Application of FOSS4G and Open Data to Support Polio Eradication, Vaccine Delivery and Ebola Emergency Response in West Africa

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Abstract
In Africa, the use of GIS technology in the health sector is still nascent, with cost and lack of expertise being significant barriers to utilization (Tanser and Le Sueur, 2002). Data is very critical to implementation of GIS to support health projects (Oppong, 1999) and one of the problems in Africa is decentralized and uncoordinated data collection (Tanser and Le Sueur, 2002) which contributes to inadequate access to spatial data to support health projects. Free Open Source Software for Geospatial (FOSS4G) solutions can play a substantial role in various health projects across the continent, mainly because of the freedom it gives to their early adopters. Currently, FOSS4G (QGIS, Open Data Kit, OSRM, etc.) and Open Data tools (OpenStreetMap, CKAN, etc.) are used across several projects in supporting Ebola emergency response in West Africa, polio eradication and vaccine delivery in Northern Nigeria. The ongoing successes of these projects using FOSS4G clearly show that usage of these solutions in the health sector is sustainable and achievable in Africa. Cost-saving from the use of mature FOSS4G, eHealth Africa (eHA), a technology focused NGO, has been invested back into capacity building activities, thereby reducing the problem of lack of GIS expertise to support health projects. eHA has been able to train local personnel on utilization and application of GIS solutions. This helps to build stronger technical knowledge of its personnel and improve health services by offering GIS solutions built on FOSS4G and cloud servers based on Open Source software to make spatial data more accessible.

1. Introduction

Africa holds a majority of the world's disease burdens, with most of the population lacking adequate access to basic resources and providing quality healthcare solutions across the continent remains complex and expensive. Geographic Information Systems (GIS) technology provides a great set of solutions for a variety of health sector needs including program implementation, infrastructure planning, monitoring and evaluation, spatial and statistical analysis, etc. Major areas of application include the assessment and mapping of environmental exposure, mapping of health outcome, and the analysis of spatial relationships between environment and health (Briggs and Elliott, 1995). For example, Geographic Information as a Science can help research scientists to understand the spatial variation of a disease, the relationship of that variation to environmental factors and the larger health care system (Tanser and Le Sueur, 2002). GIS can also provide programmatic support from vehicle routing to resource allocation. Although the use of GIS is found to be underutilized, it has been concluded that it has much to contribute to the health sciences (Tanser and Le Sueur, 2002). The use of GIS to solve public health issues has an exponential increase and has been vital to the understanding and treatment of health problems in different geographic areas (Fradelos et al., 2014). One major area of GIS application is the design, management and evaluation in health programs (McLafferty, 2003). This application is not limited to developed nations in Europe and North America only, but also to countries in developing continents like Africa (Tanser and Le Sueur, 2002). One solution to overcome challenges and financial barriers to adopting GIS technology in Africa is the use of mature Free and Open Source Software for Geospatial (FOSS4G). FOSS4G combined with Open Data platform such as OpenStreetMap which has a large community of users, can help to publish value-added products. Data-driven (processing, analysis and publication) technologies supporting open standard of the industry (Open Geospatial Consortium, GeoJSON, SQL-API) are being used

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by governments and non-governmental organizations (NGO) to support health systems and improve health outcomes in Africa. For example, eHealth Africa (eHA), a health technology NGO based in Kano, Nigeria is using several FOSS4G and open data tools to support polio eradication, vaccine delivery, and Ebola emergency response efforts across West Africa. eHA was able to build within these projects a unique GIS capability in West Africa, prove the importance of GIS in the health sector and how FOSS4G can solve these problems in low-resource settings. This paper will present this combination of FOSS4G and Open Data solutions related to three different health issues.

2. Polio Eradication

Polio is a potential fatal infectious disease, but it is endemic in only three countries in the world: Afghanistan, Nigeria, and Pakistan (Global Polio Eradication Initiative, 2015). There is no cure, however, there is an effective vaccine. One of the strategies to eradicate polio is to prevent infection by immunizing every child under 5 years old. In Nigeria, active cases were mostly located in the Northern part of the country.

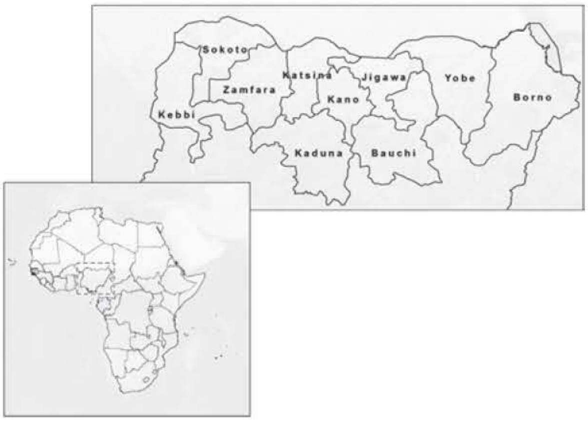

Figure 1: Polio Study Area

This region has many geographic-related challenges, such as poor critical infrastructure, high population counts, large territories, a high migration rate especially in remote areas, and security issues. Additionally, Northern Nigeria has some of the worst health care systems in the world and is plagued with incomplete data and poor accountability. For example, vaccination teams often do not visit all the settlements in their catchment area, either because the settlements are difficult to access, or a lack of awareness of the existence of the settlements in the first place since a large number of these settlements is isolated. Previously, all data collection conducted by the government was limited to paper reporting. Paper-based reporting presents a wide range of limitations: it is prone to transcription errors, lack of supervision, leads to poor accountability and data quality. Also, some settlements are hard to reach hence they are usually neglected.

2.1 Solutions

To address all these issues, eHA uses Open Data Kit (ODK) to collect data on all settlements to determine their geographic locations, the settlement type, and the names of these settlements, which is then uploaded into FormHub, a cloud-based online data server. There is availability of 2G internet network in many areas in Northern Nigeria. The data could then be downloaded into the spreadsheet for importation into other analytical softwares in order to produce map and reports. The use of ODK has ensured that all settlements are identified, mapped and visited. It has enabled better planning and resources allocation and implementation of the monthly immunization plus day (IPD) exercise. These settlements are arranged and grouped into micro plans for visitation by the vaccination teams. With all the settlement identified and known, settlements that are not visited during the IPD are known and can be identified for vaccination mop up. In order to get a better resource planning on the ground level, the road network is a crucial data source for routing and planning. However, the road network layer in Northern Nigeria is incomplete in all known sources, including proprietary data. To overcome this constraint, eHA collected a high volume of geographic data in Northern Nigeria which is shared with other NGOs and humanitarian community to support other social initiatives in Northern Nigeria. The choice of the right platform to edit and gather good road data turns out to be a crowdsourcing project, called OpenStreetMap (OSM). OSM (https://www.openstreetmap.org/) is built entirely by volunteers surveying with GPS, digitizing over imagery and field paper, and is used by the Humanitarian OpenStreetMap Team (HOT), http://tasks.hotosm.org/ a group of humanitarians that works with OSM to respond to emergency situations around the world. eHA's contributions to OSM to date is summarize in table 1. In 2014 in Nigeria, because of tremendous efforts in the country, such as the use of GIS tools and Information Technology, only 6 cases of polio were reported in the Northern part, with the last case recorded on 24 July, 2014 in Sumaila Local Government Area of Kano State, Nigeria (Global Polio Eradication Initiative, 2015). There have been no new cases of polio as of April 2015.

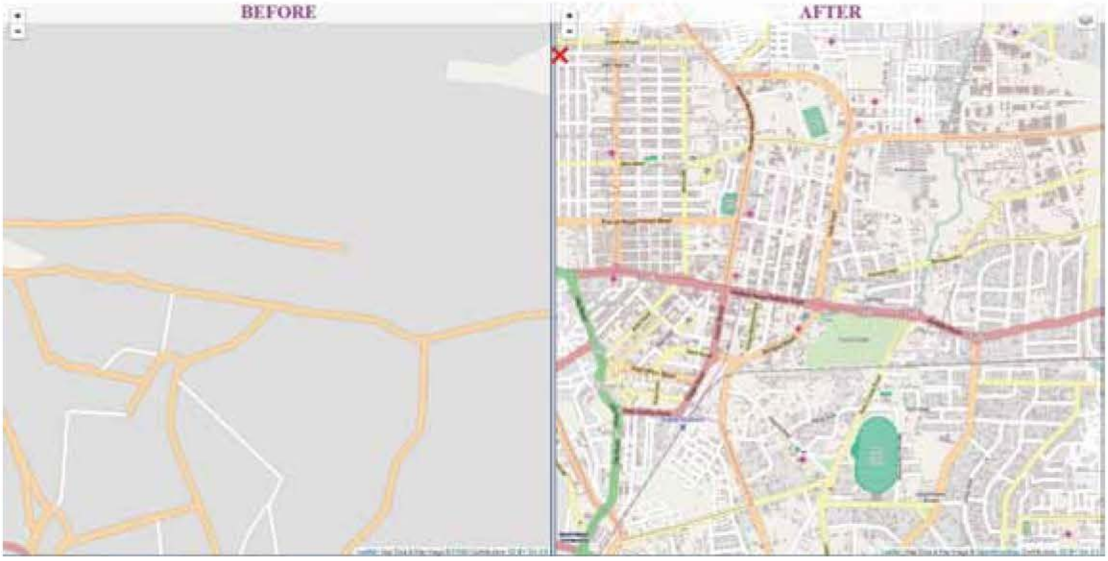

Figure 2: Before and After OpenStreetMap contribution, Kano metropolitan area

Table 1: eHealth Africa's data contributions to OpenStreetMap platform

10 Northern States of Operation	Other 26 States & FCT	Facilities	Roads & Building	8 Northern States Residential Areas
Administrative Boundary	Administrative Boundary	Health Facilities	Over 200,000km of Road Network Mapped	Settlements
ward Boundary polygon = 2788	LGA boundary polygon = 523	Kano State Health Facilities (nodes) = 1,087	Bauchi State Road and Building Mapping	Polygon = 9,430
LGA Boundary polygon = 250	State Boundary polygon = 27	Bauchi State Health Facilities (Nodes) = 1,096	Kaduna State Road and Building Mapping	Multi-polygon = 1538
State Boundary polygon = 10	Total = 550	Borno State Health Facilities (Nodes) ongoing = 1,096	Kano State Road and Building Mapping	Total = 10,968
Total = 3,048				Kano Placename=2048

3. Vaccine Direct Delivery and Routing Logistics

Vaccines are important to ensure a healthy generation, but they need to get to the targeted population at the right time, in good quality, and in sufficient quantity. However, due to inadequate logistics support by the local healthcare system, vaccines are often understocked, delivered late, or damaged due to frequent breaks in the cold-chain system that expose vaccines to high temperature. Other issues include inadequate access to vaccine in hard-to-reach areas and inadequate record keeping.

3.1 Solutions

In hard to reach areas in Nigeria, mobile health technologies and GIS solutions can overcome geographical obstacles. These innovations have proven their capacity by the process been tested and implemented by eHA in the region. For example, drivers going to the area can submit vaccine data using Open Data Kit which works offline on tablet computers which send the data to Google Spreadsheets, via FormHub, to display the delivery data on a dashboard for decision-making at the state level by the government and other stakeholders. With most cities having 2G internet coverage in Nigeria, the ODK working offline with tablets make them operable anywhere in Nigeria. The vaccine delivery project employs FOSS4G also in many aspects for this operation. QGIS, OSM, Open Source Routing Machine (OSRM) together were used to calculate distance and time travel while stock data is collected and managed through Google Documents. As data input for the routing, eHA used OSM road network and data collected on health facilities in Kano State. The data includes updated health facility data with their locations, class, type, ward, local government areas, and states they belong to. QGIS, was use to process the data on health facilities after they were collected via ODK, which determine how long, when, and how the vaccines get to the health facilities. This data is used to provide interactive routing for vaccine direct delivery. Settings were set in QGIS to determine the unit of distance and speed limit. The distance was calculated in WGS84 projection, a geographic coordinate system in line with other data sets, the output was projected by multiplying it with 111.32 to be them in metric. A QGIS function was used to determine the shortest path algorithms and calculate the distance and time travel between the health facilities. The tracks are calculated and can be exported as ESRI Shapefiles, which are then used to determine the clusters, drops, and schedule. To determine the most cost and time efficient route for vaccine delivery four considerations were made:

1. All vaccines originate from warehouses at the Zonal cold store (d_0);
2. A heuristic, FIFO (First In First Out), was used to ensure that the farthest facility based on distance was visited first, along with facilities in rural areas as those facilities tend to close earlier;
3. Determination of clusters (Cluster is the total number of health facilities that a driver makes vaccine delivery to in a day with a working time window of 6 hours, based on proximity and boundary consideration). Clusters are separated into three different working time windows during the day. This allows the health facilities to expect the delivery within particular time and plan for it.
4. Since there is no up-to-date data on traffic data, road condition, etc. an OSM standard for road classification was used. https://github.com/Project-OSRM/osrm-backend/blob/master/profiles/car.lua

For example, estimation of the speed limit on theses road type for routing were classified as follow: Trunk Road - 90 km/h, Primary Road - 65 km/h, Secondary Road - 55 km/h, Tertiary Road - 40 km/h Residential and Unclassified Road - 25 km/h, Service Road - 15 km/h, Track - 5 km/h. With these project considerations, a batch routing process (time, distance) at the back end of OSRM was designed for multiple routing processes by eHA. The result was then displayed in a dashboard that was accessible by all stakeholders including the vaccine delivery drivers, the primary health care management board, and other partners. With the use of OSM platform and FOSS4G, the Kano healthcare system has seen a huge reduction in vaccine stock-outs. More than 1800 delivery have been made in the last 270 days, with approximately more than half a million doses delivered, 45,000 km traveled and over 200 wards were visited. This equals a 98 % delivery success rate. Currently, there is still room for improvement in the routing system. For example, there need to be more streamlined procedures and integration new ideas and tools to strengthen the delivery system. With the success of the vaccines direct delivery in Kano it is expected that it will be scaled up to national level, and also to include other health commodities, which will be applicable throughout Nigeria and other countries across the continent.

4. Ebola Emergency Response

In the late 1970s, Ebola virus was discovered as the causative agent of major outbreaks of hemorrhagic fever in the Democratic Republic of Congo and Sudan (Scott et al, 1995). There have been African Ebola Epidemics from 1976 - 1979, 1994 - 1996, 2000 - 2001 and now. Details of transmission showed the import role of close contact and exposure to body fluids, particularly to caregivers, who suffered the major burden of secondary infections (Dowell et al., 1995). Communication, or the lack thereof, constituted a critical part of the response's failure at the juncture of prevention and response—the removal of the sick and the dead from communities (Abramowitz et al., 2015). Hence efforts must be made to break the cycle of transmission, even with huge foreign aids and supports; there still have to be a coordinating center where all stakeholders can partake in the fight in the most appropriate means by managing and sharing information to make better decision.

4.1 Solutions

When the first cases of Ebola were identified in Guinea in 2013, no one had any idea of the scale the same disease would progress to one year later. Apart from Guinea and Sierra Leone, where the Ebola epidemic continues to spread, an outbreak occurred in Lagos in July 2013, one of Nigeria's most populous urban areas, followed by a connected outbreak in Port Harcourt a few weeks later. Logistics and data systems support, including geospatial technical assistance were deployed to combat the virus. Many of the tools developed and lessons learned were translated to supporting Ebola emergency management in the other West African countries. The few of the many tools and approaches used were the Ebola Emergency Operation Centers and Sense follow up for contact tracing.

4.1.1 Ebola emergency operation centers

Emergency operations centers play a key role in emergency situations, serving as a central hub for all activities related to the emergency. In the case of Ebola, EOCs were built to help coordinate response efforts at the national and sub-national levels. The Humanitarian OpenStreetMap Team and other volunteers provide geographic information to response teams on roads, settlement locations, health facilities, Ebola treatment units, schools, markets, etc. All of this location data greatly aided the response teams in determining where to allocate resources such as medical teams, burial teams or contact tracers.

4.1.2 Contact tracing

Contact tracing is finding everyone who comes in direct contact with a sick Ebola patient. Contacts are watched for signs of illness for 21 days from the last day they came in contact with the Ebola patient. If the contact develops a fever or other Ebola symptoms, they are immediately isolated, tested, provided care, and the cycle starts again-all of the new patient's contacts are found and watched for 21 days. The approach of contact tracing possesses enormous potential for effectively addressing the concerns of increasing caseloads of Ebola virus disease. (Shrivastava et al, 2014) eHA developed a mobile application called SENSE Follow up in order to effectively streamline the contact tracing process from paper reporting to electronic data collection in real-time. By capturing GPS coordinates during the monitoring process, this allowed for real-time tracking of contacts. This geographic data was merged with administrative boundaries using an OSM base map in order to provide additional geographic information about the location of the contact including counties, districts, and chiefdoms. These data all flowed into a larger dashboard which stakeholders used as a decision-making tool.

5. Best Practices and Limitations

One of the essential elements of FOSS4G solutions that make it an attractive option in low-resource settings like Africa is that the tools are free, customizable and available online. There is also a larger number of communication company offering 2G internet service in Africa, which has greatly increase mobile technology users, plus the advantage of the tools working offline at low cost and software easy downloadable for free. Additionally, since these solutions are tested and verified by the Open Source Geospatial Foundation (OSGeo), their endorsement validates the tools as credible and legitimate geospatial tools at the same standard as traditional, yet expensive, geospatial tools. FOSS4G shows NGOs and other international organization that investing in their human resource produce better funds management and tremendous push to positive changes, as demonstrated in these three different issues (Polio, vaccine delivery and Ebola) in Africa.

Recently, a new FOSS4G stack of software (PostGIS, OpenLayers, CartoDB, GeoServer) was recently deployed by eHA in order to publish GIS layers (ex. Health facilities) which can be used by partners to access free up-to-date data for diverse needs (geospatial and non-geospatial, health care, base maps). One of the goals is to combine the best FOSS4G solutions into a GIS hub cloud infrastructure to distribute effective web services (ex. SQL API, Open Geospatial Consortium web services) in an Open Data (CKAN) portal based under an Open Data standardized License. Open source softwares also have their limitations; most FOSS4G projects require in-depth knowledge and skills to perform complex operations which are not taught in many schools, much less within the government. For example, open source software (as an open distributed collaboration model) projects are always dynamic and every year there is many new FOSS4G projects that comes in the market. To stay on the edge and implement FOSS4G solutions that become more effective every day, it needs substantial investment, just like any GIS license model (proprietary or open source software) on research, development and knowledge. Increasing training initiatives, OSGeo formal certification, technological transfer project and workshops where resources and technical knowledge can be limited is one way to address this barrier. Even with the zero cost in softwares, low income economic countries find it difficult to have access to fund these initiatives and get at the same time the necessary hardwares such as phones, computers or servers necessary to implement the use of these solutions and technologies.

6. Conclusions

The use of FOSS4G and Open Data shows that open technology is an appropriate and cost-effective option in Africa. These sustainable solutions to support polio eradication, vaccine delivery, and Ebola emergency management have increased the expansion and use of GIS tools while improving the health sector in Africa. Training local staff and the next generation of African-GIS specialists on the use of FOSS4G and Open Data is a critical next step to ensure that African health systems can continue to benefit from the application of these solutions to address health issues on the continent.

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