GIS Mapping:

Evidence on pro-equity interventions to improve immunization coverage for zero-dose children and missed communities

*Part of a series, this evidence brief presents results from a **rapid review** of the literature to understand the effectiveness of and implementation considerations for selected interventions, including GIS data, which could help achieve more equitable immunization coverage, specifically helping to increase coverage and better reach zero-dose children and missed communities.*

EVIDENCE SUMMARY

What is GIS mapping?	**Geographic information systems (GIS) technology** uses computer software to compile data and spatial models to create a visual representation of geographic data, often in the forms of maps. This technique is known as **GIS mapping** and has become a more common tool in planning and implementing immunization activities over the last decade.
How effective is GIS mapping in identifying zero-dose children and missed communities? PROMISING INTERVENTION	Based on findings from identified primary research studies, **GIS mapping is a promising intervention for identifying zero-dose children and missed communities**. Results from eight effectiveness studies found meaningful increases in vaccine coverage following the use of GIS mapping, with five focused on impacts specifically with unvaccinated children or those in vulnerable contexts. Many case studies from the **gray literature** relevant to GIS mapping were identified. These case studies overall found **positive results linking GIS mapping with improved vaccination coverage**, specifically in identifying zero-dose children in **migratory, rural, and conflict-affected settings.** The published literature found **similarly positive results** across a variety of settings**,** specifically with the implementation of **GIS mapping on national and regional levels.**
What are the main barriers and facilitators to implementation?	**Major facilitators** to implementation include **using field teams to verify maps**, building maps from **freely available databases**, and **potential cost efficiencies**. **Major barriers** include the need for **more rigorous training** for data collectors, **risk of technology failure** in the field, and **lack of access to accurate data sources**.
What are the key gaps?	**Key gaps** include **the lack of systematic reviews** synthesizing existing evidence, a need for **more rigorous studies**, insufficient application to subnational contexts and for routine immunization, lack of application to address **gender-related barriers**, and a general **lack of historical data** because of the novelty of the approach.

INTRODUCTION

What is GIS mapping?

Geographic information systems (GIS) can be defined as “a collection of computer software and data used to view and manage information about geographic objects, analyze spatial relationships, and model spatial processes” (1). 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 (2). 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.

Why is GIS mapping relevant for identifying zero-dose children and missed communities?

GIS mapping has been suggested as a means to identify remote or otherwise hard-to-reach communities that are often missed by immunization efforts (2). The identification of missed communities is important when planning and implementing immunization activities and promoting more equitable coverage and resource investment among these groups. GIS mapping can provide precise insights in relation to the location of health services as well as population settlements, identifying where inequalities may be particularly prevalent (1). Both UNICEF and Gavi have noted the role that GIS mapping can play in identifying zero-dose children and missed communities for immunization services (1, 2). Due to the significant potential of GIS to reduce inequalities, this evidence brief’s objective is to understand the effectiveness of GIS mapping in identifying zero-dose children and missed communities. This brief also considers factors influencing implementation of GIS mapping activities.

Theory of Change for the use of geospatial technologies for immunization programming

The framework presented below—first developed by Gavi, UNICEF, and HealthEnabled—focuses on using geospatial methods, data, and tools, including GIS mapping, to improve a wide range of activities related to immunization programming. The framework prioritizes identifying “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. This theory of change is a guide for interested groups, such as program managers, implementers, and funders, to outline how GIS approaches can strengthen immunization activities, improve planning for integration of service, and improve equitable service delivery. In this brief, we focus on evidence on utilization of the first column of the figure below related to identification and GIS mapping specifically.

Theory of change for the use of geospatial technologies for immunization programing (3)

Health Impact	Reduction in Childhood Disability and Mortality Due to Vaccine-Preventable Diseases		
Immunization Impact	≥80% of children fully immunized in all districts and equitable coverage across population subgroups based on geographic, socio-economic and cultural differences		
Improved immunization campaigns and routine immunization programs			
Immunization Outcomes	Increased number of children immunized through improved target setting	Optimized immunization resource distribution and location of services	Improved quality, timeliness, and perception of immunization services with equity in coverage between communities
Geospatial Data and Technologies Outputs	Improved **identification of zero dose and under-immunized children** through more accurate microplanning and identification of missed settlements to implement appropriate vaccination strategy	Improved **planning and allocation** of immunization resources through strengthened use of geospatial data, analysis and visualisation	Improved **service delivery** through better planning, monitoring and tracking of immunization activities for rapid problem identification and corrective action
Geospatial Data and Technologies Inputs	Produce and regularly update digital maps for health area planning based on health resources mapping through a participatory process involving local health staff to map immunization resources	Optimize distribution of resources (workforce, funding, vaccines and supplies) based on more accurate target population distribution and identification of gaps in coverage and immunization service accessibility based on geospatial accessibility analysis, coverage modelling, forecasting and other new innovations and applications	Track service delivery by location of vaccinator activities and geographically-linked notifications, immunization sessions, supervision and allocation of financial resources
Geospatial Data & Immunization Foundations	**Health System Mapping (essential):** Develop and maintain master lists and data standards for health facilities, vaccination delivery sites and cold chain, settlements, infrastructure, health area boundaries and other core geographic objects **Population Estimation (essential):** Generate and use accurate population estimates (human density and distribution) to establish targets (denominators) in immunization program planning **Analytics & Modeling for Accessibility, Coverage, and Surveillance Planning and Monitoring (when possible):** Use modeling to understand geographic accessibility to services, vaccine distribution, and immunization coverage with links to data (through HIS, IHRIS, and eLMIS) on vaccine-preventable diseases and adverse events following immunization (AEFI)		
Enablers	• Clearly defined vision, strategy and plan for a geo-enabled HIS/immunization program • Information system governance structure including custodianship of geospatial data and technologies • Policies supporting and enforcing the strategy and governance, including data accessibility • Necessary human and financial resources to ensure effective use and sustainability of geospatial data and incorporation of new technologies and innovations over the long-term		

Why was this evidence synthesis on GIS mapping undertaken?

The overall goal of this activity was to synthesize existing evidence on the effectiveness and implementation of GIS mapping to **identify** communities facing vulnerabilities in the context of immunization activities. Through a rapid review of peer-reviewed and gray literature, this work aimed to:

1. Explore how GIS mapping activities are used to identify zero-dose children, missed communities, or otherwise under-immunized populations.
2. Evaluate the extent to which current GIS mapping practices are effective in identifying zero-dose children, missed communities, or otherwise under-immunized populations.
3. Identify the main implementation considerations for carrying out GIS mapping, specific to identifying zero-dose children, missed communities, or otherwise under-immunized populations.

Notably, the original objective of this review was to synthesize evidence on the ability of GIS mapping to support *identification* of zero-dose children and missed communities. However, upon review of the literature, a lack of evidence on GIS interventions specifically and exclusively designed to improve identification was found. Outcomes were often related to indicators more relevant to *reaching* communities in vulnerable contexts, such as improved vaccination coverage. While studies needed to include results or discussion related to identification to be eligible for this rapid review, results related to reach were also included, as improved coverage can serve as a proxy for improved identification (i.e., for missed children to be vaccinated, they must first be identified). Therefore, exploring how GIS mapping activities are used to reach zero-dose children, missed communities, or otherwise under-immunized populations and their effectiveness and implementation considerations was included as a secondary objective. More information on the review methods is included in Appendix A.

RESULTS: What is known about GIS mapping?

Thirty-one eligible articles and reports were included—23 implementation-only studies, 7 studies relevant to both effectiveness and implementation, and one effectiveness-only study—most of which demonstrated promising results. Over half of the included articles were published in 2020 or later, which speaks to the growing interest in GIS mapping. The study settings were concentrated in Africa (71%), with 43% of all articles included being implemented in Nigeria. Twenty-two studies referenced equity when describing their intervention or reporting on intervention outcomes. Of those, 16 studies focused on missed or underserved populations.

Overall categorization of effectiveness

To help program planners assess whether an intervention, such as GIS mapping, should be considered for identifying zero-dose children and missed communities, a categorization scheme was used to rate interventions as potentially ineffective, inconclusive, promising, or proven. A more detailed description of this categorization can be found in the general methodology for reviews in this series [linked on the evidence map website].

Categorization	Rationale
PROMISING INTERVENTION	**All eight effectiveness studies showed positive results demonstrating that GIS mapping aids in identifying zero-dose and under-immunized communities across a variety of settings.** These studies revealed key impacts such as fewer missed settlements, an increase in vaccinated children, and improved identification of areas to be targeted. In addition, studies provided evidence of GIS mapping being used to effectively model predictors of vaccination status, such as distance to vaccination sites and remoteness of settlements. However, while studies demonstrated GIS mapping is helpful in broader contexts such as producing area maps and tracking field teams, it has limitations in more nuanced applications. Notably, there were no randomized controlled trials (RCTs) or other experimental study designs with a comparison group identified, and evidence is relatively new given the rising popularity of the technology. Additionally, many studies included results related to reaching children with immunization and not exclusively identifying them, and few studies discussed application of GIS mapping for identification within routine immunization. GIS mapping was most commonly used successfully in **migratory, rural, and conflict-affected settings.** Due to these limitations, this approach was categorized as "promising." More rigorous effectiveness studies evaluating GIS mapping across more precise outcomes, particularly related to

	identification and estimating coverage gaps for prioritization, are needed before the intervention can be classified as "proven."

Specific evidence for deriving this categorization is presented below.

Effectiveness: What is known about whether GIS mapping "works"?

What evidence has been synthesized previously on the effectiveness of GIS mapping for identification purposes?

No relevant peer-reviewed systematic reviews on GIS mapping were identified from 2010 to present; the evidence presented here is therefore based on individual published studies.

What evidence exists on the effectiveness of GIS mapping specific to identifying zero-dose children or missed communities?

Eight studies examined the effectiveness of using GIS mapping within immunization and all found positive results related to identification of zero-dose children or missed communities. Studies reported on a variety of use cases, including microplanning (including using GIS mapping to derive better local maps, identify optimal vaccination sites, and improved tracking of population movement/displacement) (4-7), tracking vaccinators to identify missed households (8, 9), identification of priority areas (10), and estimation of coverage/missed areas that need to be targeted (9, 11). Four studies discussed GIS mapping related to immunization campaigns (5, 6, 8, 10); no studies focused on routine immunization were identified. Below are detailed study descriptions:

- **GIS-generated ward-level maps were used during measles microplanning across Nigeria.** A study in Nigeria compared two microplanning approaches for its measles vaccination campaign: the northern states used GIS-generated ward-level maps to develop microplans while the southern states used the traditional "walk through" technique. A random sample of maps from both regions were validated and scored for accuracy based on population estimates, settlement layouts, and placement of vaccination sites. The plans using GIS technology had less variation in the northern states (8.2% variation in total target population) and so were more accurate than those in southern states (19.6% variation). The post-campaign survey found that none of the sampled areas in the northern states reported 0% vaccination coverage, except for one enumeration area (EA) in a state with security issues. Of the 11 EAs that had 0% vaccination coverage, ten were in states that did not use GIS-generated maps. The survey also found that GIS mapping was more successful in determining the optimal locations for vaccine activities, which participants in northern states reported as removing a major barrier to seeking services (5).
- **During a polio supplemental immunization activity (SIA) in northern Nigeria, Gammino et al. (2014) used GPS receivers to track vaccination team movements.** Their routes were overlaid onto satellite imagery and compared with hand-drawn route maps. The results highlighted low fidelity to assigned routes and swaths of households that were missed. The comparison

demonstrated the utility of GIS technology in improving hand-drawn maps and the benefit of tracking field teams in real-time (8).

- **Because of ongoing conflict in Nigeria's Borno state, a study was conducted using high resolution imagery to evaluate status of settlements to guide polio immunization.** Vegetation was used as an indicator of human habitation and intact percentages of settlements were determined. This study identified 662 partially abandoned settlements and 8,062 inhabited settlements. Following the mapping exercise to identify missed settlements, 180,155 under-five unreached children were reached in 2016 out of an estimated population of 337,411 (10).
- **In a southern province in Zambia, a prospective study was conducted to examine the application of GIS mapping for identifying zero-dose children and missed communities.** Before a mass measles and rubella vaccination campaign, structures in the catchment area were identified using satellite imagery and targeted for registration by community health volunteers. During the campaign, 73.3% of the children registered and identified as unvaccinated for measles were reached. Households were visited post-campaign to assess coverage rates and to target missed children. The geospatial model was also used to analyze factors associated with measles zero-dose status including being of younger age, having other children in the house, having a longer travel time to a health facility, and living between health facility catchment areas. The study also constructed a separate geospatial model of vaccination probabilities and used this to estimate the additional coverage that could be achieved by adding additional vaccination sites to the area that were not in place during the campaign. This additional exercise was able to pinpoint specific locations that could result in high impact, suggesting this methodology could be used to inform targeted vaccination activities in the future. The study showed the usefulness of GIS mapping in providing fine-scale zero-dose prevalence, which improved the campaign outcomes by mapping target populations and improving placement of vaccination sites (6).
- **A pre-post study testing the use of GIS-based microplanning at three geographic settlement levels in northern Nigeria compared the impact of these efforts in built-up areas, small settlements, and hamlet areas.** GIS microplanning was found to be highly effective in improving coverage rates in hamlet areas, which are smaller, less-known areas, with an immunization coverage of 82%, up from 43% during the previous campaign, but did not statistically improve immunization coverage in larger built-up areas or small settlements, both of which are more populated and therefore more easily identified without the aid of GIS technology. Following GIS microplanning in hamlet areas, polio vaccination coverage increased and seven new hamlet areas that were not reached the previous year were reached. Although the impacts were limited in areas larger than hamlet areas, five new small settlement areas that were not reached in the previous year were reached (7).
- **Under the guidance of the WHO and CDC, Mendes et al. (2021) conducted a "mapathon" event, a crowd-sourced method of geospatial mapping, to compare two forms of GIS-based microplanning.** During the mapathon, local community members or "mappers" digitized settlements within an area which were then compared to an automated feature extraction (AFE), or software-created maps. Both maps were reviewed by GIS supervisors. They found that

mapathons strengthen community engagement and involvement of local vaccinators, noting that this enhances inclusivity. However, AFE outputs had higher agreement with microplans developed by the local health authorities (30%, compared to 28% of agreement of mapathon features, with the difference in the average number of features identified being larger between the microplan and mapathon than the microplan and AFE), so they had higher accuracy scores. Additionally, the true positive rate of identifying structures was higher for AFE (90.5%) than the mapathon (84.5%). The authors note that the microplans are considered the gold standard of data in this case but acknowledge that the actual accuracy of the microplan is undetermined, posing a limitation to the accuracy assessment (though other accuracy assessment methods were used as well). Both activities were broadly effective means of integrating GIS techniques. The researchers suggested that GIS technology may be key to increasing health equity by improving the ability to map populations in vulnerable contexts accurately so they can be targeted for immunization activities, and concluded that while AFE may have higher accuracy in terms of detecting features, both have benefits and the best approach would involve both AFE and mapathons (4).

- **Touray et al. (2016) used GPS tracking of field teams via android phones to monitor settlement coverage, reduce the number of missed settlements, and improve team performance during polio vaccination campaigns in northern Nigeria.** Extensive mapping was carried out using satellite imagery, which improved performance and provided significant data on vaccination activities in the region. Researchers observed an improvement in geographic coverage and a reduction in the number of missed settlements based on pre- and post-campaign survey data. Zamfara and Bauchi states did not have reductions in missed communities, but this was due to security issues that prevented access of vaccination teams. Most states showed a reduction in missed and chronically missed settlements, or settlements that were missed regularly in the previous 3 years during polio campaigns, between 2013 and 2015. For example, the number of chronically missed settlements decreased from 1,298 to 165 in Kano state and from 742 to 295 in Kebbi state (9).
- **Utazi et al. (2018) used Demographic and Health Survey (DHS) data from Cambodia, Mozambique, and Nigeria to map vaccine coverage to evaluate whether GIS mapping is more precise in revealing trends and missed areas compared to large areas estimates from surveys such as the DHS.** Mapping revealed heterogeneities that were not apparent in previous summaries. Data showed that few districts had reached 80% coverage and that remoteness was a key variable in predicting vaccination status (11).

Other comparative evidence relevant to GIS mapping

A modelling study demonstrated potential effective use of GIS mapping for identifying missed communities and under-immunized populations. The study proposed a novel means of incorporating geospatial positioning with survey data for identification purposes. Mosser et al. (2019) analyzed diphtheria-pertussis-tetanus (DPT) vaccine coverage in 52 countries across Africa to identify inequalities in coverage at the subnational level by comparing national estimates to Bayesian model-based geostatistical estimates. They found that national estimates derived without geospatial positioning concealed missed communities. Using a Bayesian geostatistical model to estimate DPT coverage can help identify areas with low vaccination coverage and barriers to vaccination (12).

IMPLEMENTATION: What is known about "how" GIS mapping works?

In total, 30 sources, including 26 published articles and four gray literature reports, presented information relevant to the implementation of GIS mapping. Major barriers and facilitators to implementation reported are summarized below in Table 1.

Table 1. Barriers and facilitators to implementation

Major Facilitators	Major barriers
• Lower cost as compared to household surveys due to increased efficiencies • Technological advancement improving accuracy and increasing accessibility • Simplified logistics • Using freely available data sources • Working within existing DHS survey methodology • Verifying maps with field teams • Triangulating population data with multiple sources	• Using data sources that may be inaccurate to build maps • High start-up costs related to GIS software • Technology failure in the field—dead batteries, device malfunctions, poor cellular service in rural areas • Need for frequent training on new technology • Maps generated with satellite imagery can be outdated if significant time gap between mapping and activities • Requiring GIS-specialized team members

Implementation Outcomes

Below is a summary of specific implementation considerations related to acceptability, appropriateness, cost, feasibility, fidelity, and other factors that expands on the barriers and facilitators summarized above.

Acceptability and Appropriateness

Across many studies, GIS mapping was determined to be a useful tool for improving immunization efforts because it can aggregate large amounts of data and provide more granular information on missed communities not captured by surveys (13). Using satellite imagery, GIS maps can produce more accurate vaccine coverage estimates and offer more accurate renderings than hand-drawn maps (11, 14). Twelve studies used GIS mapping to aggregate data on a national or international level, which speaks to the appropriateness of GIS as a tool for accurately managing immunization data on a large scale (11, 13-23). In their mapping of ten African countries, Takahashi demonstrated how GIS technology increases the capacity of vaccine organizers to visualize and target cold spots (areas of low coverage), especially those that cross national borders (20). Few studies discussed the acceptability of the GIS technology itself or related issues, such as perceived data ownership.

Cost

In the context of identifying missed communities, there was consensus that GIS mapping is cost-effective, especially compared with alternatives such as improving the quality of data obtained through national health surveys, which can be costly (11, 22, 24). Two studies noted that while GIS technology can be an expensive upfront cost, costs should decrease as the technology becomes more accessible (4, 25). In their study in Mozambique, Haidari et al. (2017) estimated that $140,758-$323,693 in future health care costs and lost productivity could be saved if 40% of the target population (10-year-old girls not vaccinated with HPV immunization in 2015) was reached, facilitated by more accurate maps allowing them to find and target hard-to-reach girls with the HPV vaccine (14). To this point, Ali et al. (2020) found that immunization programs using GIS mapping incurred higher expenses than those relying on traditional microplanning because more missed individuals were identified and vaccinated, which brings increased costs, as well as costs associated with training and data collection related to the GIS method. However, the authors determined that the GIS approach was cost effective based on the cost per disability-adjusted life year averted (26).

Feasibility

Most studies discussed feasibility across a range of settings. Some studies aggregated data on a national level to identify areas of low coverage while others focused on urban poor or remote rural settings. Wild et al. (2019) demonstrated the feasibility of using GIS mapping as a mechanism to intentionally locate and include a nomadic pastoralist community in a remote lowland area between Ethiopia and South Sudan in a sampling frame for a health survey (24). Feasibility was considered high across many studies (4, 6, 9-11, 17-20, 25, 27-30) mostly because of reduced cost, higher efficiency, and simpler logistics compared to traditional survey techniques (5, 14). Two studies iterated that GIS mapping should be used more widely in immunization efforts and across different settings (13, 22).

Several challenges to feasibility were cited throughout the articles. Issues related to GIS technology—like missing data or coordinates in maps (15) and weaknesses of specific GIS programs in picking up clusters—were study-specific (16). Likewise, simple failures like dead batteries in the field and GPS devices collecting coordinates outside of activity times were isolated incidents (8). Perhaps the most salient challenge is that maps can be inaccurate if there is a significant delay between map creation and their use in vaccination activities (8). Wild et al. (2019) noted that availability of high-resolution satellite imagery would significantly reduce the need for manual reconnaissance for verification and thus reduce delays between mapping and implementation and increase capacity to cover wider geographic areas (24).

A consistent theme across many studies is that the accuracy and usefulness of GIS-produced maps are limited by the quality of data used to build maps. Many protocols relied on data from national censuses, previous DHS surveys, and post-campaign estimates, which they voiced as a major concern to implementing GIS mapping to its full potential (11, 13, 16-19, 21-23, 27).

Case studies have shown using GIS technologies is feasible across different stages of immunization programs. In **Nigeria**, GIS methods were used during microplanning to identify and reach unvaccinated children in a hard-to-reach, security compromised, and migratory setting with polio vaccines. This was done by developing a list of areas with zero-dose children, or those with no previous vaccine history, and creating plans to visit these areas. Vaccinators were provided maps and location-tracking and data collection tools to support monitoring and accountability. Through GIS-supported microplanning and vaccinator monitoring, the number of unvaccinated children living in previously unreached settlements decreased by nearly 10,000: from 34,210 in 2019 to 24,994 in 2020. In addition, 2,023 settlements initially identified as “inaccessible” were reached in 2020, bringing the settlement coverage to 71% of settlements in 2020, up from 68% in 2019 (31).

In response to a polio outbreak in **Cameroon**, there was an effort to map all health districts and health service areas. These efforts were prioritized to improve future planning and preparation for immunization campaigns and strengthen polio surveillance efforts. While the impact of the health mapping activities on immunization activities was not isolated and reported, the program was perceived as successful, and the new maps were integrated into the national Health Information System to improve planning. The activities were scaled and prioritized in the 2020-2024 Digital Health Strategy, with efforts to routinely update facility lists and provide capacity training to incorporate geospatial data (1).

In **Myanmar**, GIS methods were used to improve immunization coverage in populations in vulnerable contexts. Efforts to improve immunization inequity using GIS methods were prioritized after a review of the Expanded Program on Immunization (EPI) showed high numbers of missed children in special populations, especially within cities, urban settlements, and unregistered settlements. These efforts were aligned with and strengthened by ongoing efforts by the Ministry of Health to geo-enable the Health Information System. The use of GIS data in Myanmar provided information on population distribution and supported the maintenance and sharing of master lists for health facilities, communities, and other areas of interest. This improved the EPI’s ability to identify inequities in vaccination coverage and health outcomes, reprioritize and allocate available resources to areas with poor service delivery to mitigate with waste, and monitor immunization progress in reaching national and global development targets. These activities have led to sustained systematic improvements (2, 32).

Fidelity

Studies did not discuss the fidelity, or the extent to which the intervention was carried out as intended, in relation to identification. However, fidelity of GIS mapping in terms of reaching children with immunization was touched on in several articles. This gap may reflect challenges of linking identification of missed communities using GIS mapping with activities to reach them.

Gammino et al. (2014) used GPS coordinates to create maps of catchment areas that were then used to draw routes for vaccinators, but they noted that teams did not always follow the pre-planned routes (8). One study used GIS technology to support real-time reporting from teams in the field and found it to be an effective monitoring technique because it ensured activities were being completed correctly (33). In addition, gray literature showed how GIS activities have been used to support the planning and monitoring of integrated campaigns. In **Nigeria**, a program that delivered polio immunization and vitamin A together through an integrated platform in rural, hard-to-reach areas was strengthened by GIS methods. GIS technology allowed field teams to be tracked with GPS data in real-time by supervisors, which improved accountability and fidelity to ensure that the activities were implemented as planned (33).

Examples of implementation by GIS mapping intervention type

Implementation studies presented the use of a variety of GIS mapping approaches. Examples highlighting the diversity of GIS mapping use cases are described in the table below with a specific emphasis on geographic level and equity reference group (ERG) settings.

GIS mapping intervention type	**Example of intervention**	**Geographic level (ERG setting)**
Vaccination coverage and population modelling	Data from Demographic and Health Surveys (DHS) were aggregated to map spatial patterns of measles vaccination across ten African countries. Some highlighted cold spots were transnational, authors recommend collaboration to address coverage gaps (20).	Regional
	DHS data were used to map coverage at a 1x1 km resolution in Nigeria, Ethiopia, the Democratic Republic of Congo, Cambodia, and Mozambique. Coverage of DTP3 and MCV were compared as proxies for routine immunization and supplementary immunization activities (SIA), respectively (13).	
Identification of priority areas/barriers to vaccination	Geospatial analysis of four rounds of India's National Family Health Survey mapped patterns in prevalence, distribution, and drivers of zero-dose children over a 24-year period. Malnutrition, low socioeconomic status, and urban or rural settings were strong predictors of zero-dose (16).	National
	An ecological study in Ecuador combined data from a measles immunization survey with recent census data and performed multiple spatial regression to assess a correlation between socioeconomic status and vaccination status (19).	
	Data from post-campaign coverage surveys produced maps comparing the effectiveness of specific immunization campaigns and identified persistent cold spots in Nigeria. Authors recommend methodology as readily scalable for implementation in other low- and middle-income countries (22).	
	Using satellite imagery and vegetation growth as a proxy for habitation, researchers developed more accurate estimates of	Subnational (conflict-affected)

	polio zero-dose children in Nigeria. Villages in Borno state were previously inaccessible due to conflict with Boko Haram (10).	
Session/vaccinator tracking	During polio SIAs in northern Nigeria, field teams carried GPS trackers overlaid on satellite imagery to identify commonly missed areas and allow for real-time monitoring. Aerial views of dense urban areas in Kano district improved efficiency of vaccination teams (8).	Subnational (urban poor)
	For a polio vaccination campaign in Nigeria, GIS-based maps provided accurate and specific locations for hard-to-reach settlements and vaccination teams were monitored in real-time using GPS to ensure coverage (28).	Subnational (remote rural)
Microplanning	Nomadic groups are often "invisible" to traditional DHS survey coverage. Geospatial sampling methods allowed researchers in Ethiopia to locate and survey the Nyangatom pastoralist community on core maternal and child health indicators, including vaccination status (24).	Subnational (Remote rural)
Geographic accessibility	A model was created to measure spatial access to COVID-19 vaccination centers in urban Mashhad, Iran. The mapping identified the periphery and poor areas of the city most isolated from vaccination services (30).	Subnational (urban poor)

Existing evidence gaps and areas for future research

This review identified several important gaps regarding the evidence base for GIS mapping and its ability to identify zero-dose and under-immunized children and missed communities:

- **There is a lack of systematic reviews on GIS mapping specific to its utility in "identification" for immunization programs.** Given the overall positive results of individual studies identified in this rapid review, a formal synthesis of current evidence would be beneficial.
- **The use of GIS technology in health interventions is still relatively new** and considerable advancements have been made even in the last five years. While the evidence available is promising, more nuanced applications and implications need to be evaluated, especially as the technology continues to evolve. Studies identified did not thoroughly discuss the acceptability and capacity of implementers to widely use GIS mapping, which would be an important consideration in future research.
- **A standardized categorization of types of GIS mapping approaches used for identification purposes would facilitate learning more about each.** Uses of GIS mapping varied widely across studies identified and uses did not easily fit into existing typologies. Such a categorization could help program implementers better understand how GIS mapping could be applied to facilitate identification of zero-dose children, missed communities, or otherwise under-immunized populations.

- **Most aspects of implementation were not deeply considered** in the studies, although notably many studies involved community members in GIS mapping activities, mostly through microplanning activities. There is potential to explore community engagement as a facilitator to and benefit of GIS mapping.
- **Few studies focused on specific ERG settings.** None touched on gender-related barriers. There is an opportunity to apply GIS mapping in very specific contexts, but few have done so.
- In terms of study rigor, **no studies with a comparison group representing the absence of GIS were included in the rapid review**. There is a need for more rigorous studies to understand specific questions on effectiveness and implementation considerations, especially with the growing interest in GIS mapping as an approach to improving identification of zero-dose children and missed communities.

Limitations

Despite undertaking a comprehensive search strategy, this synthesis involved a rapid literature review; relevant citations may have been missed. Additionally, this review included only relevant peer-reviewed publications and available gray literature sources. It is possible that more evidence exists, especially programmatic data unavailable through the sources searched. Publication bias, although not formally assessed, might be of relevance, especially if successful GIS mapping approaches are more likely to be published than unsuccessful ones. Also, despite the use of standardized forms and trained staff members, data interpretation was somewhat subjective, especially given that formal, quantitative synthesis of outcomes was infeasible. Additionally, GIS mapping is just one tool working within the immunization framework, and it was iterated across several articles that GIS mapping is only as accurate as the data put into the model. Studies that relied on DHS data, post-coverage surveys, and census data were sensitive to the accuracy of the maps, which were not necessarily designed for this purpose.

Conclusions

How should pro-equity programming shift based on findings?

As GIS mapping uses novel technology across a variety of settings to identify and reach missed communities and zero-dose and under-immunized children, it may be a key tool to address inequity in immunization. Vaccination programming in low- and middle-income countries often suffers from limited resources, poor infrastructure, and high financial investment to see significant improvements in coverage rates. GIS mapping could offer an alternative approach to addresses those problems. A variety of use cases for GIS mapping are relevant to improving identification of zero-dose children and missed communities, as well as identification of barriers to immunization, both for routine immunization and immunization campaigns. For example, GIS mapping can be used to estimate vaccination coverage, identify priority areas or barriers to vaccination, track vaccinators to identify missed households, create microplans, and determine geographic accessibility. Examples of regional and national-scale GIS mapping demonstrate that by aggregating large amounts of data easily, GIS technology can provide a snapshot of coverage rates for an entire region or country—or even more than one country—and can highlight geographic disparities missed using other means. The limitations previously discussed remain, including challenges related to feasibility, fidelity, and limited evidence on cost, but widely integrating GIS mapping into existing identification approaches could be a unique tool in advancing pro-equity programming.

Based on the findings, should GIS mapping interventions with an equity perspective be brought to scale?

Unlike many approaches, GIS mapping does not face many challenges in scaling up to a national level for certain use cases. In fact, 14 studies implemented GIS techniques on a national or international level because the technology allows for quick analysis of large swaths of data (5, 11, 13-23, 27). This mirrors another pattern—when a country first introduces routine immunization, campaigns are often implemented at the national level to maximize reach. There is a lack of studies on discrete, focused campaigns that are rolled out to target specific regions and communities. Therefore, many studies reviewed analyzed GIS mapping related to campaigns at the national level. Some overarching findings that are relevant to scale-up are listed below.

- **Feasibility of scaling up**: There is evidence that GIS mapping can be scaled as demonstrated by regional- and national-level GIS mapping approaches. Approaches at lower levels, including in remote rural and urban poor settings, demonstrated that it is likely feasible to use GIS-generated maps to support microplanning in multiple local areas, though there would be associated costs and challenges, particularly when attempting to scale up in local areas across an entire country.
- **Cost-effectiveness**: While studies included in this review suggest that GIS mapping can be cost-effective, evidence was limited in terms of which use cases of GIS mapping are more likely to be cost-effective, and many studies did not present cost data. More information on the cost of GIS mapping for purposes of identification is required before recommendations related to scale can be made.
- **Routine immunization**: Few studies discussed the relevance of GIS mapping for identification within routine immunization efforts explicitly. Most studies focused on GIS mapping in relation to campaigns or coverage estimates/identifying priority populations in general.
- **Utilization at a local level**: While scale up to national levels is feasible and GIS mapping provides much value at large scale, there are many benefits to narrowing the scope to specific ERG settings and scaling the use of GIS maps for microplanning across multiple lower levels. As examples noted earlier, one study mapped villages in a conflict zone in Nigeria when field teams could not reach them (10). Another study used satellite imagery to find a nomadic pastoralist community so that survey teams could capture their data (24). Utilizing GIS mapping at a local level facilitates community engagement, an aspect of implementation that can be crucial for success but is often absent in remote mapping activities.

Appendix A. How was this evidence synthesis conducted?

SEARCHING, DATA EXTRACTION, AND ANALYSIS: The review followed a general methodology for all topics in this series. In brief, the methodology involved comprehensively searching electronic databases from January 2010 through January 2023, conducting a gray literature search, screening through all citations, and developing topic-specific inclusion criteria. Data were extracted into standardized forms, and results were synthesized narratively.

INCLUSION CRITERIA: We included studies that described an intervention that used GIS mapping to identify zero-dose children, missed communities, or otherwise un/under-immunized populations, or barriers to vaccinating these populations. For effectiveness studies, articles needed to present data relevant to **identification of priority populations** through GIS mapping, or **identification of barriers** to immunization for underserved populations through GIS mapping. For implementation studies, we included any description of implementing an intervention that involves GIS mapping to improve **identification of priority populations or barriers** to immunization, including factors related to adoption, feasibility, acceptability, fidelity, appropriateness, implementation cost, penetration, or sustainability, particularly as related to specific underserved geographic areas or communities. We included both effectiveness studies (defined as using a multi-arm design or using pre/post or time series data to evaluate an intervention involving GIS mapping) and implementation studies (defined as any study containing descriptive or comparative data relevant to implementation outcomes). Studies had to take place in low- or middle-income countries (as defined by the World Bank) and among a community, population, or geographic area described as vulnerable, marginalized, underserved, or otherwise disadvantaged.

SEARCH RESULTS:

- 183 articles were identified in the published literature search.
    - 149 articles were excluded during the title and abstract screening for irrelevance, leaving a total of 33 articles for the full-text review.
    - 7 articles were excluded during full text review for a total of 26 articles, including:
        - 0 existing relevant reviews
        - 7 effectiveness studies (also relevant to implementation)
        - 26 articles related to implementation
- 12 potential reports were identified in the grey literature:
    - 4 reports were included as implementation studies
- 1 study was identified through other means (through recommendations from experts in the field)
- In total, 31 articles and reports were included:
    - 8 effectiveness studies
    - 30 implementation studies

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