GIS mapping: A promising approach to identifying and reaching zero-dose children in Zambia

A CASE STUDY

KEY LESSONS LEARNED

- District and facility leaders are highly interested in using more accurate data to inform immunization micro-planning.
- Community engagement was crucial to ensuring accuracy of maps and identifying zero-dose children.
- GIS mapping is more expensive than hand-drawn maps, but more accurate. Governments should budget accordingly.
- Technical capacity must be built to conduct GIS mapping and analysis, and for community-level data collectors to use technology to capture data.

1. DESPITE HIGH RATES OF IMMUNIZATION, COMMUNITIES AND CHILDREN CONTINUE TO BE MISSED

National immunization rates are generally high across Zambia, with a 94% coverage rate for the first dose of diphtheria, tetanus toxoids, and pertussis (DTP) vaccine, 90% coverage for the first dose of the measles vaccine, and 80% coverage for the first dose of polio vaccine reported in 2021 (WHO/UNICEF Estimates of National Immunization Coverage [WUENIC]).

Despite high national coverage rates, pockets of inequities exist. These inequities are driven by geographic and sociodemographic factors (including wealth, rural or urban slum residence, number of children in the household, and education of mothers) that result in households and/or communities continuing to be missed (Gavi, 2018). Many zero-dose children live in households that are missed by the formal health sector altogether. Strategies, especially at the micro-level are needed to identify those that have been previously missed so they can be targeted for services.

Geographic Information System (GIS) technology offers a potential solution because it can aid in the development of detailed, accurate maps, often revealing households or communities that had not been known previously; identify micro-level variations in coverage that had been obscured using more aggregated data; and allow for modeling and prediction, such as predicting how coverage would be affected if vaccination sites were added.

CONTEXT

In Zambia, children can be immunized through routine service delivery at facilities; during national mass non-selective campaigns (which are designed to vaccinate children who did not receive routine doses and are carried out every four to five years); and through outreach activities in communities including mobile and door-to-door vaccination services.

Since 2017, initiatives have been underway to strengthen routine immunization service delivery including dissemination of EPI guidelines, training a national training pool on the Reaching Every District/Child (RED/C) approach, orienting frontline health care workers (HCWs) and providing supportive supervision and mentorship in select districts, funding district-level outreach, and implementing biannual child health days.

EVIDENCE ON GIS MAPPING AS A TOOL TO REACH ZERO-DOSE CHILDREN

GIS mapping can identify remote or hard-to-reach communities that are often missed by immunization efforts (UNICEF, 2016). This is important when planning and implementing immunization activities and promoting more equitable coverage and resource investment among these groups. GIS mapping can provide insights to identify "chronically missed settlements and locations with the highest number of zero-dose and under-immunized children," producing reliable target population estimates to improve the number of vaccinated children and informing immunization managers to strategically and optimally allocate resources (Gavi, 2020). GIS approaches can strengthen immunization activities, improve planning for integration of services, and improve equitable service delivery.

Civil Society Organizations (CSOs), community health workers, and community health volunteers play an important role in increasing demand at the community level through social mobilization, edutainment, door-to-door outreach, and defaulter tracing. The Health Promotion Unit within the Department of Health Promotion, Environment and Social Determinants leads advocacy, communication, social mobilization, and engagement of influential stakeholders. Community engagement can also facilitate identification of zero-dose children, tracking and follow-up.

Challenges include demand side issues (e.g., cultural, religious, or traditional beliefs of caregivers); access issues (e.g., living far from a facility, living between two facility catchment areas, or living near a facility that does not have cold chain capacity); and supply side issues (e.g., stock-outs or insufficient stocks of vaccines at facilities that serve large dense urban catchment areas).

METHODS

Data for this case study were collected during qualitative interviews with key informants supplemented with data from published and grey literature. Key informants worked with the Zambia Expanded Programme on Immunization (EPI) and its international partners, including those involved in a GIS mapping activity that took place in Choma District in 2020. Interviews were conducted in June and July 2023. Informants shared their perspectives on why GIS mapping was selected as an intervention to identify and reach zero-dose children and how the approach can contribute to closing the immunization gap. This data allows us to understand key informants' perspectives on the value and challenges of utilizing GIS mapping as a tool to identify and reach zero-dose children. However, the qualitative nature of the data does not allow for the formal, quantitative evaluation of GIS.

2. USE OF GIS MAPPING TO IDENTIFY ZERO-DOSE CHILDREN IN ZAMBIA

GIS mapping of households is one strategy Zambia has used to inform service delivery planning and target strategies to identify and reach zero-dose households. Use of GIS mapping increases the identification of zero-dose children, reach to missed children and communities, and monitoring of immunization efforts, aligning with Gavi's IRMMA Framework to increase equity in routine immunization programs.

WHAT IS GIS MAPPING?

GIS are a "collection of computer software and data used to view and manage information about geographic objects, analyze spatial relationships, and model spatial processes" (Gavi, 2020). GIS systems are used to gather and organize spatial data and related information for both display and analytic purposes. Geospatial technologies have been successfully used to improve immunization programs by strengthening planning and preparation, delivery of vaccines, and data and monitoring (UNICEF, 2016). GIS mapping specifically involves the use of computer software to compile data and spatial models to create a visual representation of geographic data in the form of maps.

INTERVENTION

GIS mapping was used in 2020 to identify and reach eligible zero-dose children in Choma District; to conduct an analysis of factors associated with zero-dose status; to assess heterogeneity in vaccination coverage at the micro-level; and to predict changes in coverage if additional vaccination sites in specific areas are added (Arambepola, 2021).

Zambia's Ministry of Health, district health leadership, facility providers, community health workers (CHWs) and community health volunteers (CHVs) collaborated with a study team to use GIS mapping software to identify and reach zero-dose children for a measles and rubella vaccination campaign. The study team (comprised of the Johns Hopkins University International Vaccine Access Center [JHU IVAC], Akros Zambia, and Macha Research Trust) used satellite geospatial imaging to identify households and create detailed community maps. Facility providers and CHWs confirmed catchment area boundaries for each facility. CHWs, CHVs, and community members used those maps to enumerate households and identify all vaccine eligible children, including those that were zero-dose.

After the MOH conducted a mass measles and rubella vaccination campaign in November 2020, households that had previously been identified with zero-dose children were re-visited by CHWs and CHVs to see whether the children had been reached. Those who remained unvaccinated were offered vaccines at their home.

The study team analyzed data from the GIS mapping and household visits to identify factors associated with zero-dose status before the national mass campaign. In addition, geospatial modeling was used to calculate DTP and measles zero-dose prevalence, to assess the likelihood of a zero-dose child being vaccinated during the campaign, and to identify optimal locations throughout the district to add additional outreach sites in future campaigns.

LEVEL OF IMPLEMENTATION

This GIS mapping initiative was carried out in 10 health facility catchment areas of Choma District, Southern Province. Two of the catchment areas are densely populated and urban, while the other eight are rural. Overall vaccine coverage in Choma District is high (DTP1=99%, MCV1=93%, and MCV2=73%), though pockets of under- or un-vaccinated children remain (Arambepola, 2021).

This activity took place at the same time as Zambia's nation-wide non-selective measles campaign. It was critical to plan the GIS mapping activity around the dates of the national campaign to determine if the campaign was reaching the identified zero-dose children.

CHALLENGES ADDRESSED BY INTERVENTION

Use of GIS mapping addressed the following challenges that immunization programs often face in identifying and reaching zero-dose children (Arambepola, 2021):

- Identifying the location and prevalence of zero-dose children within a community, as they are less likely to be engaged with routine health care services or the formal health sector.
- Underrepresentation of remote or marginalized communities in studies or surveys, which often recruit participants who are already engaged with the health care system.
- Targeting outreach activities to zero-dose children given a limited understanding of their location or barriers to vaccination.
- Determining if routine or mass vaccination campaigns reach underserved communities or individuals.
- Continuing to reach the same households or communities that already access routine health services during mass campaigns.
- Developing microplans that rely on less accurate hand-written maps of communities.

REVEAL: AN OPEN-SOURCE GIS PLATFORM

Reveal is an open-source platform that uses geospatial data to drive delivery of health interventions (Reveal, 2023). Reveal ensures equitable access to life-saving immunizations and other services by supporting field teams to identify where people live and what services are needed. Reveal promotes powerful analytics by combining geospatial data and context-specific planning and accountability tools to provide necessary information that ensures all families in need are found and receive services.

Reveal is an approved Global Good through digital square and is featured in the World Health Organization's Digital Health Atlas.

3. TECHNOLOGY, COMMUNITY ENGAGEMENT, AND DATA ANALYSIS FACILITATED IMPLEMENTATION

CREATING DETAILED MAPS THROUGH GIS SOFTWARE

Use of Reveal software was instrumental for this GIS mapping initiative in Zambia. First, Reveal was used to create maps from satellite images, with the maps identifying all built structures within the community. Facility staff and CHWs identified facility catchment areas and major landmarks, which were uploaded into the maps. CHVs used Reveal's mobile, map-based interface to visit each structure and enumerate households and identify and register eligible children under 60 months of age. Household data were uploaded into the platform, including immunization status of each eligible child (allowing for identification of zero-dose children). After the mass vaccination campaign was complete, CHVs re-visited homes with eligible children and recorded their immunization status in the Reveal platform. The geospatial and household data made it possible for the district and study team to identify and track zero-dose children, conduct analysis on drivers of zero-dose status, and model the effects of additional outreach sites.

> "Micro planning is now informed by better maps than the handwritten maps. It reveals areas where nobody's attending facilities, particularly the bordering areas between catchment areas."
>
> —Key Informant

LOCAL OWNERSHIP AND COMMUNITY ENGAGEMENT INSTRUMENTAL FOR SUCCESS

District-level interest and commitment was vital to ensure data would be used to inform programming. District health leaders took ownership of the GIS mapping initiative because it gave them accurate, micro-level data to plan their vaccine campaigns and outreach services, as well as routine health services. District leaders were engaged from the beginning of the project and were very supportive throughout. District leaders had previously tried to conduct mapping but without the aid of GIS technology, so interest was already high in developing better maps and data for planning purposes.

Community engagement was critical for collecting and using the data produced by GIS mapping to microplan. Communities were engaged in deciding how to identify and reach zero-dose children, including tracking and follow-up strategies. Routine immunization and mass national campaigns often take a top-down approach, with communities being told when and where to receive immunizations for their children. The GIS mapping activity took a bottom-up approach, starting with community engagement to work with and learn from communities to develop the GIS maps. Those maps, in turn, better informed planning of the national campaign and outreach services in Choma District.

EXPERTS SUPPORTED PREDICTIVE MODELLING

GIS and household data were used to predict effects on coverage of adding vaccination sites in specific areas. Experts from the study team led the modeling efforts.

PARTNERSHIPS

Partnerships facilitated the GIS mapping activity in Choma District**.** The study team collaborated with local communities, health facilities, and district leaders to plan and implement the project. International partners including Gavi, JHU IVAC, Macha Research Trust, the World Health Organization (WHO), and UNICEF among others, provided funding, technical assistance, and implementation support.

> **KEY LESSONS LEARNED**
>
> - GIS mapping better informs microplanning than hand-drawn maps. Communities and facilities continue to use the maps generated by the GIS activity for other health programs.
> - Community engagement in GIS mapping helped strengthen accuracy of maps, household data, and social accountability
> - High costs and limited technical expertise are a barrier to scale-up.

BARRIERS TO IMPLEMENTATION

COST AND TECHNICAL EXPERTISE

Cost and limited technical expertise in-country were cited as major barriers to scaling up GIS mapping in Zambia. GIS mapping requires electronic data collection, storage, and processing. In addition, community-level data collectors require tablets or smart phones and the skills to use them. GIS is a newer technology in Zambia, and there is limited expertise in-country to implement GIS mapping interventions, often resulting in the need to partner with international organizations or external experts. There is a need to build local capacity to lead GIS mapping efforts, rather than relying on international organizations or short consultancies. To address the cost challenge, the government is currently planning and budgeting for some GIS mapping activities to target zero-dose children in 23 districts across Zambia in the next two years. One informant suggested conducting GIS mapping every four to five years (during national campaigns), instead of annually, to save on costs. GIS mapping initiatives should plan to build capacity of community-level data collectors to use the requisite technology.

ADAPTING TO THE COVID-19 PANDEMIC

The GIS mapping activity took place in the fall of 2020, when the COVID-19 pandemic was taking a toll in the Southern Province. The pandemic had little effect on the GIS mapping activity but a greater effect on the ability to roll out the national vaccination campaign and outreach activities. Health facilities would normally provide immunization outreach services in the community, but during the pandemic many of those outreach activities stopped, resulting in missing families that live far from facilities and rely on outreach services. In addition, COVID-19 caused mistrust of the health system. During the November 2020 national mass vaccination campaign, communities needed clear, easy-to-understand information about immunizations before deciding to vaccinate their children. Community engagement and demand generation thus became a key enabler during this time to reach all eligible children with immunizations.

4. RESULTS

HOUSEHOLDS WITH CHILDREN UNDER 5 MAPPED AND REGISTERED, INCLUDING ZERO-DOSE CHILDREN

Detailed maps were created that allowed for identification of all households. Aerial satellite imagery identified 41,952 built structures in the district, which comprised 10,758 households (some households were comprised of multiple structures). Household visits conducted by CHVs registered all eligible children, and allowed for a deeper understanding of who had been missed to date. A total of 13,519 children were eligible for the study, of whom 1,870 (13.8%) were younger than 9 months and eligible for DTP1; 11,649 children were 9-60 months and eligible for the MCV1 vaccine. Of these children, 322 were classified as zero-dose for DTP1, and 470 were classified as zero-dose for MCV1 (Arambepola, 2021).

"When we used GIS, we discovered that zero dose children live in boundary areas where they don't know which clinic they belong to. When you ask the parents of most missed children, they will say "No, we go to this clinic." So there's that confusion somehow. So, they are actually neglected because even the staff were thinking that they belong to the other clinic, and they don't get followed up."

— Key Informant

There was significant variation in DTP and measles zero-dose prevalence prior to the national campaign by facility catchment area, with Batoka catchment having low prevalence (7.1% for DTP1; 0.2% for MCV1); and Kamwanu catchment having high prevalence (58.9% for DTP1; 3.7% for MCV1) (Figure 1). Within catchment areas, there was some variation in DTP1 and MCV1 coverage before the campaign, as well as variation in the campaign's effectiveness in reaching zero-dose children. For example, zero-dose prevalence increased as distance to the nearest health facility increased, as well as in areas that were approximately equally distant between two facilities. This data revealed where children are most at risk of outbreaks despite high national or even district-level coverage of vaccination (Arambepola, 2021).

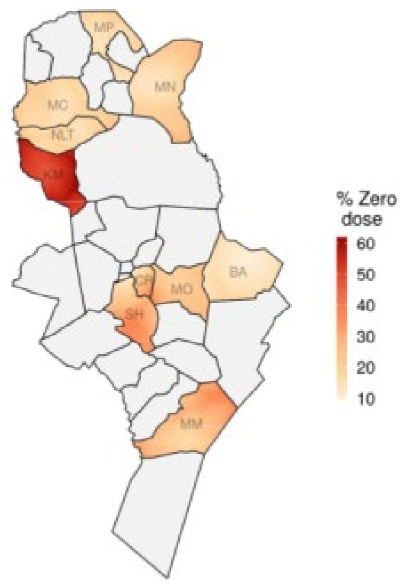

Figure 1. GIS mapping and household visits revealed variation in DTP1 zero-dose prevalence between catchment areas (Arambepola et al., 2021; Creative Commons Attribution 4.0 https://creativecommons.org/licenses/by/4.0/).

NEARLY ALL ELIGIBLE ZERO-DOSE CHILDREN REACHED WITH IMMUNIZATIONS DURING CAMPAIGN AND OUTREACH ACTIVITIES

Nearly all zero-dose children who were categorized before the national campaign and followed up after the campaign and outreach were vaccinated. Table 1 displays the reported study results from the pre-and post-campaign period (Arambepola, 2021).

Table 1. Identified zero-dose (ZD) children reached with vaccinations during the national campaign and outreach activities

Age	Eligible and registered in study	Classified as zero-dose[1]	ZD children vaccinated during national campaign	ZD children vaccinated during outreach activities	ZD children who remained unvaccinated
< 9 months	1,870 (13.8%)	322 (17.3%)	n/a[2]	n/a	n/a
9-60 months	11,649 (86.2%)	470 (4.3%)	338 (73.3%)	118 (25.6%)	5 (1.1%)

"There was suspicion that campaigns were just vaccinating the same children who came to the clinics. With GIS, we went around and mapped children and their vaccination status. After the campaign, we found we were reaching the same children. GIS mapping unveiled unreached communities."

—Key Informant

FACTORS ASSOCIATED WITH ZERO-DOSE CHILDREN IN CHOMA DISTRICT WERE IDENTIFIED

Data analysis found the following factors were associated with zero-dose status prior to the campaign (Arambepola, 2021)

- Zero-dose prevalence decreased as age of child increased.
- Zero-dose prevalence increased as travel time to nearest health facility increased.
- Zero-dose prevalence was higher in households located between two facilities (i.e. at the edge of two facility catchment areas).
- Zero-dose prevalence was higher in households with at least one younger eligible child.

[1] Zero-dose classification: children younger than 9 months who had not received DTP1; children 9-60 months who had not received MCV1.
[2] The study did not conduct a post-campaign check for the entire under 9 month zero-dose group. Of the 322 zero-DTP1 dose children, 104 were followed up, of which 31 were now over 9 months and received the MCV1 vaccine, 67 were given the DTP1 vaccine, and 6 remained unvaccinated.

MODELING GIS DATA TO OPTIMIZE FUTURE CAMPAIGN AND OUTREACH PLANNING

The study team used the geospatial household data to model the effect of placing additional campaign or outreach sites. The model estimated that locating additional campaign sites in catchment areas where the most zero-dose children live and no site exists within a 60-minute walk (i.e., Shampande and Mapanza catchment areas) would have the greatest effect. Researchers were able to map the optimal geographic location of additional outreach sites, which can be useful in planning future immunization activities within limited budgets (Figure 2).

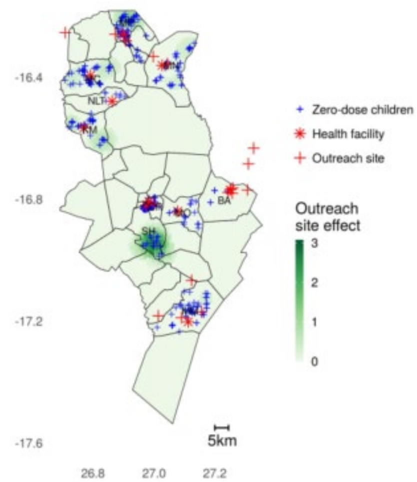

Figure 2. Geospatial models identify optimal locations of additional outreach sites (Arambepola et al., 2021; Creative Commons Attribution 4.0 https://creativecommons.org/licenses/by/4.0/*).*

5. SCALE-UP REQUIRES FUNDING, CAPACITY BUILDING, COLLABORATION WITH HEALTH AUTHORITIES, AND THOUGHTFUL PLANNING

GIS mapping was an effective approach to better identify and reach zero-dose children with immunizations in Choma District. The GIS mapping approach is viewed as so promising that several informants suggested applying GIS technology to better target other public health interventions (beyond immunization) to underserved populations. Scaling up will require dedicated funding, building local capacity for GIS technology, high interest and ownership by district health authorities, and strong community engagement strategies.

Despite the potential of this technology to close the immunization gap in Zambia and elsewhere, it has not yet been widely adopted, likely due to high costs and limited in-country expertise. GIS is a resource-heavy intervention with technical expertise needed for design, implementation, analysis, and interpretation. In addition, reliance on unpaid CHVs for household visits calls into question the fairness and sustainability of relying on unpaid volunteers.

To address the issue of cost, GIS-based microplanning scale-up is included in Zambia's approved Full Portfolio Planning from Gavi. Funding is specifically set aside to build capacity in 23 districts to implement digitized GIS microplanning processes targeting communities with zero-dose children. With this dedicated funding over the next two years, additional districts will be able to use GIS mapping to plan, evaluate, and learn about the effect of additional service delivery points and outreach services in reaching zero-dose children.

Creating geospatial models from GIS data that predict optimal locations for additional immunization sites will only be useful if that information is acted upon. It is therefore crucial to work with local and national health authorities to plan the timing of any GIS initiative to provide timely information that can be used to plan additional sites before a national mass campaign. Now that local health authorities in Choma District have the modeled locations for additional outreach sites, there is a need to implement and evaluate these sites to determine if they can sustainably reach missed households and communities with routine services. Such an evaluation could be part of the country's learning agenda.

The research team is currently planning a study to further explore the reasons that zero-dose children have been missed, focusing on factors at different levels of the health system (e.g., national policy, district, health facility, community, household).

REFERENCES

Arambepola RY. Using geospatial models to map zerodose children: factors associated with zero-dose vaccination status before and after a mass measles and rubella vaccination campaign in Southern Province, Zambia. BMJ Global Health. 2021 Dec;6(12):e007479.

Gavi. Joint Appraisal Report 2018 Zambia. Geneva; 2018.

Gavi. Improving immunization coverage and equity through the effective use of geospatial technologies and data. Geneva; 2020.

Reveal. How do you ensure no one is missed by life-saving health services? 27 July 2023. Available from: https://revealprecision.com/

UNICEF. Improving vaccination coverage and reducing inequities: Use of GIS in immunization programs. New York; 2016.

World Health Organization, UNICEF. WHO/UNICEF Estimates of National Immunization Coverage (WUENIC). Geneva and New York; n.d. Available from: https://immunizationdata.who.int/pages/profiles/zmb.html

Zambia Ministry of Health. Zambia National Health Strategic Plan 2017-2021. Lusaka; 2017.

Zambia Ministry of Health. 2022-2026 National Health Strategic Plan. Lusaka; 2022.