovative approach of using closer-to-reality travel time estimates combined with verification of functionality status of health facilities.

Implications of all the available evidence

Travel time to reach obstetric care has important mortality and morbidity implications for pregnant women and girls and their babies. Navigation applications like Google Maps, which we have used in our study, have the capacity to capture relevant and context-specific data on travel time, which will be crucial for service planning. The granularity of the approach used in this study opens new opportunities in the field of within-city accessibility to health care that extends beyond emergency obstetric care. In addition, there is now a chance to layer other datasets that allow more detailed and realistic characterisation of the populations in greatest need. There is a clear need to ensure that estimates are disaggregated by time of the day, day of the week, and choice of health facilities to ensure more policy-relevant evidence and action to bridge accessibility gaps. Potential associations between travel time to health facilities and care outcomes can now be studied, especially within the context of urbanisation. These new capabilities constitute a step change compared with widely used methods and will be crucial towards universal health coverage. Future research needs to explore possible integration of other dimensions of accessibility including cost, quality of care, and availability of structures that aid access to fully maximise the potential of this approach.

environments, traffic congestion, and expanding informal settlements.[6,7] By 2050, 70% of the global population will be urban dwellers, and 40% of the projected additional 2·5 billion urban dwellers will be concentrated in Africa.[8]

To date, most explorations of geographical access to emergency obstetric care have been based on modelled travel time using the cost-friction approach and open-source route mapping.[9,10] However, such models insufficiently reflect the lived experience of travel to care in urban settings.[7,11] Ignoring the variability in traffic conditions results in as much as a three-time overestimation of geographical coverage of services compared with reality.[12] Furthermore, almost all geographical accessibility studies using modelled approaches estimate travel time to the nearest health facility,[10] despite established evidence that pregnant women in urban settings bypass the nearest health facility even in emergencies.[13,14]

A comparative analysis of access to emergency obstetric care in Lagos, Nigeria—Africa’s largest megacity—found that navigation applications such as Google Maps provide closer-to-reality travel time estimates to health facilities in urban areas compared with modelled approaches,[7] because they use more realistic road and traffic conditions (appendix 1 pp 1–2). Evidence generated from such analysis[15] can inform priorities for health service planning.

Nigeria consists of 36 states and a Federal Capital Territory. The states are divided into 774 local government areas, which are further divided into 8813 wards—the lowest administration level. Of the country's population of 220 million, 53% live in urban areas, with a projected increment to 70% expected by 2050.[8] Evidence shows significantly higher odds of maternal deaths and stillbirths in urban areas compared with rural ones, especially in the south of the country.[16–18] The objective of this study was to assess the geographical accessibility of comprehensive emergency obstetric care using data from a database of geocoded functional health facilities in the 15 most populated cities in Nigeria and driving time estimates to the three nearest facilities for eight travel time scenarios spanning peak and non-peak hours, including weekends and weekdays.

Methods

Study design

This population-based spatial analysis was conducted in Nigerian cities with an estimated (2022) or projected (2030) population of at least 1 million: Aba, Abuja, Benin City, Ibadan, Ilorin, Jos, Kaduna, Kano, Lagos, Maiduguri, Onitsha, Owerri, Port-Harcourt, Uyo, and Warri. These 15 cities accounted for 26% of the population in Nigeria in 2022 (appendix 1 p 3).

This study involved assembly of data to define extended city boundaries; to verify comprehensive emergency obstetric care facility functionality, and geographical location; and to map the population distribution of girls and women aged 15–49 years (ie, of childbearing age; herein referred to as women for brevity) to estimate travel time to care. Details of the methods used to collect and collate data for the study and estimate travel time have been published elsewhere (appendix 1 pp 1–2).[19] Ethical approval was obtained from the National Health Research and Ethics Committee in Nigeria (NHREC/01/01/2007-11/04/2022) and University of Greenwich Research and Ethics Committee in the UK (UREC/21.4.7.8).

Data assembly

Because actual boundaries of the included cities were not available, we delineated extended city boundaries (including suburbs) of each city by its constituent local government areas by spatially overlaying the vector file of the local government area boundaries,[20] WorldPop's gridded surface of population at 100 m² resolution (the constrained 2020, UN adjusted version),[21] Google Maps, which was accessed as a basemap through ArcMap 10.5, and Global Human Settlement (GHS) layers of gridded surfaces (version GHS-SMOD R2023A).[22] For each city, all local government areas with parts of higher population density than the surroundings within the area or marked as urban, suburban, or peri-urban in the GHS layer were selected for analysis.[23] PMM led the city border delineation process supported by coauthors familiar with the context (AB-T, TO, OO, UG-A, and BBA).

See Online for appendix 1

A list of hospitals in the 15 selected cities and information on facility name, ownership, location (local government area and GPS coordinates), and operational status (open or closed) was extracted from the 2018 Nigeria Health Facility Registry.[24] These data were complemented by state-specific lists in Lagos state and from stakeholders familiar with health service provision in other states. Data on emergency obstetric care service availability were obtained through a facility functionality assessment survey to identify facilities open 24 h a day and able to conduct caesarean sections (used as a proxy for comprehensive emergency obstetric care). Facility ownership was also confirmed (ie, public [federal or state] or private [for-profit, not-for-profit, faith-based, military, or police-owned facilities]). The survey was led by AB-T, TO, OO, UG-A, and BBA and involved in-person facility visits conducted by research assistants using a short questionnaire between March 1 and Aug 31, 2022.

The population distribution of women aged 15–49 years was obtained at 1 km² spatial resolution from the WorldPop open spatial demographic data portal.[25] WorldPop uses dasymetric techniques to create a constrained gridded surface by disaggregating 2006 census data from local government areas based on weights derived from covariates such as land use, land cover, and night-time lights.[22] National estimates were projected to match UN Population Division 2022 estimates while adjusting for rural–urban differences. Data for age and sex multipliers were derived from census and household data and were applied to the projected national estimates to derive the proportion of women aged 15–49 years nationally. Geospatial layers of various resolutions were resampled to 0·36 km² to match the resolution used for travel time.[26]

Outcomes

The study outcome was comprehensive emergency obstetric care geographical coverage, which was assessed using three indicators: (1) the median travel time to comprehensive emergency obstetric care facilities, (2) the percentage of women aged 15–49 years who live within three time thresholds (≤15 min, ≤30 min, and ≤60 min) of a comprehensive emergency obstetric care facility, and (3) the number of unique comprehensive emergency obstetric care facilities reachable within the same three time-thresholds under eight traffic scenarios.

Statistical analysis

To obtain travel time to the identified comprehensive emergency obstetric care facilities, we considered the entire study region as being made up of level 14 S2 cells.

The S2 cell optimises the splitting of a spherical surface into grid cells of approximately equal size. Specifically, level 14 S2 cells are approximately 600 m by 600 m.[26] This resolution was selected to balance between accuracy and computational feasibility needed for analysis. For each cell, travel time by driving was extracted from the Google Maps Platform's internal Directions Application Programming Interface (API), which offers closer-to-reality travel time estimates compared with other approaches, such as the cost-friction surface approach and Open Source Routing Machine.[7] This ability to generate closer-to-reality travel time estimates is possible because of the API's use of road network data; crowdsourced data on road conditions; and current and historic road traffic patterns both in terms of speed and human routing preference, within a machine learning environment, to estimate travel time compared with the assumed or user-defined speeds used by alternative approaches (appendix 1 pp 1–2).[7,27] For this study, estimated travel times by driving were from each cell centre, which represented the potential location of women (ie, the origin of their journey to care) to the three nearest comprehensive emergency obstetric care facilities, by facility ownership (ie, public, private, and both). For each ownership, travel time was derived during eight traffic scenarios covering weekdays and weekends and a range of daily time periods spanning peak (0600 h to 0800 h and 1800 h to 2000 h) and non-peak traffic (0100 h to 0300 h and 1300 h to 1500 h).[19] The extraction of travel time from the API was done in January, 2023. To validate the travel time estimates, journeys to care in each city were randomly selected and API-generated travel time for those journeys were compared with estimates from the typical travel time function on the front end of Google Maps.[19]

For each city, we estimated the three indicators of geographical coverage of median travel time, percentage of women aged 15–49 years who lived under three different time-thresholds, and number of unique facilities reachable within these three different time-thresholds, using travel time to the three nearest comprehensive emergency obstetric care facilities from the centre of each S2 cell, at the level of the city and ward. Ward-level median travel time (IQR) is reported for assessment of within-city heterogeneity. Where possible, findings were further contextualised against established lists of informal settlements in the country.

In this paper, we present results for the cities of Maiduguri and Kaduna, which had the median travel time extremes (lowest and highest) and summary plots for all cities.

Analysis and visualisation as static maps were done with R (version 4.2.0) and ArcMap (version 10.8.1). Data used are publicly available and described in detail elsewhere.[19]

Role of the funding source

The funder of the study had no role in study design, data analysis, or data interpretation, but technical members of the funder's organisation contributed to data collection of travel time estimates and contributed to the writing of the report.

Results

The 15 cities consist of 104 774 local government areas with a range of two in Maiduguri to 20 in Lagos. Across the included cities there were 1440 wards. In 2022, the estimated population of each city ranged from 1·1 million in Maiduguri to 20·6 million in Lagos, and the total number of women aged 15–49 years living in these cities was 11·5 million (appendix 1 pp 3–4). The functionality and location of 2020 comprehensive emergency obstetric care facilities was identified, ranging from 26 in Maiduguri to 796 in Lagos, with a median of 76 per city. Of all facilities, 1778 (88%) identified facilities were private for-profit, 121 (6%) were operated by the state or federal government, and 121 (6%) were private not-for-profit. The total number of functional comprehensive emergency obstetric care facilities per 100 000 women aged 15–49 years ranged from 6·5 in Abuja to 33·3 in Owerri (appendix 1 p 4).

Results on travel time, the percentage of studied women with comprehensive emergency obstetric care coverage, and the number of comprehensive emergency obstetric care facilities within reach under different time thresholds are available for each city in appendix 1 (pp 5–14). Overall, the city-level median travel time to the nearest comprehensive emergency obstetric care facility during all eight travel scenarios was between 13 min and 18 min in Maiduguri (the city with the lowest median travel time) and 42 min and 46 min in Kaduna (the city with the highest median travel time; table and figure 1).

Median travel time to the nearest (public or private) comprehensive emergency obstetric care facility showed more similarity across many of the 15 cities (range 8–30 min). Median travel time to the nearest (18 min), second nearest (22 min), and third nearest (25 min) public facility were similar in Maiduguri, but the increases in travel time to reach the next nearest public comprehensive emergency obstetric care facility were more substantial in other cities, including Onitsha, Aba, and Owerri, due mostly to the time to reach the third nearest facility (figure 1A; appendix 1 pp 15–17). Accounting for both public and private facilities, changes in median travel time to the nearest, second nearest, and third nearest facilities did not vary substantially across cities.

Also, at the city level, the percentage of women aged 15–49 years within 15 min of any comprehensive emergency obstetric care facility ranged from 55% in Abuja to 95% in Lagos, and, of comprehensive public facilities, from 8% in Aba to 89% in Maiduguri (figure 1). This coverage increased under the 30-min travel time threshold but remained low in some cities (eg, 33% in Aba for public facilities). The coverage of public comprehensive emergency obstetric care facilities with 60 min travel time ranged from 85% to over 90% in 13 cities.

	Public								Public or private							
	Weekday 0600 h to 0800 h	Weekday 1300 h to 1500 h	Weekday 1800 h to 2000 h	Weekday 0100 h to 0300 h	Weekend 0600 h to 0800 h	Weekend 1300 h to 1500 h	Weekend 1800 h to 2000 h	Weekend 0100 h to 0300 h	Weekday 0600 h to 0800 h	Weekday 1300 h to 1500 h	Weekday 1800 h to 2000 h	Weekday 0100 h to 0300 h	Weekend 0600 h to 0800 h	Weekend 1300 h to 1500 h	Weekend 1800 h to 2000 h	Weekend 0100 h to 0300 h
Maiduguri																
Median travel time to a comprehensive emergency obstetric care facility (min)																
Nearest	18 (11–30)	18 (12–30)	18 (12–30)	18 (12–30)	18 (11–30)	18 (12–30)	18 (12–30)	18 (11–30)	13 (8–26)	13 (8–26)	13 (8–26)	13 (8–26)	13 (8–26)	13 (8–26)	13 (8–26)	13 (8–26)
Second nearest	22 (16–33)	22 (17–34)	22 (17–34)	22 (16–33)	21 (16–33)	22 (17–34)	22 (17–34)	22 (16–33)	16 (11–28)	16 (11–28)	16 (11–28)	16 (11–28)	16 (11–28)	16 (11–28)	16 (11–28)	16 (11–28)
Third nearest	24 (18–36)	25 (20–37)	25 (19–37)	24 (18–36)	23 (18–36)	24 (19–37)	24 (19–37)	24 (18–36)	18 (13–30)	18 (13–30)	18 (13–30)	18 (13–29)	17 (12–29)	18 (13–30)	18 (13–30)	17 (13–29)
Percentage of women aged 15–49 years within reach of a comprehensive emergency obstetric care facility																
Within 15 min	236 509 (89%)	236 509 (89%)	236 509 (89%)	236 509 (89%)	239 166 (90%)	236 509 (89%)	236 509 (89%)	236 509 (89%)	249 796 (94%)	249 796 (94%)	249 796 (94%)	249 796 (94%)	249 796 (94%)	249 796 (94%)	249 796 (94%)	249 796 (94%)
Within 30 min	257 768 (97%)	257 768 (97%)	257 768 (97%)	257 768 (97%)	257 768 (97%)	257 768 (97%)	257 768 (97%)	257 768 (97%)	260 425 (98%)	260 425 (98%)	260 425 (98%)	260 425 (98%)	260 425 (98%)	260 425 (98%)	260 425 (98%)	260 425 (98%)
Within 60 min	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)	265 740 (100%)
Number of comprehensive emergency obstetric care facilities within reach																
Within 15 min	1	0	0	1	1	0	0	1	5	4	5	5	5	5	5	5
Within 30 min	3	3	3	3	3	3	3	3	17	16	16	17	17	16	16	17
Within 60 min	4	4	4	4	4	4	4	4	25	25	25	25	25	25	25	25
Kaduna																
Median travel time to a comprehensive emergency obstetric care facility (min)																
Nearest	42 (29–59)	45 (31–63)	46 (32–65)	42 (29–59)	40 (28–58)	44 (31–62)	46 (32–65)	42 (29–59)	30 (20–49)	30 (20–50)	30 (20–51)	29 (19–49)	29 (19–48)	30 (20–50)	30 (20–51)	29 (19–49)
Second nearest	46 (35–63)	50 (37–68)	51 (38–70)	46 (34–63)	44 (33–61)	49 (37–67)	50 (38–69)	46 (34–63)	38 (27–56)	39 (28–58)	40 (29–59)	38 (27–56)	38 (27–55)	39 (28–58)	40 (29–59)	38 (27–56)
Third nearest	52 (40–70)	56 (43–74)	57 (44–77)	52 (40–70)	50 (39–68)	55 (43–73)	57 (44–76)	52 (40–70)	52 (30–58)	56 (32–61)	57 (33–64)	52 (30–58)	50 (29–57)	55 (31–61)	57 (32–63)	52 (30–58)
Percentage of women aged 15–49 years within reach of a comprehensive emergency obstetric care facility																
Within 15 min	328 387 (64%)	292 470 (57%)	292 470 (57%)	323 256 (63%)	343 780 (67%)	302 732 (59%)	297 601 (58%)	328 387 (64%)	395 091 (77%)	389 960 (76%)	384 829 (75%)	395 091 (77%)	400 222 (78%)	384 829 (75%)	384 829 (75%)	395 091 (77%)
Within 30 min	451 532 (88%)	446 401 (87%)	446 401 (87%)	451 532 (88%)	456 663 (89%)	446 401 (87%)	446 401 (87%)	451 532 (88%)	472 057 (92%)	472 057 (92%)	472 057 (92%)	472 057 (92%)	472 057 (92%)	472 057 (92%)	472 057 (92%)	472 057 (92%)
Within 60 min	487 450 (95%)	487 450 (95%)	482 319 (94%)	487 450 (95%)	487 450 (95%)	487 450 (95%)	482 319 (94%)	487 450 (95%)	497 712 (97%)	497 712 (97%)	497 712 (97%)	497 712 (97%)	497 712 (97%)	497 712 (97%)	497 712 (97%)	497 712 (97%)
Number of comprehensive emergency obstetric care facilities within reach																
Within 15 min	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Within 30 min	0	0	0	0	0	0	0	0	8	6	6	8	9	6	6	8
Within 60 min	2	2	2	2	2	2	2	2	30	26	25	30	31	27	26	30

There were 265 740 women aged 15–49 years in Maiduguri in 2022 and 513 105 in Kaduna.

***Table:* Median travel time, percentage of women aged 15–49 years, and number of facilities within reach under different time thresholds in Maiduguri and Kaduna**

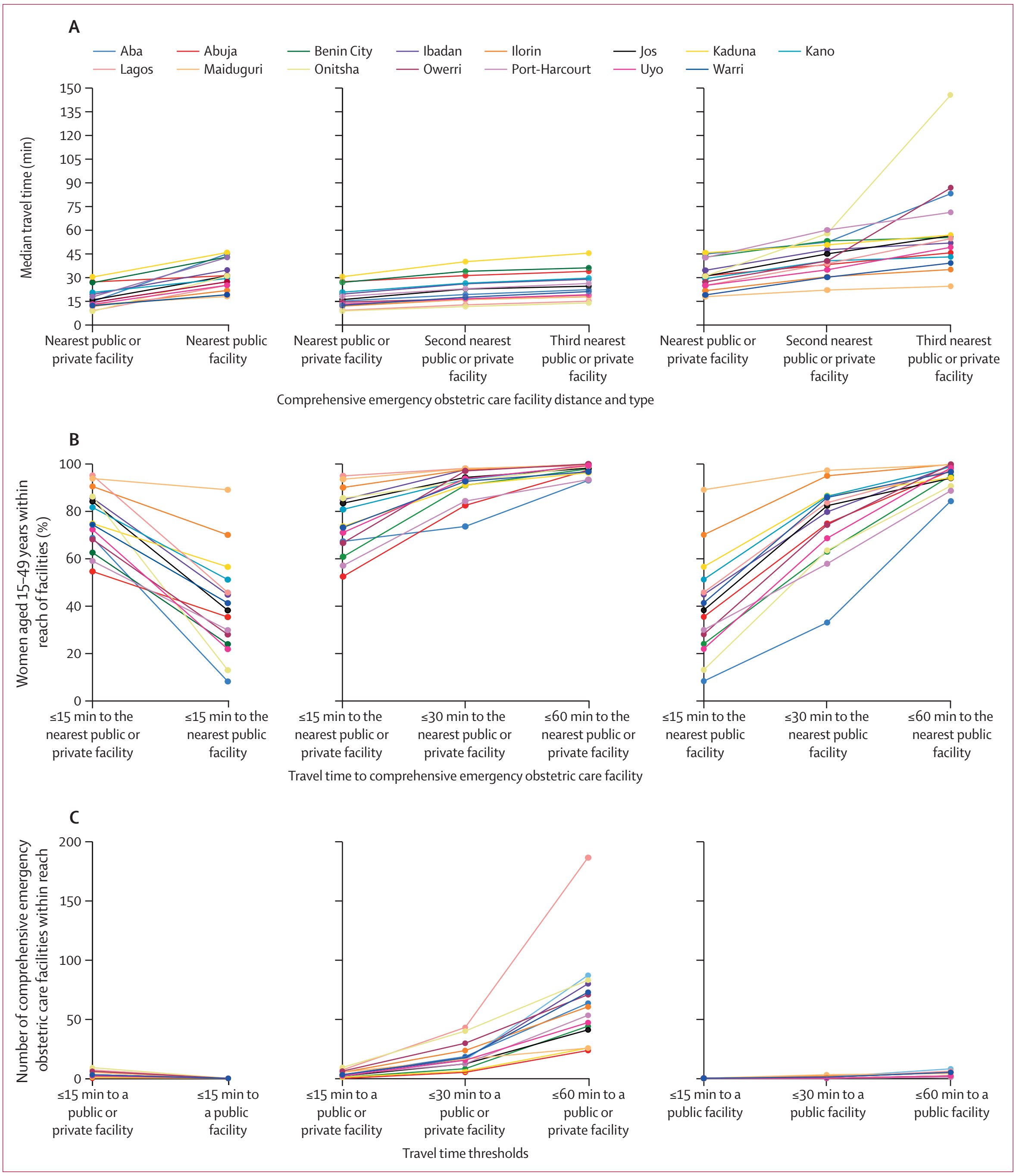

Figure 1: **Median travel time to comprehensive emergency obstetric care facilities (A), percentage of women aged 15–49 years within reach of these facilities (B), and median number of comprehensive emergency obstetric care facilities within specific travel times (C) in the 15 cities**

For the peak traffic hours of 1800 h to 2000 h on weekdays, the median number of public comprehensive emergency obstetric care facilities reachable within 15 min for the study population was zero in all cities (figure 1C). The median number of public comprehensive facilities reachable within 30 min remained at zero in eight (53%) of 15 cities (figure 1). Considering both public and private comprehensive facilities, the city with the highest number of facilities reachable within 15 min was Onitsha (n=9), while the city with the highest number of facilities within 30 min (n=42) and 60 min (n=182) was Lagos. At the ward level (ie, within cities), travel time in different wards showed substantial differences (figure 2). For the nearest public comprehensive emergency

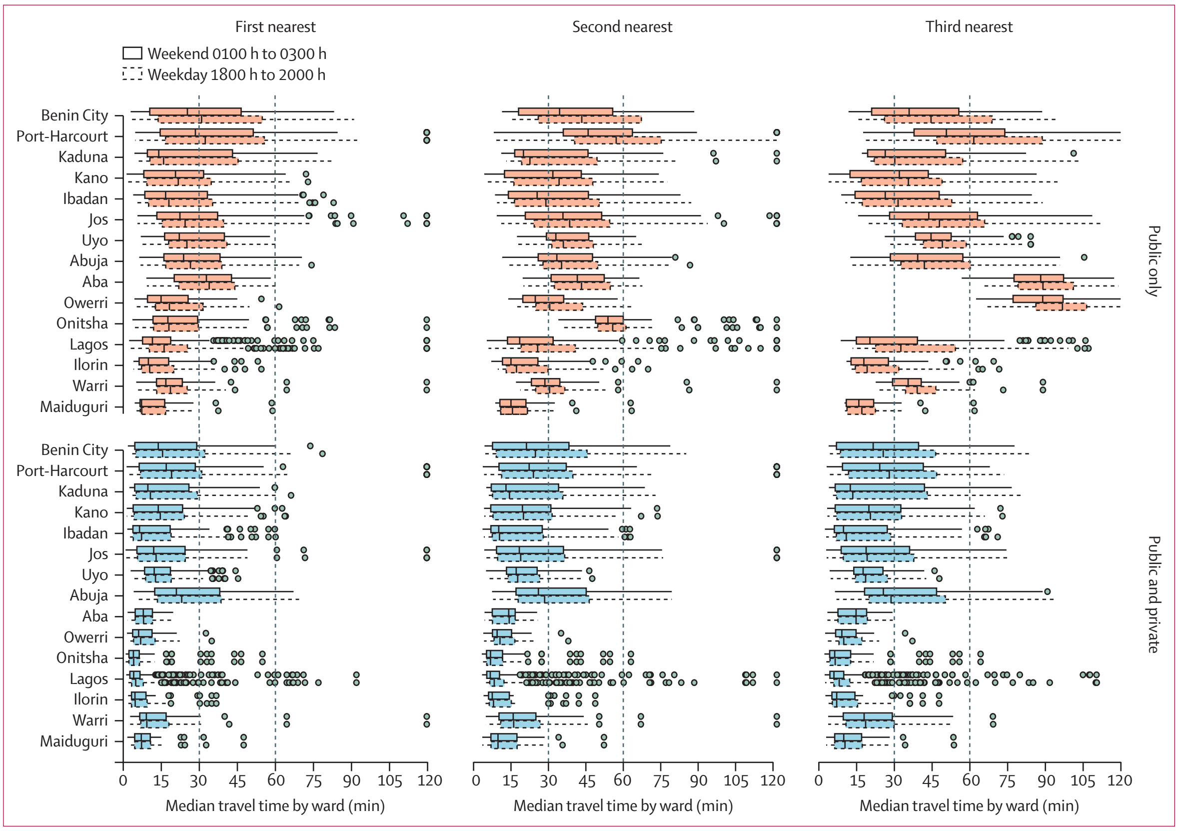

Figure 2: **Travel time to comprehensive emergency obstetric care facilities by ward in 15 cities, during weekdays 1800 h to 2000 h and weekends 0100 h to 0300 h**

Edges of boxes represent quartiles, whiskers extend to 1·5 × interquartile range, and outlier values are plotted as individual points beyond the whiskers.

obstetric care facility, the IQR of median travel time varied from the narrowest in Maiduguri (10 min) to the widest in Benin City (41 min). Ward-level median travel time values were less than 60 min in most wards (at least 90%) but were over 2 h in some (<1%; appendix 1 p 18). Ward-level travel times to either public or private facilities were less variable based on IQR than median—4 min for Lagos to over 20 min in Kaduna, Benin City, and Abuja. The comparisons across wards were similar during weekdays (1800 h to 2000 h) and weekends (0100 h to 0300 h), which were typically the longest and shortest times to travel, respectively (figure 3). Median travel time reduced substantially for the majority of wards in some cities when considering public and private facilities instead of public alone. For instance, in Lagos the median travel time to the third nearest facility (public or private) between 1800 h and 2000 h on a weekday was below 12·3 min in 283 (75%) of the 377 wards—a reduction from 54·3 min if only public facilities were considered. However, the median travel time remained greater than 60 min in 11 (3%) wards regardless of inclusion of private facilities.

The percentage of women aged 15–49 years within 30 min of a comprehensive emergency obstetric care facility for the measured eight different times throughout the week in a random sample of 40 (11%) of the 377 wards in Lagos are shown in figure 3. Coverage of public comprehensive care facilities varied substantially in some wards by time of day (eg, 35% for weekday 1800 h to 2000 h *vs* 100% for weekend 0100 h to 0300 h in FESTAC I ward [AM002], for instance), while it remained static in others (eg, in Ojo Town [OJO13] and Apapa II—Liverpool road and environs [APA02] wards). Overall, for the 40 randomly selected wards, there were more fluctuations in the percentage of women aged 15–49 years within 30 min of a public comprehensive emergency obstetric care facility than in the percentage within 30 min of public and private combined (figure 4). Similar patterns were also observed in other cities and wards, although some cities, such as Maiduguri and Ilorin, had a similar level of accessibility throughout the day and week for public comprehensive care facilities in most wards (appendix 1 p 18).

The percentage of women aged 15–49 years within 30 min travel time of public comprehensive emergency obstetric care was typically lowest during weekdays between 1800 h and 2000 h, and highest during the weekend between 0100 h and 0300 h. In parts of Kano, Lagos, Owerri, Port-Harcourt, and Uyo, coverage was 0–25% for weekdays at 1800 h to 2000 h and 75–100% for

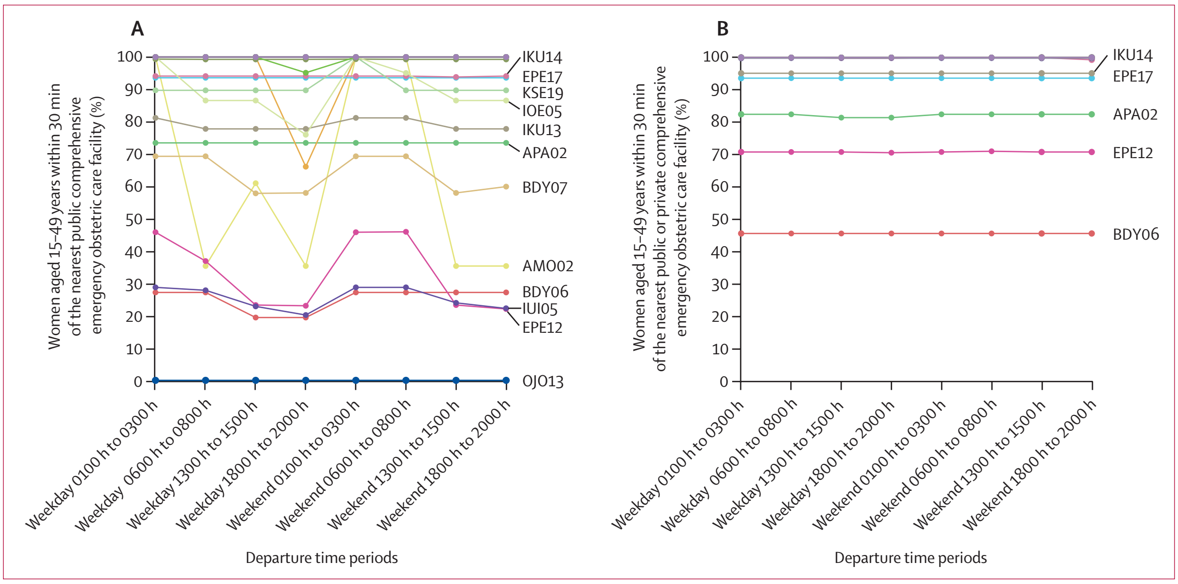

Figure 3: **Percentage of women aged 15–49 years within 30 min travel time to the nearest comprehensive emergency obstetric care facility at eight different times by ward in Lagos**

Data are for a random sample of 40 wards in Lagos. Wards are listed on the right of lines. (A) Women aged 15–49 years within 30 min of the nearest public comprehensive emergency obstetric care facility. (B) Women aged 15–49 years within 30 min of the nearest public or private comprehensive emergency obstetric care facility.

weekends at 0100 h to 0300 h—differences of at least 60 percentage points. In other cities, such as Aba, Maiduguri, and Onitsha, coverage remained similar on weekdays and weekends (appendix 1 p 18).

Ward-level differences in coverage with and without consideration of private facilities were largely similar in Abuja, Maiduguri, and large parts of Warri (appendix 1 p 18) between 1800 h and 2000 h (when travel time is typically the longest). In other cities, however, including Aba, Jos, Lagos, and Uyo, ward-level coverage decreased from 100% when considering public and private comprehensive emergency obstetric care facilities to 0% when considering only public comprehensive care facilities. In Lagos, wards with high coverage of public and private comprehensive emergency obstetric care facilities but low coverage of only public comprehensive care facilities included areas characterised as informal settlements (eg, Ajangbadi, Okokomaiko, Ilogbo-Elegba, and Oto-Awori).

Discussion

This study assessed geographical accessibility to comprehensive emergency obstetric care facilities in 15 large Nigerian cities using closer-to-reality travel time estimates. To our knowledge, this study is the first on emergency obstetric care accessibility to have considered real-life traffic differentials at scale in a low-income and middle-income country. We found that even under the heaviest traffic conditions, women aged 15–49 years in all cities were within a median travel time of 45 min to the nearest public comprehensive emergency obstetric care facility. However, in five cities (Aba, Jos, Kaduna, Onitsha, and Port-Harcourt), between 5–15% of women did not have a comprehensive care facility within an hour's travel, especially within the public sector. During peak traffic times, the median number of public comprehensive emergency obstetric care facilities available within 30 min was zero in eight of the 15 cities. We identified within-city geographical inequities of accessibility to comprehensive care, notably for Benin City, Port-Harcourt, and Kaduna.

We found that most locations in the 15 cities were within an hour's drive to one or two public comprehensive emergency obstetric care facilities. Our results suggest reasonably acceptable geographical accessibility, based on WHO's 2-h benchmark to emergency obstetric care.[4] Even in Kaduna, the city with the lowest coverage, 94% of women were within 1 h travel time of a comprehensive emergency obstetric care facility under peak traffic conditions. The contextualised spatial analysis of comprehensive emergency obstetric care facilities and accessibility to them suggests that the main drivers of coverage to comprehensive care within these cities are traffic and distribution of functional comprehensive care facilities across the city. For example, functional comprehensive emergency obstetric care facilities in Maiduguri appeared to be evenly spread across the city centre and its suburbs, while in Kaduna, facilities were mostly clustered in the centre. Also, cities with particularly serious traffic congestion (notably Abuja, Benin City, and Port-Harcourt)[28,29] were found to have the poorest coverage when public and private facilities were combined. These factors might explain why Lagos, despite having a substantially higher number of functional facilities, did not have the best availability (by number of facilities per

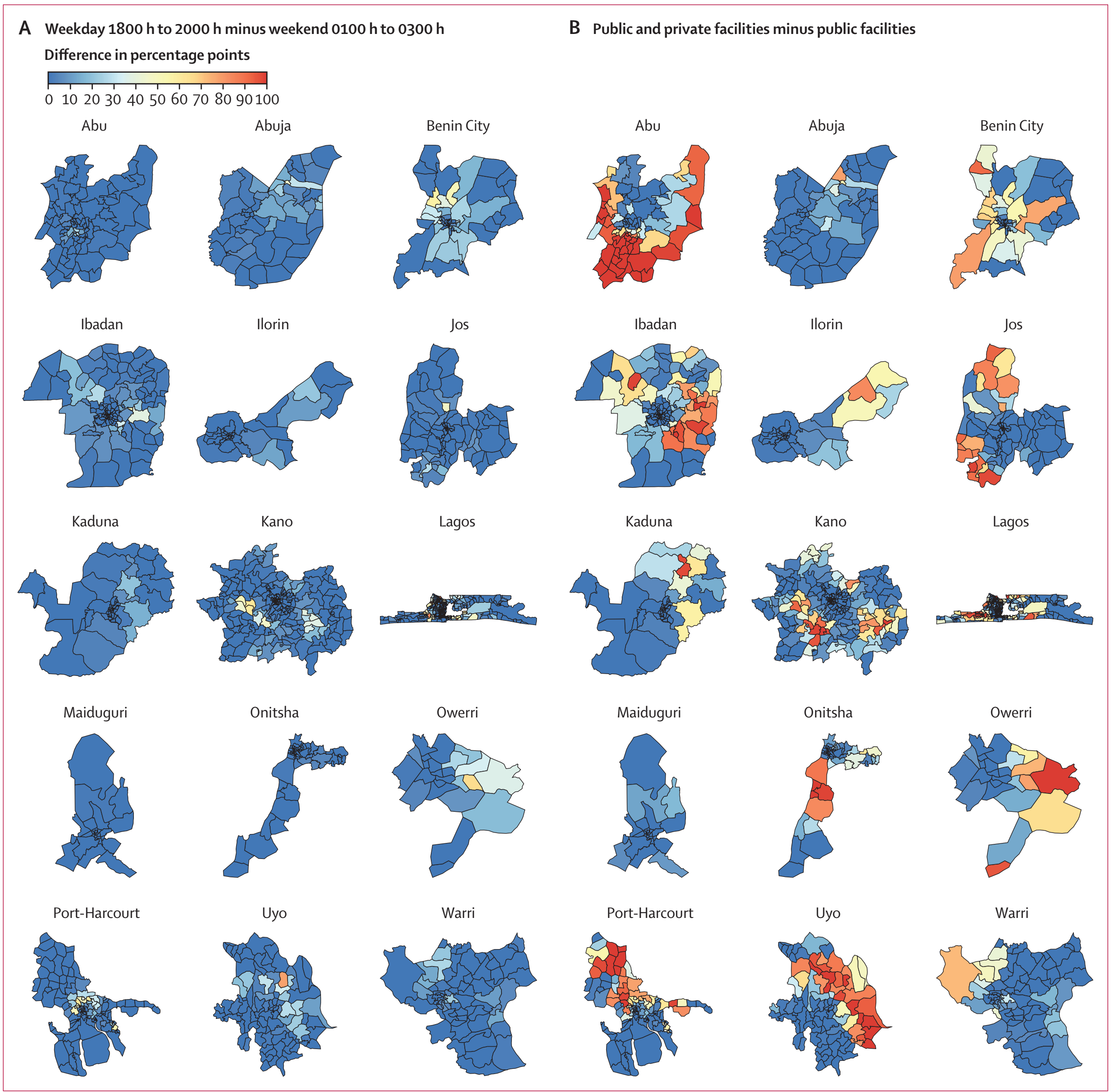

Figure 4: **Ward-level differences in percentage points of women aged 15–49 years within 30 min reach of comprehensive emergency obstetric care facilities in 15 cities**

100 000 women aged 15–49 years) or accessibility. In Aba, geographical accessibility was particularly worse when only considering public (and not private) comprehensive emergency obstetric care facilities, because the only two functional public care facilities are both in the northern part of the city.

Although city-level estimates might be relevant for comparative performance (ie, between city), granular ward-level estimates can reveal within-city inequities and help guide decision making in cities.[30] We found within-city inequity in the geographical accessibility of comprehensive emergency obstetric care facilities. Specifically, accessibility problems occur in places without any local facilities and women therefore need to travel across wards or neighbourhoods for care. Cities such as Benin City, Port-Harcourt, and Kaduna had the widest gaps across wards. In addition, layering geolocated informal settlements with our data, we were able to identify some informal settlements as areas with the worst accessibility to public sector care.

Our analysis has several strengths. First, our study was based on algorithmic outputs generated using Google Maps' internal Directions API, which has been shown to offer closer-to-reality time estimates compared with commonly used models such as the cost-friction surface approach and Open Source Routing Machine.[7] Second, we included both public and private comprehensive emergency obstetric care facilities and confirmed their functionality, in contrast to other large-scale efforts that have been limited to the public sector and not confirmed functionality. Third, our approach integrated the variability of traffic throughout the day and week. Fourth, we used several time thresholds for calculation of coverage, in line with emerging evidence showing that even travel time of 30 min increases odds of stillbirth and maternal death during referral.[17,18] Finally, our approach of using a higher-resolution spatial scale of 0·36 km² made it possible to granularly assess spatial accessibility at the level of wards. This approach is required for higher accuracy and robustness in model inputs to guide local policy and decision making.[30] For example, the approach allowed us to identify informal settlements as having lower coverage, which is relevant as 1 billion people globally and a third of Africa's urban population currently live in these settings.[8]

For the **digital dashboard** see https://goo.gle/emergencyobstetriccare

However, our results have limitations. First, we acknowledge that bypassing the nearest facility is common in care seeking. To account for this, our accessibility metrics were based on the three nearest functional comprehensive emergency obstetric care facilities, thereby capturing some level of choice. Second, the route mapped by the API is based on the routine travel of commuters, which might not be aligned with one a service user might take in an emergency. Third, we assumed travel occurs by vehicle. Although it is true that some pregnant women may access emergency obstetric care by walking, motorised transport including taxis and privately owned cars are used by a large majority in an emergency.[14] Linked to this is our assumption that a vehicle was available to all women at the time of need. Fourth, we made a pragmatic decision to use facilities with caesarean section capacity as a proxy for all comprehensive emergency obstetric care services. However, we do not know availability of other services. For example, assisted vaginal delivery or blood transfusion might not be available in all facilities all the time, irrespective of whether they are public or private.[14] Finally, our urban delineation was based on qualitative assessment as we included areas ranging from very dense to peri-urban areas. Although this aligns with the expansion of urban areas into peri-urban areas and reflects the lived reality of rapid urbanisation, it also means that some of the fringes of our selected areas might include some less urban segments.

Our findings have substantial policy and planning implications. Local governance which takes a multi-sectoral approach involving health, urban and regional planning, and transportation is needed to optimise emergency obstetric care geographical accessibility. Beyond suboptimal distribution of comprehensive emergency obstetric care facilities, rapid urbanisation, expansion of vehicle ownership, poor roads, and lack of law enforcement, all contribute to the traffic seen in African cities. Innovative approaches aimed at minimising traffic and diversifying commuting options for city populations are needed[31] to ensure that roads are more accessible to those who need them the most, including pregnant women in an emergency. Urban redesign initiatives focused on addressing comprehensive emergency obstetric care geographical accessibility such as ambulance-only lanes or roads and direct passes to hospitals, targeting areas of inequities to situate available ambulances, and community awareness campaigns targeting reorientation of commuters to give way to emergency vehicles are options to consider. To maximise the usefulness of the evidence from this research, the data that informed it was also used to develop a publicly available digital dashboard allowing an interactive visualisation of different travel scenarios to aid service planning and decision making. Future developments should include other emergency obstetric care services and other dimensions of access including quality of care, cost of care, and availability of structures to support access such as ambulances,[32] and reflect seasonal variations in accessibility.

See **Online** for appendix 2

In conclusion, inequities in the geographical accessibility of emergency obstetric care exist in Nigerian cities. However, the location and magnitude of such inequities differ across cities, with informal settlements being of particular concern. Although our innovative approach can be data intensive, requiring data from up-to-date facility verification and closer-to-reality travel time estimates,[15,19] it offers an opportunity to generate more context-specific, finer, and policy-relevant evidence to support improving the geographical accessibility of emergency obstetric care in urban Africa. Replication of this approach across urban areas of the continent will aid the identification of targeted cost-effective strategies that ensure that we leave no one behind, including all pregnant women, in efforts to realise universal health coverage.

Contributors

AB-T, KLMW, and PMM conceptualised the study and prepared the analytical plan for the study with support from TO and LB. AB-T, TO, OO, UG-A, and BBA led the facility functionality verification activity conducted as part of the study. NS, YS, GP, MK, SV, TS, and CS were involved in aggregating the travel time estimates from Google's internal Directions Application Programming Interface used for the study. AB-T, PMM, PTM, LB, KLMW, UG-A, and I-OOA conducted the literature review that informed the study. KLMW conducted the analysis of the data with support from AB-T, PMM, and LB. AB-T, KLMW, and PMM prepared the first draft of the manuscript. AB-T, KLMW, TO, PMM, OO, UG-A, JW, I-OOA, PTM, NA, CN, BBA, and LB contributed to the interpretation of data. All authors were involved in editing of the article, commented critically on the manuscript, and approved the final version of the manuscript. All authors had full access to all the data in the study, and had final responsibility for the decision to submit for publication.

Equitable partnership declaration

The authors of this paper have submitted an equitable partnership declaration (appendix 2). This statement allows researchers to describe how their work engages with researchers, communities, and environments in the countries of study. This statement is part of *The Lancet Global Health*'s broader goal to decolonise global health.

Declaration of interests

NS, YS, GP, MK, SV, TS, and CS are current or past employees of Google, which developed the Google Maps Platform. AB-T and BBA are funded by the Bill & Melinda Gates Foundation (investment identification

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Data sharing

The datasets used for this analysis are publicly available. These include a database of health facilities with capacity for caesarean section in urban Nigeria (https://doi.org/10.6084/m9.figshare.22689667) and a geospatial database of close-to-reality travel times to obstetric emergency care in 15 Nigerian conurbations (https://figshare.com/s/8868db0bf3fd18a9585d).

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Editorial note: The Lancet Group takes a neutral position with respect to territorial claims in published maps.

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