Using Geographic Information Systems to Meet Global Health Challenges

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Cover photograph by MEASURE Evaluation, showing HIV program managers in Iringa Region, Tanzania, using GIS maps to allocate care and treatment services to areas of greatest need.

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Abbreviations

BEmONC	basic emergency obstetric care
CEmONC	comprehensive emergency obstetric care
GIS	geographic information system
IDSR	integrated disease surveillance and response
M&E	monitoring and evaluation
QGIS	quantum geographic information system
RHIS	routine health information system
USAID	U.S. Agency for International Development
VMMC	voluntary medical male circumcision
WHO	World Health Organization

Abstract

Recent years have seen tremendous growth in interest in geographic information system (GIS) technology. These systems manage data, facilitate analysis, and generate effective information products that can support decision making. Considerable investment in health systems has increased the availability of reliable data, making GIS well suited to support global health and development activities.

At its most effective, GIS is a tool employed in pursuit of a larger objective, such as improving response to disease outbreaks, increasing access to treatment, or reducing maternal mortality. It enhances the ability of program managers to distribute services efficiently and equitably. As a supporting tool, its value may be overlooked if attention is limited to service delivery and health outcomes.

This document presents specific examples of how GIS has served programs associated with key global health and development priorities. It is intended for program managers, technical specialists, and decision makers.

GIS and Global Development Priorities

As countries strive to meet global development goals, the efficient use of resources as well as efforts to address geographic inequity will be critical. Effectively allocating limited resources requires high-quality, disaggregate data both on burden of disease and existing resource distribution. With the advent of DHIS 2 software and other eHealth systems, facility and district health data have become increasingly available in digital formats. Access to data, however, is not sufficient: Data must be processed and analyzed, and the resulting information presented to decision makers in useable formats.

> A geographic information system (GIS) can support efforts by a country or program to improve the use of health data, and thus enhance the ability of program managers or policymakers to see and address health challenges.

In this brief, we present examples demonstrating how geographic information systems are being applied across the health development sector. We focus on the use of GIS for:

Achieving an AIDS-free generation. We highlight Iringa, Tanzania, where district health managers and implementing partners used GIS to help scale up HIV prevention and treatment services (Cunningham, et al., 2014; Mahler, et al., 2015)

- Protecting communities from infectious diseases. We highlight the Ebola response in West Africa, where GIS has been used to help coordinate the Ebola response (Corbett, 2015), as well as to identify vulnerable areas for reconstruction efforts (U.S. Agency for International Development [USAID], n.d.);
- Ending preventable child and maternal deaths. We highlight western Uganda, where GIS has been used to identify gaps in obstetric care to prioritize facilities for program support (Serbanescu, 2014).

These and other examples illustrate four ways in which mapping health information can help program managers:

- Providing information needed for improved **efficiency**. This may include identifying areas of overlapping services, reviewing alignment of services with target populations, or comparing financial data and service statistics to identify costly sites with low returns on investment.
- Identifying **equity** gaps. Creating an environment for universal health coverage is a priority. Doing so will require identifying and addressing the gaps that can be caused by poor geographic access, insufficient services, or poor quality services, and might be for the population as a whole or for specific subpopulations.
- Monitor programs and understand **epidemic trends**. Mapping program coverage over time can identify areas where further scale-up or support is needed, or where strategies may need to be changed. Mapping patterns in incidence or prevalence, including morbidly or mortality hotspots, may reveal locations where programs are lacking or ineffective.
- Understand **vulnerability and context** more clearly, including demographics, economic development, populations in need of financial protections, transportation options, and (when relevant) land use patterns and disease ecology.

The opportunities for GIS for health continue to grow rapidly, due in part to three fundamental changes over the past decade: increases in data, improvements in software, and growing capacity.

- High-quality spatially referenced data, including both health facility locations and administrative boundaries, are increasingly available for general use. This may reflect increased demand for geospatial analyses and information products, as well as the broader open data movement.
- Classic proprietary systems (e.g., ArcGIS Online and ERDAS IMAGINE) have gotten better and more user-friendly; there is a growing number of open-source software options with high GIS capacity (e.g., QGIS) or more limited mapping capacity (e.g., Google Earth). Web mapping options (e.g., ArcGIS online, Google Fusion Tables, and Drupal) have seen substantial growth as a viable method for sharing large data sets with key constituencies. There has been a blending between GIS and data management tools (DHIS 2 and EpiInfo), general data analysis tools (R and STATA), and data visualization (Drupal).
- More people with basic geospatial skills are available for employment, and more resources to train them are available, as well. This human resources pool includes the historical geospatial professions (GIS analysts, geographers, and cartographers, etc.); monitoring and evaluation professionals familiar with health programs and health statistics; as well as a growing number from the data science field, with its focus on database management, analysis of big data, and data visualization.

Illustrative Examples

The following examples show how improved access to geographic, granular information has supported health programs seeking to reach major global health goals: the creation of an AIDS-free generation, ending preventable child and maternal deaths, and protecting communities from infectious diseases.

Achieving an AIDS-free generation

At the national or global level, great strides have been made in HIV treatment and prevention. National declines, however, can mask subnational clusters experiencing gaps in service, or can mask specific subpopulations where HIV prevalence and transmission remain high.

> National declines in HIV can mask subnational gaps in service, or subpopulations where HIV prevalence and transmission remain high. GIS-integrated data can reveal these opportunities for outreach.

Addressing this equity gap requires program managers to better understand such geospatial variation and demographic variation in HIV prevalence (Tanser, et al., 2009), consider existing service coverage and outcomes (Cunningham, et al., 2014), and identify transmission hotspots (Weir, et al., 2002). Survey data or antenatal care surveillance data can be used to generate "smooth" maps, which estimate prevalence and the number of persons living with HIV at a fine resolution (Zulu, et al., 2014). Maps of existing programs, service outcomes, and disease burden can be used to inform future program efforts, including scale-up of treatment coverage and increased access to and uptake of evidence-informed prevention services (Mahler, et al., 2015). Potential outreach locations for particularly vulnerable populations, such as female sex workers, orphans and vulnerable children, men who have sex with men, and people who inject drugs, must be identified for improved outreach and consequent service delivery while maintaining confidentiality to ensure protection of rights and privacy.

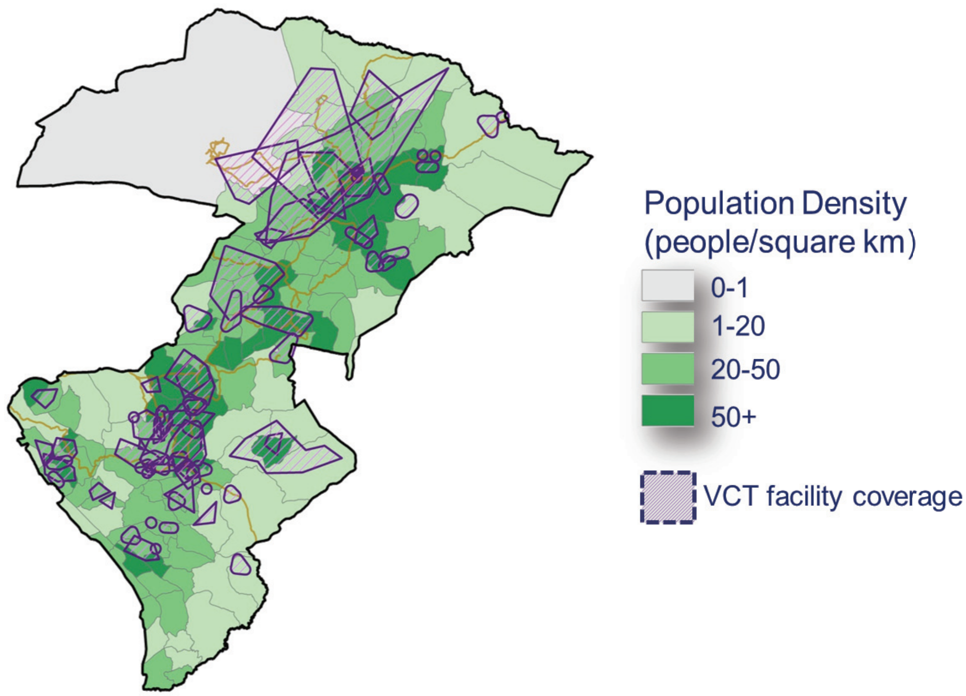
Maps can guide HIV program implementation, by supporting program managers' efforts to assess geographic and transportation barriers to care (Lankowski, et al., 2014). Access to antiretroviral therapy can be compared with patient outcomes, because patients who must travel far distances to receive services may choose to forgo them. An assessment of fixed voluntary counseling and testing or voluntary medical male circumcision (VMMC) may reveal the need for future scale-up or for mobile sites.

Finally, GIS can be used to integrate multiple pieces of data based on common geography. For instance, it can be used to integrate information on patient load, available staff, and types of services offered at facilities. This allows program managers to identify facilities that are under-performing or over-burdened and nearby facilities that could serve as referral centers. Financial data, if available at disaggregate scales, can be mapped against the services facilities offer to generate estimates of their efficiency. This process can identify facilities that require support or supervision, and also where services need to be scaled back and patients referred elsewhere. Investigating service coverage and outcomes in context with relevant ancillary data including road corridors, employment opportunities, population density, and general demographics can inform conversations about a health program's priorities.

Use of GIS to support the scale-up of HIV prevention and treatment activities in Tanzania

MEASURE Evaluation collaborated with USAID/Tanzania to build the capacity of local staff and subcontractors to provide HIV programs in Iringa Region, in Tanzania. We worked with community stakeholders to identify and map site locations of high-risk behaviors and the availability of HIV prevention materials (e.g., condoms, flyers, etc.). We also mapped HIV prevention and care and treatment sites and their catchment areas. When the maps showing locations of high-risk behaviors were linked with catchment maps, program managers could identify facilities or community-based organizations that could provide more outreach to those locations. The catchment maps were combined with population data and service statistics to estimate service coverage provided for each site. By examining unmet need, service area coverage, and priority populations together with factors such as travel distance and physical barriers, program managers could identify gaps. For example, they could use the maps first to identify an overburdened, high-volume site in a high-burden area, and then to identify alternative sites, taking into consideration proximity as well as facility capacity. This allowed them to identify a nearby clinic where care and treatment services could be scaled up.

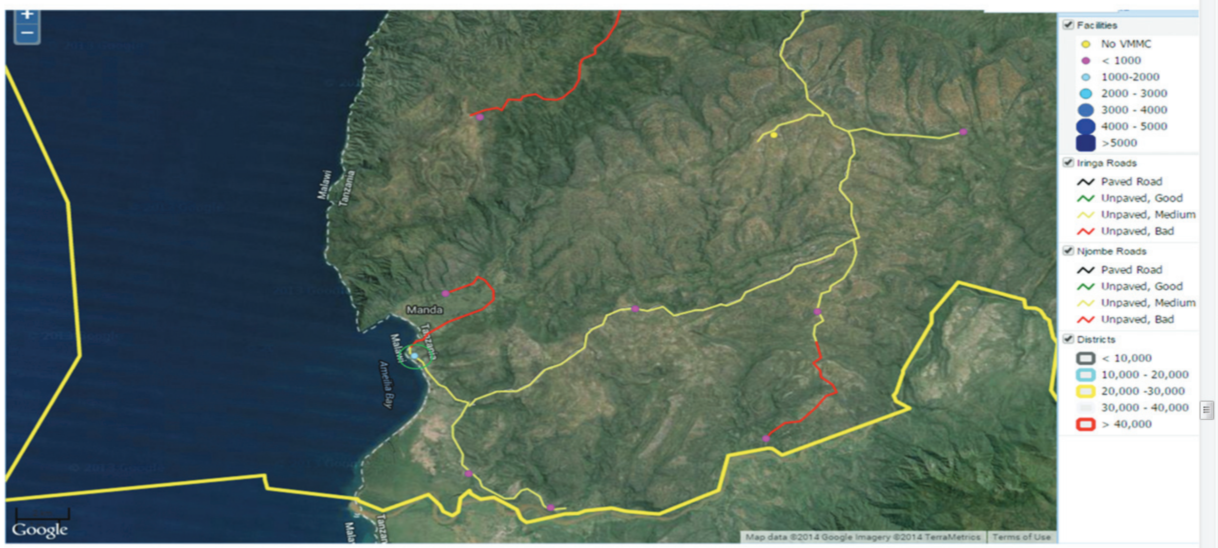
Figure 1. HIV Voluntary Counseling and Testing Facility Coverage Compared with Population Density, Iringa District, Tanzania



This map compares population density in Iringa Region, Tanzania with HIV voluntary counseling and testing facility coverage to identify potential gaps in program access (Cunningham, et al., 2014).

The USAID-funded Maternal and Child Survival Program enhanced the geospatial data that MEASURE Evaluation had collected with new information to guide male circumcision outreach and mobile services. Additional health facility locations were collected. Areas of high HIV prevalence were linked with fixed VMMC site locations and population data to identify priorities and generate estimates of the size of the populations needing service. VMMC statistics from fixed and mobile services were linked to population targets to allow program managers to track progress geographically. These maps were used to plan and prioritize additional support and mentorship for facilities already offering services, to identify rural facilities whose services could be scaled up, and to plan campaigns and mobile VMMC services based on current need and historical performance. Information on road quality enabled program managers to identify which facilities could be visited when; several were unreachable during the rainy season. The result: Over a four-year period, Tanzania's Ministry of Health and Social Welfare was able to circumcise more than 250,000 men ages 10–35, raising the regional average from under 30 percent to over 80 percent.

Figure 2. Interactive Map of Facilities Performing 0–1,000 Voluntary Medical Male Circumcisions and Quality of Roads in Tanzania



This interactive map shows facility locations, VMMC program sites, and roads. This information enabled VMMC program managers to identify low-performing facilities that might need support and determine whether they were accessible in the rainy season or only in the dry season (Mahler, et al., 2015).

Protecting communities from infectious diseases

Geospatial tools can support efforts to protect communities from infectious diseases—both emerging and pre-existing—through mapping and analyzing epidemic trends (Chabot-Couturea, et al., 2015). In an increasingly connected world, global epidemics can emerge and spread rapidly both within and across countries. Responding to existing or new threats requires rapid identification of the disease at an early stage in the epidemic, and rapid response in the right places. This requires strong, active integrated disease surveillance and response (IDSR) systems with clear channels of communication for rapid reporting. Many of these IDSR systems are electronic, and disease reports are geographically tagged to enable program managers to respond quickly. Geographic information systems can be linked with IDSRs to map cases early. General maps at high scales can be used as advocacy tools (as appropriate), enabling countries or program managers to advocate and mobilize necessary support. Maps that are more detailed can support efforts to identify the causes of the outbreaks, examine population mobility and disease transmission (Lee, et al., 2011), identify the support needed for prevention and response, and direct that support both to impacted areas and nearby areas at increased risk of transmission. In addition to enhancing the initial disease surveillance and response, GIS can be used to identify local partners working close by who can be engaged in an outbreak response; track the spread of the outbreak against the response; and support efforts to coordinate responses, by ensuring that everyone knows where everyone else is working. Linking data to web mapping applications can provide an effective way of disseminating rapidly changing information to a wide audience during a crisis or outbreak. Tracking patterns in outbreaks over time may help managers identify for further investigation locations at higher risk for an epidemic's spread.

> Using maps, program managers can build resilient health systems, by identifying and prioritizing gaps in surveillance networks and services.

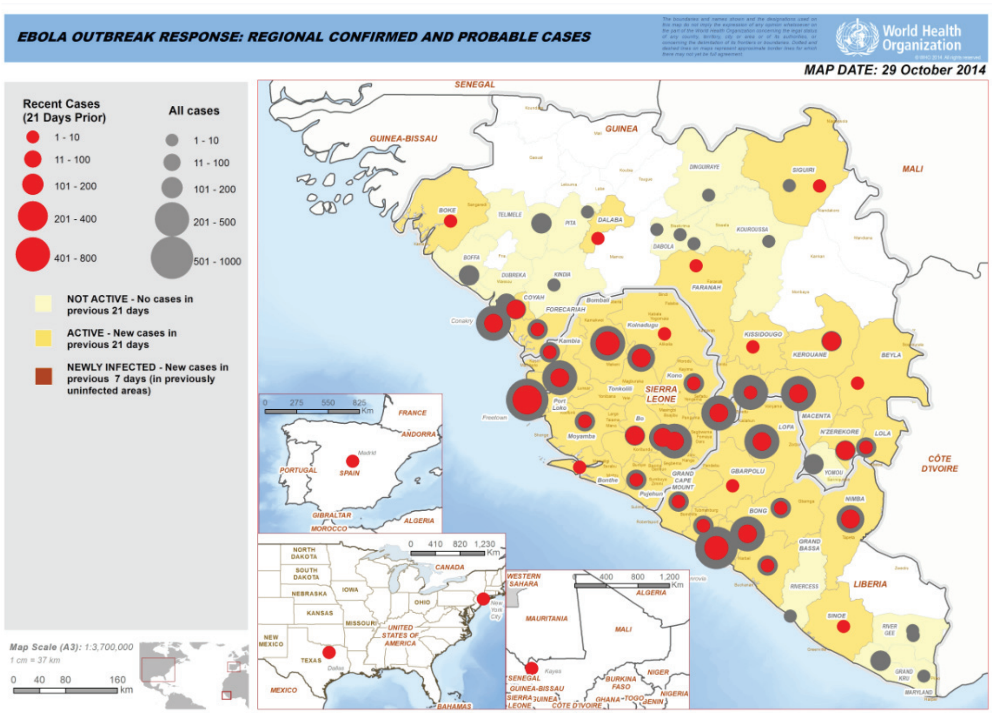
In addition to being a tool for directly mapping and analyzing epidemic trends, GIS can be used to provide contexts useful in assessing risk, vulnerability, and resilience, by mapping areas at risk of amplification and spread due to population mobility or structural factors (e.g., poverty and weak health systems). "Risk maps" are typically developed based on historical outbreaks; on vector habitat; or on locations of high human/animal interaction, where the animal hosts are known to carry zoonotic disease. "Vulnerability assessment maps" may examine household size, housing materials, sanitation (latrines or toilets), access to safe drinking water, or poverty. Together with population estimates, this information can help programs designed to build resilience before an epidemic, provide context for response during an epidemic, and support work to end an epidemic and rebuild health services. Rapid amplification and spread are most likely to occur in situations where existing health services and surveillance are weak. Using maps, program managers can build resilient health systems, by identifying and prioritizing gaps in existing surveillance networks as well as in service provision due to lack of facilities, infrastructure, or trained staff.

Use of GIS to coordinate responses to the Ebola outbreak in West Africa

The World Health Organization (WHO), the Emergency Operations Center at the U.S. Centers for Disease Control and Prevention, and the U.S. Global Development Lab and USAID GeoCenter used GIS in the Ebola outbreak in Sierra Leone, Guinea, and Liberia. With it, they coordinated their responses, identified areas at high risk, tracked new cases of the epidemic against prevalent areas while the epidemic was in progress, and allocated resources.

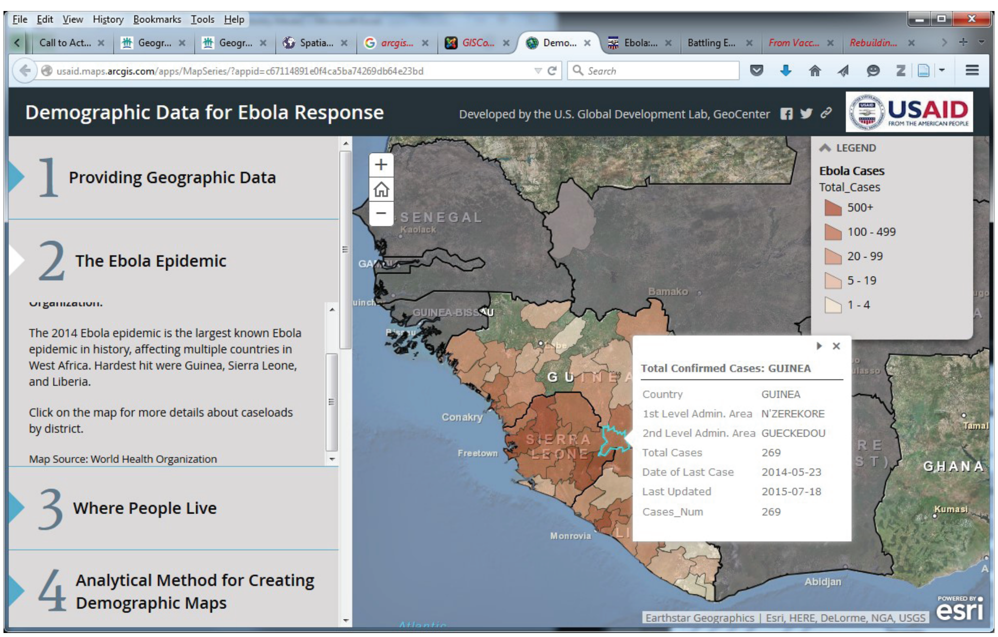
GIS is also being used in reconstruction efforts to identify locations at high risk that could be prioritized based on their social contexts. Reconstruction efforts include programs aimed at enhancing food security through distribution and support to farmers; improving access to education for children while integrating Ebola-related messaging in curricula as needed; and supporting the re-establishment of community- and facility-based health services and enhancement of laboratory surveillance systems.

Figure 3. Confirmed and Probable Cases of Ebola in West Africa as of October 2014



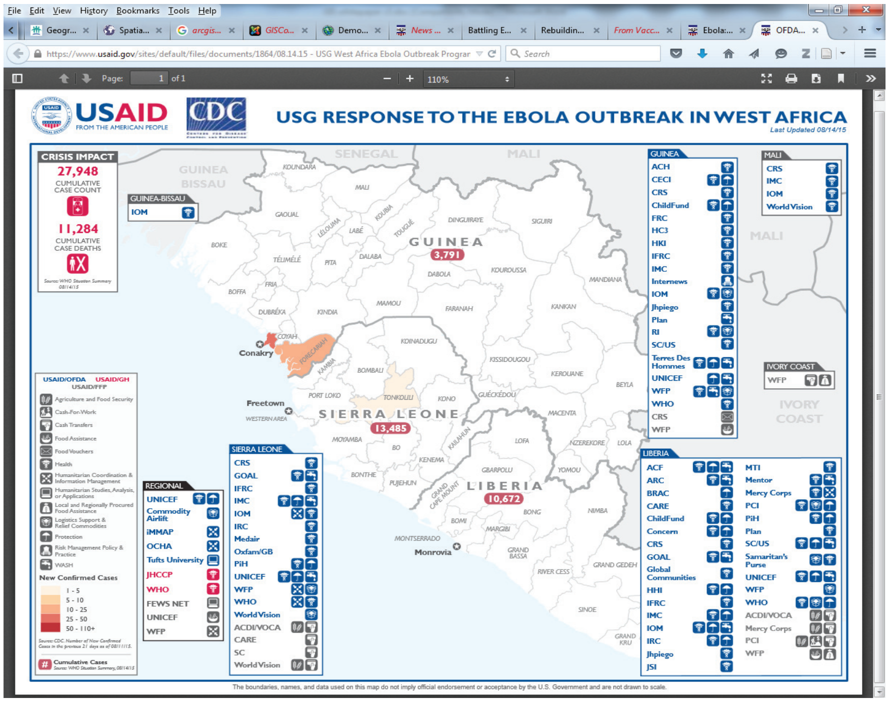
New and recent cases of Ebola in West Africa as of October 29, 2014 are shown. This map, and others like it, allow program managers to identify areas with current active transmission and previous transmission, and to quantify the intensity of the epidemic in each area (WHO, 2014).

Figure 4. Map of Ebola Incidence in West Africa by Demographic and Household Variables



This web map provides necessary demographic context for program managers seeking to support Ebola reconstruction efforts. It shows Ebola incidence, population density, average household size, the proportion of female-headed households, access to toilets or latrines, and access to safe drinking water (USAID, n.d.).

Figure 5. U.S. Government Activities in Response to Ebola in West Africa



This map (and others like it) shows the cumulative number of Ebola cases, the subnational areas where new cases are occurring, and which partners, funded by which U.S. government agency, are involved in what services in which countries. It provides a high-level view of who is doing what and where to improve coordination (Corbett, 2015).

Ending preventable child and maternal deaths

Health programs aimed at ending preventable child and maternal deaths are varied across the continuum of care for mothers, newborns, and infants. They benefit from maps of service catchment and coverage, malnutrition risk, and disease surveillance efforts, among other topics. We focus on two examples:

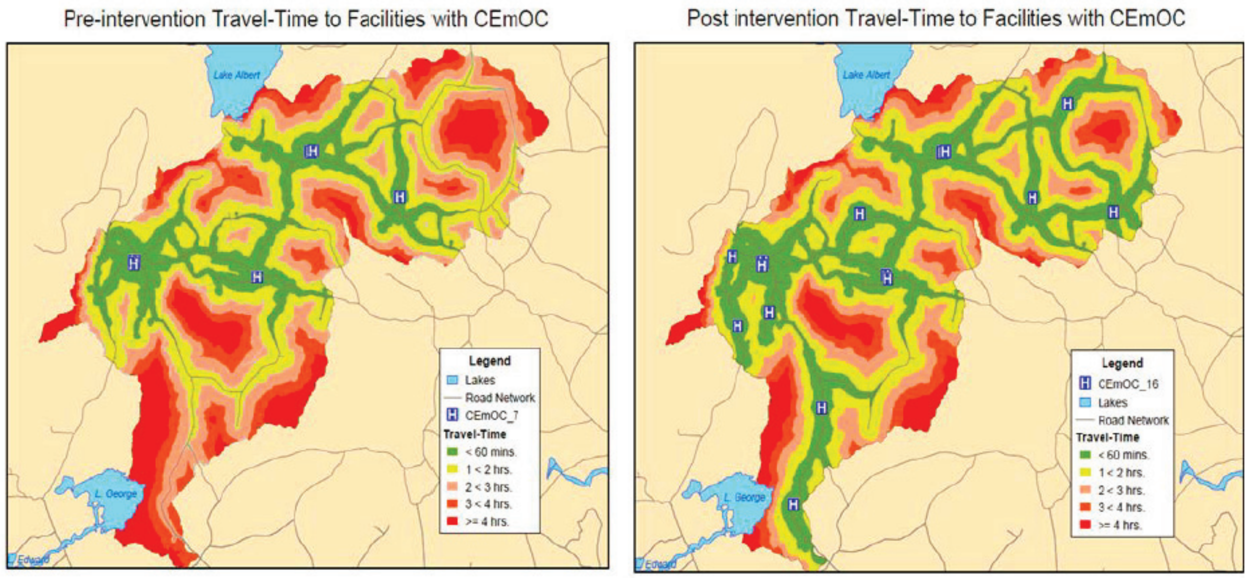
- Improved access to obstetric care
- Microplanning for immunization

Use of GIS to identify gaps in comprehensive emergency obstetric care coverage in Uganda

GIS has been used extensively for assessing and improving access to basic emergency obstetric care (BEmOC) and comprehensive emergency obstetric care (CEmOC).

Global recommendations for access to CEmOC state that access within a two-hour travel period is critically important for the mother's survival if she has complications during delivery. In scaling up CEmOC services to meet this need, GIS has been used to map existing BEmOC and CEmOC services, travel times to these services, and population density. By correlating these three factors, program managers can identify areas where large populations lack services and identify BEmOC sites near those populations that could be upgraded to CEmOC. This was done in Uganda, where upgrading facilities improved physical access to services.

Figure 6. Access to Comprehensive Emergency Obstetrical Care in Western Uganda Before and After Interventions to Improve It



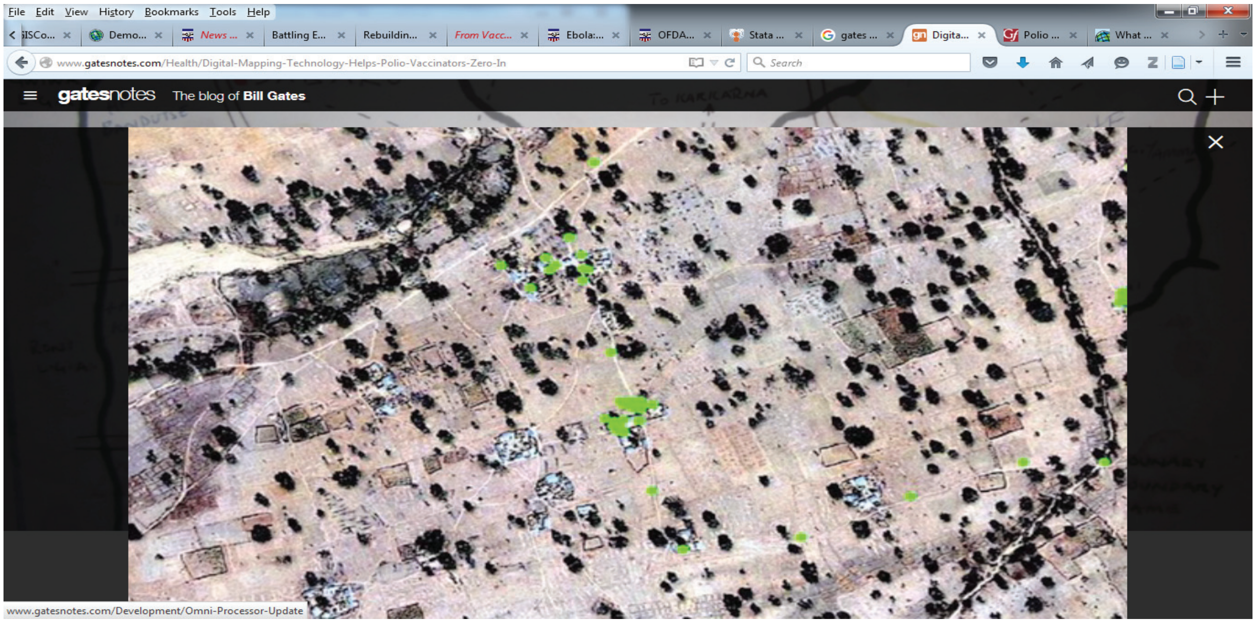
Population within 2-hour travel time of CEmONC facility increased from 62% to 77%

This map shows improvement in CEmOC service coverage in western Uganda, because of an intervention by Saving Mothers, Giving Life. The map on the left depicts the distribution of facilities providing CEmONC service before the intervention; the map on the right shows improved access after the intervention was implemented (Serbanescu, 2014).

Mapping for microplanning: reaching every village

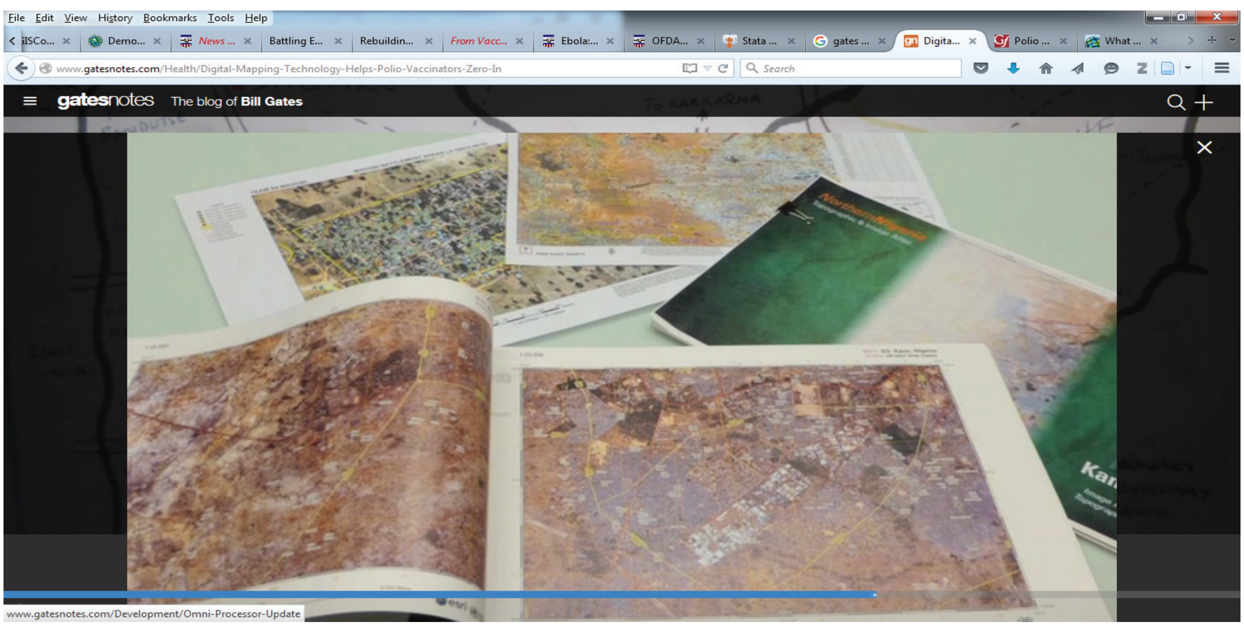
Polio eradication campaigns in northern Nigeria offer good examples of the use of GIS for immunization. Geographic data on health facilities, schools, religious buildings (primarily mosques), villages, ward boundaries, and local government area boundaries were collected. By mapping these pieces of information together with topography and roads, program managers were able to assign villages to different campaigns in an efficient manner. If a village from one ward was on the "wrong" side of the river, limiting access, the village could be assigned to the ward on the other side of the river for outreach and immunization campaign services. Data generated from satellite images enabled program managers to estimate the size of the populations they wanted to reach (children to be immunized) more precisely and track progress against those targets. Geographic trackers were placed with each immunization team. This enabled the program manager to review her/his team's progress at the end of each week, identify villages or households that had been overlooked, and schedule visits to them.

Figure 7. Villages and Households Missed in a Polio Immunization Campaign in Northern Nigeria



This map presents satellite imagery together with GPS points showing areas where a polio immunization team has visited in northern Nigeria. When aggregated to a larger scale and linked with village geo-coordinates, maps like this can show at a glance which villages or households were missed and need to be visited during campaign "mop-up" (Gates, 2012).

Figure 8. Material Used by Polio Immunization Teams to Plan Campaigns in Northern Nigeria



Printed maps and atlases of local government areas and towns in northern Nigeria were used by polio immunization teams to improve plans for campaigns and to ensure that every village was reached (Gates, 2012).

GIS's Added Value

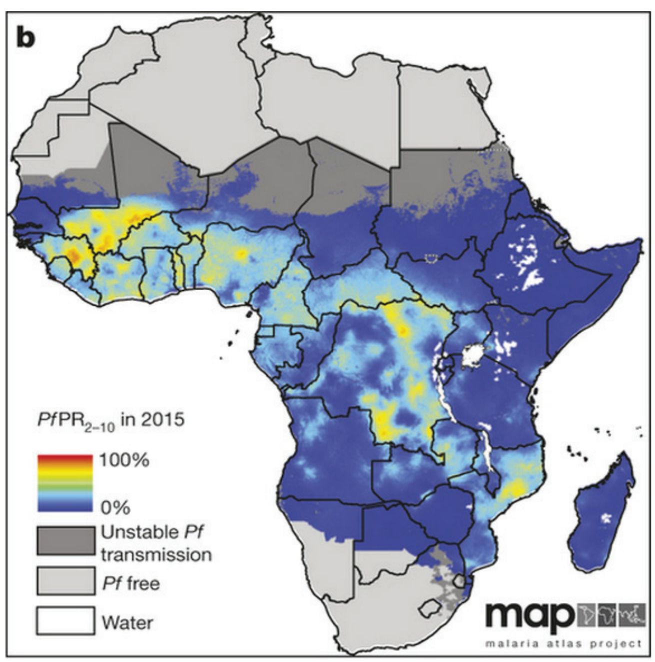
The preceding examples illustrate how public health professionals are using GIS. With it, they can improve program **efficiency**, identify **equity** gaps, monitor programs, and improve their understanding of **epidemic trends**, **vulnerability** to a health issue or to an epidemic's spread**,** and the **contexts** that influence a population's health and an intervention's success.

> GIS maps can be viewed at multiple scales (facility, district, region) to meet the needs of multiple audiences.

Three overlapping factors make geospatial tools uniquely suited to accomplishing these four tasks.

First, GIS can frame data within common geographic contexts to allow program managers to layer or integrate health and ancillary information from different sources, considering data from each source alone as well as in relation to data from the other sources. Linking data in this way can provide necessary perspective to inform discussions on resource allocation or program strategies. For example, program managers can align human resources data with the number of patients visiting each facility, to identify facilities that are overburdened or have extra capacity. Public health data can be linked to data on ecology for an assessment of malaria risk; to socioeconomic data for an analysis of social vulnerability; or to a combination of data on population, land cover (the physical material on a geographic area's surface), roads, and service delivery points to examine gaps in program access.

Figure 9. Prevalence of Malaria among Children Ages 2–10 in Africa



The Malaria Atlas Project combines information on malaria prevalence from surveys, environmental factors, and demographic factors to estimate malaria (Plasmodium falciparum) infection prevalence rates in children ages 2–10 (Bhatt, et al., 2015).

Second, GIS gives program managers a geographic perspective on health statistics for a given location in relation to adjoining areas. If an area with low prevalence of an infectious disease is adjacent to one with high prevalence, it may be at higher risk for its disease burden to increase, because the disease might be transmitted along paths or roads from the neighboring area. Clusters of high prevalence might indicate underlying systemic vulnerabilities that need to addressed.

Third, GIS gives program managers an information product that can spur discussions. Maps are powerful visual images providing a shared context for discussions. They can be viewed at multiple scales (facility, district, region) to meet the needs of multiple audiences.

The Current GIS Environment: Increases in Availability of Geospatial Tools, Human Resources, and Data

Software costs, staff skills, and data are no longer the limiting factors they were a decade ago (MEASURE Evaluation, 2014). With increased availability of tools, increased human resources, and better data, spatial information products are increasingly more accessible for health programs.

Geospatial tools

Increasingly, GIS is being integrated in other analytic tools as part of a comprehensive data visualization and analysis toolkit (Global Health Sciences, n.d.). As the number of high-quality open source software options grows, so does the array of choices available to programs. One tool growing in popularity—QGIS (the "Q" stands for "quantum")—is a free alternative to the current, industry-standard, proprietary GIS program (MEASURE Evaluation, 2013). Web mapping platforms (e.g., ArcGIS Online and Druple) allow people to share maps rapidly with a wide audience; these maps can be updated and re-disseminated easily as new data become available. In many cases, web mapping can be considered part of a broader suite of data visualization and analysis tools. Rapid mapping applications (e.g. Google Fusion Tables; E2G) and the integration of GIS in data management systems (ArcGIS for Excel, DHIS 2, EpiInfo) allow monitoring and evaluation (M&E) or data science professionals with limited geospatial training to create high-quality maps quickly. Most of these software options can be installed easily, and staff can be trained to use them with existing tools and curricula.

Human resources

> Better data and better tools have increased the capacity to use GIS worldwide. GIS software can be installed and staff can be trained easily.

Recent years have seen burgeoning cadres of M&E staff and data science staff with basic GIS skills able to create maps or perform simple geographic analyses. This means that an organization does not necessarily need dedicated GIS staff. The growth in the number of professionals having GIS skills can be attributed partly to improvements in software availability as well as usability; increasing demand by decision makers for geospatial information products; and increased availability of training resources and guidance documents designed for non-GIS professionals. Such resources include both big-picture guidance and step-by-step instructions for key GIS tasks. The use of GIS in data science has grown in step with the data science field, and also as part of a general movement toward assembling and analyzing large data sets. Further, as databases such as DHIS 2 collect vast amounts of health data, the ability to routinely process and convert high volumes of data into meaningful information has become more important.

The abilities to process, investigate, and use high volumes of data at multiple scales and to set up analyses that can be conducted routinely with only marginal effort allow managers to adjust their programs frequently throughout the year.

Data

Two recent trends in geographically oriented health data are:

- Increased density of information at high resolutions
- Increased availability of contextual layers, also at high resolution

Improvements in technology are driving these trends. Some examples: Tools such as smart phones have simplified the collection of geospatial data. Pre-processed satellite imagery is readily available. As GIS technology and software gain traction, demand for spatial data has increased. As the development field shifts to open data, the importance of local context is becoming clearer, as is the importance of identifying and addressing pockets or gaps in health coverage.

Contextual data and the interplay among multiple layers of data—for example, high resolution disaggregated population data, satellite imagery, and maps of road networks, rivers, and terrain—provide new perspectives on the determinants of a program's success. Routine health information systems and IDSRs are becoming more sophisticated, and often provide health data at high resolution—at the facility or even community level. Techniques for taking this data, as well as data from surveys, and creating "smoothed" maps is increasing access to risk-maps by program staff, and with it, the ability of staff to set effective and efficient priorities for their interventions.

As routine health information systems improve, access to high-quality data at the facility level has become the new norm. In this data environment, integration of GIS with data is becoming easier. If the facilities are geographically located (have geo-codes), linking a routine health information system (RHIS) with a GIS or a decision support system (as has been done within the DHIS 2) allows maps to be generated routinely as new information becomes available. Although setting up the initial link between the GIS and RHIS requires substantial initial effort, the pay-off can be significant, as program managers and M&E officers are able to visualize their data rapidly.

Conclusion

As countries make progress toward global development goals, challenges and program gaps will become increasingly local. Programs will go from a focus on reaching every district to reaching every community, and increasingly they will need access to subnational and even subdistrict data. Geospatial tools—with their ability to examine and overlay multiple factors at once; to examine health information across multiple scales; and to provide geographic context—are uniquely suited to support health programs in this environment. Maps and other GIS-produced information products can illuminate spatial and temporal trends in communities, support program planning, and enhance advocacy messages. Barriers to GIS use continue to fall. GIS is increasingly integrated in or linked with existing data collection or data management systems. Improvements in routine health information systems have provided a wealth of geographically disaggregated data.

The geospatial environment provides program managers with an opportunity to leverage the power of GIS to improve program efficiency as well as address equity gaps.

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Appendix: MEASURE Evaluation Geospatial Resources

An array of software options exists for those wishing to map data. In response to the need for guidance on which tool to use for what task, the MEASURE Evaluation GIS Working Group evaluated the features and ease of use of five common mapping applications: ArcGIS, Quantum GIS (QGIS), Epi Info, Google mapping tools, and DevInfo.

- https://www.cpc.unc.edu/measure/publications/ms-13-80

USAID's Demographic and Health Surveys (DHS) Program and MEASURE Evaluation have created a set of detailed training materials to support use of the open source QGIS software. These materials are modular and easily adapted, and they use DHS health indicators for examples.

- http://spatialdata.dhsprogram.com/resources.html

MEASURE Evaluation also provides broad guidance on analytic techniques for using GIS for M&E, and for mapping community-based global health programs.

- http://www.cpc.unc.edu/measure/publications/ms-13-76
- http://www.cpc.unc.edu/measure/publications/ms-14-98

MEASURE Evaluation has also created guidance for using geography to link facility and survey data; HIV data; and family planning and reproductive health data.

- https://www.cpc.unc.edu/measure/publications/ja-13-167
- https://www.cpc.unc.edu/measure/publications/sr-14-86
- https://www.cpc.unc.edu/measure/publications/sr-12-74

For those considering "how, why, and where" to incorporate geospatial resources in your activities, these documents provide a detailed summary:

- https://www.cpc.unc.edu/measure/publications/ms-11-41a
- https://www.cpc.unc.edu/measure/publications/ms-11-41-b

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