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The economic value of increasing geospatial access to tetanus toxoid immunization in Mozambique

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ABSTRACT

Background: With tetanus being a leading cause of maternal and neonatal morbidity and mortality in low and middle income countries, ensuring that pregnant women have geographic access to tetanus toxoid (TT) immunization can be important. However, immunization locations in many systems may not be placed to optimize access across the population. Issues of access must be addressed for vaccines such as TT to reach their full potential.

Methods: To assess how TT immunization locations meet population demand in Mozambique, our team developed and utilized SIGMA (Strategic Integrated Geo-temporal Mapping Application) to quantify how many pregnant women are reachable by existing TT immunization locations, how many cannot access these locations, and the potential costs and disease burden of not covering geographically harder-to-reach populations. Sensitivity analyses covered a range of catchment area sizes to include realistic travel distances and to determine the area some locations would need to cover in order for the existing system to reach at least 99% of the target population.

Results: For 99% of the population to reach health centers, people would be required to travel up to 35 km. Limiting this distance to 15 km would result in 5450 (3033–7108) annual cases of neonatal tetanus that could be prevented by TT, 144,240 (79,878–192,866) DALYs, and $110,691,979 ($56,180,326–$159,516,629) in treatment costs and productivity losses. A catchment area radius of 5 km would lead to 17,841 (9929–23,271) annual cases of neonatal tetanus that could be prevented by TT, resulting in 472,234 (261,517–631,432) DALYs and $362,399,320 ($183,931,229–$522,248,480) in treatment costs and productivity losses.

Conclusion: TT immunization locations are not geographically accessible by a significant proportion of pregnant women, resulting in substantial healthcare and productivity costs that could potentially be averted by adding or reconfiguring TT immunization locations. The resulting cost savings of covering these harder to reach populations could help pay for establishing additional immunization locations.

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1. Introduction

With tetanus being a leading cause of maternal and neonatal morbidity and mortality in low and middle income countries, ensuring that pregnant women have geographic access to tetanus toxoid (TT) immunization can be important. Tetanus results from toxins produced by *Clostridium tetani* that block neurotransmitter release and leads to generalized muscle spasm, respiratory compromise, and autonomic dysfunction [1]. The TT vaccine is a routine part of many countries' World Health Organization (WHO) expanded program on immunization (EPI) regimens. Studies have shown the TT vaccine to be highly efficacious (80–100%) in preventing neonatal tetanus (NNT) [2]. However, the continuing occurrence of NNT – which is estimated to have caused 61,000 deaths in 2011 [3] – suggests that many pregnant women are not receiving the TT vaccine. Indeed, only 64% of pregnant women are estimated to have received at least two doses of TT in 2014 [4]. As previous work has shown, distance to the closest immunization

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location can be an impediment to a person getting immunized [5]. However, immunization locations in many systems may not be placed in a planned manner to optimize access across the population. Instead, decision makers may prioritize other factors, such as political considerations [6]. Issues of access must be addressed in order for vaccines in the current routine immunization schedule to reach their full potential, let alone new and upcoming vaccines.

To determine how well the TT immunization locations meet the population demand in Mozambique, our team developed and utilized SIGMA (Strategic Integrated Geo-temporal Mapping Application) to quantify how many people in the relevant target population are reachable by existing TT immunization locations in Mozambique, how many cannot access these locations, and the potential costs and disease burden of not reaching these geographically harder-to-reach populations.

2. Methods

2.1. Mozambique population and immunization

Mozambique is a low-income country in southern Africa with a population of 25,727,911 [7]. Based on data from the Ministry of Health (MOH), the EPI in Mozambique administers vaccines to the population at 1377 health centers located throughout the country. The EPI schedule currently includes TT for pregnant women, who on average comprise 5% of the population, to prevent neonatal tetanus.

2.2. SIGMA

For this study, we developed SIGMA for Immunization, a geospatial information system (GIS) to estimate the population that may be reachable by specified immunization locations. SIGMA is written in the Python and Javascript programming languages, using the Django web application framework [8] and Leaflet interactive mapping library [9], and includes points-of-interest (POI) data from OpenStreetMap [10] as well as population density data from the Global Rural-Urban Mapping Project (GRUMP) [11]. A SIGMA-generated model allows one to place immunization locations on a map and draw a catchment area around each location. The model overlays these catchment layers onto geospatially explicit population data that incorporates the immunization target population based on relevant demographic statistics (e.g. crude birth rate to estimate newborn population and different age groups of the population over time). SIGMA can be used to characterize the population served by these catchment areas, and the populations not served by any catchment area. Using a combination of disease risk, vaccine efficacy, and cost and burden of each disease case, the reachable and unreachable populations can be translated into disease cases, costs (e.g. treatment and productivity losses), and disability-adjusted life years (DALYs).

2.3. Data sources

We searched four major electronic databases (the United States National Library of Medicine and the National Institutes of Health Medical (PubMed) [12], WHO Global Health Observatory Data Repository [11], Scopus [13], and EconLit [14]) to locate peer-reviewed studies and grey literature on the costs and health effects of tetanus between 2005 and 2014. Our primary focus was the disease risk, vaccine efficacy, and costs and burden per case of neonatal tetanus in Mozambique; however, due to the limited number of papers specific to this country, we expanded our search to include other countries. The search, performed in 2015, used variations of the following keywords: "tetanus," "epidemiology," AND "economics." Relevant Medical Subject Headings (*MeSH*) terms and a full listing of all types of impact evaluations were used in the search. Additional manual bibliographic searches from relevant review papers revealed additional articles and grey literature. We limited our search to English and French studies presenting tetanus impact data conducted between 2005 and 2014 in Mozambique and other African countries.

We based our estimates of disease risk and burden on baseline, high, and low values found in the literature. We used 100% (80–100%) for TT vaccine efficacy [2], with unprotected individuals developing neonatal tetanus at a rate of 23 per 1000 live births [15]. Each case of neonatal tetanus incurs $3410 ($1705–$5114) in treatment costs in 2015 USD [16] and $16,903 ($16,820–$17,327) in productivity losses (based on a $639 GNI per capita [17]). Productivity losses represent the net present value of all productivity lost over the lifetime of the patient due to illness, disability, and loss in life years. Each case also incurs 26.5 (26.3–27.1) DALYs [18], based on disability weights of 0.640 per acute episode of tetanus, 0.388 for motor deficits, and 0.469 for mental retardation in children 0–4 years of age [19,20]. To estimate treatment costs, we converted costs from Brazil reported in 2010 USD to Mozambican Meticais (MZN), accounting for the purchase power parity (PPP). We used the monetary conversion rates from USD to Brazilian Real (BRL) in 2010 (year of reported costs), the PPP conversion factor for BRL into PPP International dollar ($Int) in 2010, and the PPP conversion factor for Mozambican Metical (MZN) into PPP $Int in 2010. We used these indicators in Eq. (1) to derive the Mozambican cost equivalent.

$$\text{Cost of treatment in Mozambique} = \text{Cost of treatment in Brazil} \times (R_{US\rightarrow BRL} \times CF_{BRL\rightarrow \$Int})/CF_{MZN\rightarrow \$Int} \quad (1)$$

2.4. Immunization location catchment area scenarios

Each scenario tested a catchment area radius for health centers (i.e. the greatest distance pregnant women may travel to obtain TT) to determine the percentage of the population reachable by these locations. As data on the actual catchments are lacking, sensitivity analyses covered a range of catchment area sizes to include realistic travel distances and to determine the area some locations would need to cover in order for the existing system to reach at least 99% of the target population.

For each scenario, we quantified the number of pregnant women who would fall outside the catchment area of any health center. We estimated the annual number of vaccine-preventable cases of neonatal tetanus each scenario would incur among unreachable populations (Eq. (2)), as well as the resulting DALYs, healthcare costs, and societal costs in the form of productivity losses. Costs are reported in 2015 USD assuming a 3% discount rate.

$$\text{Vaccine-preventable cases} = \text{Target population outside of catchment area} \times \text{Vaccine efficacy} \times \text{Disease risk} \quad (2)$$

3. Results

3.1. Population reachable and not reachable by TT immunization locations

Fig. 1 shows the relationship between catchment radius and target population covered. The population covered increases at an accelerating rate until it peaks at 17% additional population coverage for each added kilometer in catchment area radius. Beyond a radius of 4 km, each subsequent gain in population coverage

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