

Application of GIS in Public Health Practice: A Consortium's Approach to Tackling Travel Delays in Obstetric Emergencies in Urban Areas

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Abstract

Geographic Information System (GIS) has become an effective and reliable tool for researchers, policymakers, and decision-makers to map health outcomes and inform targeted planning, evaluation, and monitoring. With the advent of big data-enabled GIS, researchers can now identify disparities

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and spatial inequalities in health at more granular levels, enabling them to provide more accurate and robust services and products for healthcare. This paper aims to showcase the progress of the On Tackling In-transit Delays for Mothers in Emergency (OnTIME) project, which is a unique collaborative effort between academia, policymakers, and industrial partners. The paper demonstrates how the limitations of traditional spatial accessibility models and data gaps have been overcome by combining GIS and big data to map the geographic accessibility and coverage of health facilities capable of providing emergency obstetric care (EmOC) in conurbations in Africa. The OnTIME project employs various GIS technologies and concepts, such as big spatial data, spatial databases, and public participation geographic information systems (PPGIS). We provide an overview of these concepts in relation to the OnTIME project to demonstrate the application of GIS in public health practice.

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1 Introduction and Background

In 2020, the World Health Organisation estimated that around 287,000 women lost their lives worldwide due to maternal causes, which corresponds to nearly 800 maternal deaths occurring every day, or approximately one every two minutes [11]. This problem is particularly prevalent in Low- or Middle-Income Countries (LMICs), with Africa being particularly affected [11]. Africa not only accounts for the highest percentage of maternal deaths (69% of the global total of 287,000) and stillbirths (45% of the global total of 1.9 million), but it is also undergoing rapid urbanisation. Two-thirds of the world's population will live in urban areas by 2050 with a significant proportion of these additional 2.5 billion urban residents concentrating in Africa [9]. In urban settings, the odds of maternal death and stillbirth are significantly higher, partly explained by traffic-ridden journeys with longer travel time [5, 6, 4].

Timely access to emergency obstetric care provided by trained healthcare personnel can significantly reduce maternal deaths [12]. However, women with obstetric emergencies must travel to healthcare facilities capable of providing EmOC to access the needed care. Delays encountered during this journey from home to a healthcare facility providing EmOC have a significant impact on the health outcomes of both mothers and newborns [4, 10]. Many of these deaths are preventable with timely and effective intervention, highlighting the essentials of receiving EmOC in time. Therefore, there is a need to understand the travel time between the location where a need for obstetric emergency services arises and possible locations with EmOC facilities. This is particularly critical to prevent avoidable maternal deaths and stillbirths, as well as achieve the Sustainable Development Goals (SDG) for maternal and newborn mortality by 2030¹. However, the current approaches of estimating travel time, either reported or modelled estimates, do not accurately represent the dynamics of the journey between the women's location and EmOC facilities [7]. This is mainly due to lack of observational data on healthcare seeking behaviour to robustly parameterise the access

¹ <https://www.who.int/europe/about-us/our-work/sustainable-development-goals/targets-of-sustainable-development-goal-3>

models [3]. Thus, different dynamics such as traffic conditions, time of the day, weather variations, and other eventualities are not accounted for [3]. Further, majority of existing evaluations of travel time focus only on the public facilities, ignoring the significant role played by the private sector. In addition, these analyses evaluate travel time to the nearest facility, ignoring the possibility that a closer facility may be bypassed for alternative choices.

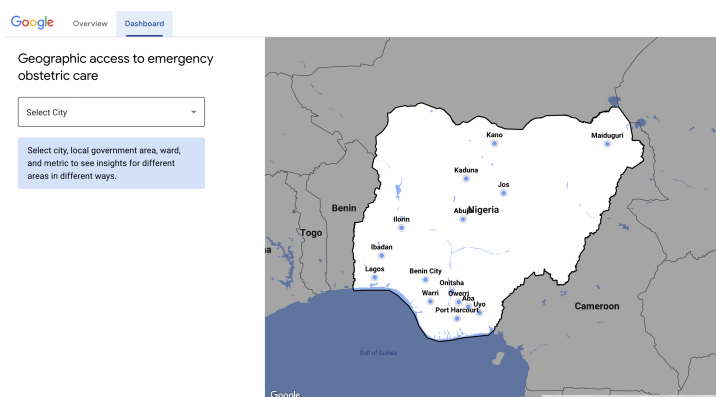
The OnTIME Consortium² is a cutting-edge partnership that brings together academics, decision-makers, and Google to offer solutions to the challenges encountered by pregnant mothers and caregivers in LMICs. The goal of the OnTIME project being delivered by the Consortium is to first assemble a geo-coded database of public and private hospitals with EmOC in major African conurbations and second, use this database to estimate close-to-reality travel times to the closest, second-closest, and third-closest facilities capable of EmOC services. A key deliverable of the OnTIME project is a digital dashboard³ (Figure 1) that enables policymakers to optimise the geographic accessibility of EmOC by providing more realistic estimations of travel time and geographic coverage within policy actionable units. The availability of more accurate coverage data represents the next frontier in policy-making and research for improving EmOC access in urban settings of LMICs [3]. The OnTIME project has a phased approach, starting with the most populated conurbations in Nigeria in phase 1. The second phase will focus on selected conurbations in Africa that have publicly available lists of health facilities with attributes of service provision, and eventually to other LMICs in Southeast Asia and Latin America (phase 3). In the completed first phase (2022-2023), focus group discussions and interviews were conducted with policymakers in Nigeria, and an online survey involving over 200 policymakers and researchers across Africa was carried out to obtain insights on the essential components and the implementation of the proposed dashboard. A facility functionality verification was conducted in 15 cities across public and private hospitals in Nigeria, which were selected based on a population of at least 1 million in 2022 or projected to reach 1 million by 2030. This effort led to the development of the digital dashboard that displays the time it takes for pregnant women to access EmOC of different levels in the selected urban areas of Nigeria. The displayed travel catchment areas reflect the functional geographical coverage and accessibility of EmOC, indicating areas of inequitable access that require prioritisation. This dashboard will inform and catalyse policy actions to improve geographical accessibility, contribute to Nigeria's commitment to universal health coverage and SDG 3, and ultimately lead to reduced maternal and perinatal mortality. There is an open database of generated travel time accompanying the dashboard (discussed in 2.1). The subsequent sections illustrate the GIS approaches employed in the initial phase of the OnTIME project.

2 Spatial Mapping and Big Data

Spatial mapping is commonly employed in public health to offer valuable understandings into the arrangement and availability of healthcare resources. This data can guide choices concerning the positioning of healthcare facilities and the distribution of healthcare resources. One of the current advancements in GIS is coming from our increasing capability of collecting, storing, processing and visualising mass volume of information of great complexity, a phenomenon known as “big data” [8]. By including the geographic coordinates in big data, it becomes big spatial data. As stated by the UK's national mapping agency Ordnance Survey, “with this additional spatial dimension, much deeper insights about the records in a dataset, and their relationships can often be drawn” [13].

² <https://www.ontimeconsortium.org/>

³ <https://emergencyobstetriccare.webapps.google.com/overview>



■ **Figure 1** OnTIME project's core deliverable: a digital dashboard displaying geographic access to emergency obstetric care designed for policymakers.

The OnTIME project involves several big spatial datasets. The data retrieved from Google Directions API includes spatial data on road networks, real-time and historical traffic data. Our industrial partner, Google, incorporated this vast amount of data to generate realistic routes between locations and predict the driving time between settlements and facilities providing EmOC. From the retrieved data, the following summaries can be computed: i) travel times to the first, second, and third nearest EmOC facilities, ii) the count of health facilities within 15, 30, and 60 minutes of driving time, and iii) proportion of women of child bearing age (15-49 years) within the same time thresholds. These time estimates are disaggregated by facility ownership (public, private and a combination of both), for eight traffic scenarios at different time of day and day of week.

The project also includes a large geo-coded dataset⁴ that stores information on the functionality and capability of both public and private hospitals offering EmOC from 15 cities in Nigeria. In the second and third phases of the project, comparable large-scale spatial databases will be constructed, concentrating on other LMIC urban areas. The extent of the 15 Nigerian cities was established by using spatial overlays to cross-reference the shapefiles of the local government area (LGA) boundaries⁵ with WorldPop⁶'s gridded surface of population (at a resolution of 100 m²), Google Maps, and the Global Human Settlement⁷ layers showing gridded surfaces of urban areas. Where applicable, locals were consulted to confirm the results. The centroids (as origins) of a 600 m² gridded dataset covering the entire study region were used to compute routes to the nearest EmOC facilities (as destination) using the Google Directions API.

3 Public Participation GIS

PPGIS is a “field within geographic information science that focuses on ways the public uses various forms of geospatial technologies to participate in public processes, such as mapping and decision making” [14]. Surveys and interviews are frequently used tools in PPGIS as a way to engage with stakeholders and gather their opinions and feedback on particular

⁴ <https://www.ontimeconsortium.org/relevant-databases>

⁵ <https://grid3.org>

⁶ <https://www.worldpop.org/>

⁷ <https://ghsl.jrc.ec.europa.eu/>

issues or topics. To ensure a fit-for-purpose dashboard, we conducted an online survey with policymakers and researchers to understand key considerations needed for developing a policy-ready dashboard of geospatial access to EmOC in Africa. We gathered information about participants' knowledge of the locations where poor geographic accessibility to EmOC is a concern, the technological resources currently utilised for EmOC service planning, their dashboard feature preferences, and the possibility of a dashboard to tackle the issue of inadequate EmOC accessibility.

Moreover, government stakeholders at both the state and federal levels in Nigeria were involved through a combination of in-person and virtual semi-structured interviews. These interviews were conducted with six policymakers and 17 senior civil servants, representing seven states across five geopolitical zones and the Federal Capital Territory, Abuja. Results [2] suggests that technocrats recognise the ideal of data-driven needs assessment in enhancing maternal care, although this is frequently impacted by various factors such as political pressures, persistent community advocacy, irregular short-term administrative cycles, and donor-driven funding decisions. Despite the possibility of obstacles, there is substantial enthusiasm and acceptance for the use of GIS-enabled dashboard to aid in health planning, particularly in circumstances where innovation and technology are already ingrained in the current government's administrative approach [2].

4 Discussion and Future Work

This paper showcases how GIS can be used to collect, represent, and reason data, leading to better public health planning and decision-making. Specifically, it illustrates the use of spatial mapping, big data, spatial database and PPGIS to address maternal care delays in the OnTIME project. To enable more informed decision-making, it is essential to incorporate geospatial data and leverage advanced GIS techniques. The potential future work includes:

- A further in-depth investigation of access inequality between regions can be conducted. Spatial auto-correlation could be used to assess the spatial agglomeration characteristics of accessibility. To explore the underlying reasons for the imbalance in geographic accessibility, socio-economic factors are extracted, thus enabling further analyses to investigate spatial associations by spatial statistical techniques such as geographically weighted regression.
- The adoption of the spatiotemporal exploratory data analysis in the project. This is a methodological approach to detect and describe patterns, trends, and relations in data in both space and time [1]. Spatiotemporal analysis can be used to examine the trends and patterns of EmOC utilisation and need over time.
- Propose an ontology that identifies and decomposes geographic access elements of maternal healthcare into a hierarchy of categories, which is further systematised using extensions of existing formal ontologies. This way, we can provide a methodology- and context-independent measure of geographic accessibility that could then be used to extrapolate conceptual models for a variety of wider public health applications.

Ultimately, the OnTIME Consortium is committed to contribute to global efforts to reduce maternal mortality by generating closer-to-reality assessments of geographic access gaps to critical maternal health services. The Phase I has already strongly shown that a collaborative and participatory approach makes GIS data more meaningful and yields greater impact, especially in a time in which the global community is committed to “leave no one behind”.

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