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Paul C. Marum Date

**Analysis of the spatial and temporal distribution of Ebola cases in Bong County, Liberia: Implications for the role of general Community Health Volunteers in public health surveillance and response**

By

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Master of Public Health

Global Epidemiology

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Professor Philip Brachman
Faculty Thesis Advisor

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Faculty Thesis Advisor: Philip Brachman, MD

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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**Abstract**

**Analysis of the spatial and temporal distribution of Ebola cases in Bong County, Liberia: Implications for the role of general Community Health Volunteers in public health surveillance and response**

By Paul C. Marum

**Background:** The Liberian Ministry of Health reported 10,866 cases and 4,806 Ebola related deaths in the epidemic of 2014-15. An extensive system of community health workers served rural populations to convey information on symptoms, transmission risks and treatment for Ebola.

**Methods:** Geographic coordinates were recorded via GPS for all 39 health facilities in Bong County. Participatory mapping was conducted with the supervisors of general Community Health Volunteers (gCHVs) to identify and geolocate the villages where the 525 gCHVs reside. These data and other map sources were used to geolocate Ebola cases listed in Bong County records.

**Results and Findings:** By mid-2015, Bong County had achieved good coverage of gCHVs in all health districts. Of the 171 confirmed and probable Ebola cases, 156 were geolocated. Almost all cases (170/171) occurred between July and December 2014; cases living within 5 kilometers of a healthcare facility (HCF) displayed a typical epidemiologic curve with the majority occurring in August and September. Cases living 5 or more kilometers from a HCF primarily occurred later, from October to December, with three large clusters in rural communities. Hospitalization rates increased over time. The overall case fatality rate (CFR) in Liberia was 45%; in Bong County CFR was 41%; differences in CFR were minimal comparing hospitalization rates and distance from HCF in Bong County.

**Discussion:** The significant delay of Ebola incidence in more rural areas relative to the early peak in more urban areas suggests an initial protective effect of rural isolation. However, there remained significant danger of poorly controlled outbreaks in rural communities. The three major clusters in Bong County, all in more rural communities, highlighted the risk of rapid local transmission in these populations. Community health workers, including gCHVs, represent an important resource for rural disease control.

**Future Directions:** These findings reinforce the need for rural community public health interventions to prevent and control infectious diseases. Additional training of gCHVs in disease surveillance and community level infection control measures may empower gCHVs, and the rural populations they serve, to detect and respond to future outbreaks.

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## Introduction

The Ebola outbreak that started in the West African nation of Guinea in December, 2013, and subsequently spread to neighboring Sierra Leone, Liberia as well as other countries, was one of the most dramatic public health emergencies thus far in the 21st century, and caught the attention of the entire world. Geographic information systems (GIS) played an important role in the public health response to the epidemic, as well as facilitating communication and media attention to this previously neglected area of the world. Public health mobilization occurred at multiple levels, from international agencies, the US and other countries, to national and local governments to individual volunteers working to protect their own communities. The efficient coordination of these community health workers and volunteers was hampered by a lack of detailed and accurate geospatial information regarding their distribution in the early days of the epidemic. International, national and local leadership was perceived to be inadequate in the early days of the epidemic but is generally recognized to have strengthened over time. Identification and prompt referral of suspected cases to treatment units from rural and remote communities was hindered by the distance to, and inaccessibility of, health facilities and health workers.

In this thesis, the distribution of community health volunteers and health facilities in Bong County, Liberia will be described. The impact that distance from health care facilities had on the prompt identification, isolation and hospitalization, and outcome of Ebola cases in Bong County will be analyzed. In addition, the course of the epidemic from July to December, 2014, will be described.

**Background: Ebola Epidemic in West Africa**

The 2014/2015 Ebola epidemic in West Africa is the largest known outbreak of Ebola and eventually resulted in 28,637 cases and 11,315 deaths as of December, 2015.[1] The overall accuracy of these data remains unknown, especially in terms of the large number of "suspect" cases and whether they should be included in final counts. The three countries primarily affected were Guinea, Sierra Leone, and Liberia; cases also occurred in Senegal, Mali, Nigeria, the US, Italy, Spain, and the UK. In 1976 the virus was first identified by a team of researchers from Belgium working in the Democratic Republic of Congo (DRC); they named the virus after the nearby Ebola River.[2] Since that time, there have been 25 documented outbreaks in Africa; of these 13 of these have occurred since 2000.[3]

The most severe outbreak prior to the current one occurred in northern Uganda in 2000/2001; there were 425 confirmed cases with 224 deaths.[2] In more recent outbreaks, containment improved, with fewer cases, better protection of health workers, and better laboratory confirmation of cases.[4] These previous outbreaks occurred primarily in rural areas, and control activities, including travel limitations, resulted in these outbreaks not spreading to large urban populations. Further, these outbreaks occurred almost exclusively in countries in central Africa, including Congo, Gabon, DRC, South Sudan and Uganda.

The 2014/2015 Ebola outbreak in West Africa had a number of unique features. It was essentially the first outbreak in West Africa (other than one possible case in Cote d'Ivoire in 1994); it was the first to affect large urban populations; there was considerable cross-border transmissions between nations, and Ebola rapidly spread to many locations in these countries, unlike previous outbreaks which were concentrated in the original location of the outbreak.[2] The natural reservoir of Ebola is thought to be bats; it is also thought

that contact with bats and wild game, and eating of bush meat may be sources of transmission.[3]

In addition, the rapid spread to urban areas and the potential for spread through air travel created a great deal of hysteria and fear in western countries, which may have contributed to the out-pouring of resources from western countries who feared importation of Ebola to their own populations.[5]

Lessons Learned from previous epidemics regarding control of Ebola

Ebola is characterized by a rapid progression from symptom onset to critical illness to death. The onset of symptoms represents the onset of very high contagiousness so any delay between onset of symptoms and isolation and care of the patient decreases the chance of survival of the patient as well as increases the potential for transmission.[6]

The 2000/2001 epidemic in Uganda revealed key aspects of effective control. Training of multi-disciplinary teams to prepare for Ebola outbreaks through participatory training resulted in gains in knowledge and skills relating to surveillance and preparedness.[7] In the Masindi, Uganda outbreak in 2000, nosocomial transmission in a hospital resulted in 25 additional cases when the index patient traveled home. Quarantine imposed by the community helped prevent transmission beyond the index family and health workers. This study also documented very high fatality rates at the beginning of the outbreak, with lower fatality rates due to better case management after more training of the response team.[8] Other lessons learned from the Uganda Ebola outbreak of 2000/2001 were that effective control measures included interventions to minimize transmission in the healthcare setting and in the community, strengthened national and local coordination, and capacity building for on-going surveillance. Challenges in Uganda included inadequate protective materials,

high rates of death among health workers, incorrect information, and rejection of survivors in the community.[4]

Recent reports from the 2014/2015 West Africa outbreak confirm some of the lessons learned from Uganda. A rapid and well coordinated response is essential as is minimizing transmission in health care facilities, as many health care workers and other patients were infected in health facilities that were not prepared adequately for infection prevention and control.[9] Guidance on the risks associated with traditional burial practices was widely disseminated and "dead body teams" were recruited to go to homes and communities with reports of deaths, and they removed the bodies so that community transmission was interrupted, though in some early cases there was resistance to these burial teams.[10]

The establishment of Ebola Treatment Units (ETUs) was a key aspect in control, as infection prevention measures were more carefully implemented, patient survival was significantly better than in general health care facilities, and isolation of patients in ETUs interrupted transmission to family members and communities.[11] Arrangements were also made for safer burials of patients who died.[12] Provision of correct information to communities was also essential; a study in Liberia in September and October, 2014, documented high rates of awareness and reasonably high rates of correct knowledge of modes of transmission of Ebola, but also documented high rates of fear of Ebola patients, survivors, and Ebola treatment units.[13]

**Ebola Outbreak in Liberia**

Ebola was first confirmed in Liberia on March 30, 2014 and rapidly spread, especially in the capital city of Monrovia.[2] A massive national and international effort to control the

epidemic was launched. As of December 2015, there had been 10,666 suspected, probable, and confirmed cases in Liberia, with a total of 4,806 deaths. Of the cases, 3,151 were confirmed Ebola cases, 1,879 were probable cases, and 5,636 were suspected cases.[1]

Ebola cases in Liberia were concentrated in Montserrado County, which includes the capital city of Monrovia; these urban cases accounted for over half of all cases in Liberia. Transmission also occurred in many rural and remote areas of Liberia; a rapid response to these outbreaks in remote areas included the immediate isolation of symptomatic persons, either through self-isolation in the home or transfer to an Ebola treatment unit. These measures resulted in decreased transmission and improved survival of patients.[6] When a cluster of patients was identified in Mahwah village, Bong County, in August 2014, after consultations with local leaders, community quarantine was imposed: residents of Mahwah were not allowed to leave and non-residents could not enter the village; local markets were closed and food rations were brought in by the World Food Programme; cross-river transport by farmers was strictly regulated, and symptomatic patients were taken to an Ebola Treatment Unit. After these measures were instituted, no additional infections occurred. Support for these measures by local leaders in the community was essential for the implementation of these interventions.[14]

Liberia was declared Ebola free by the World Health Organization on May 9, 2015, 42 days after the last laboratory confirmed case was buried on March 28.[15] However, subsequent outbreaks occurred in Liberia, in June and November, 2015, with 6 and 3 cases respectively.[16, 17]

One of the key health education messages in the Ebola response throughout West Africa was to encourage anyone with symptoms to go as quickly as possible to a health facility for assessment and care. Health authorities in Liberia needed to inform everyone

what the symptoms were, and the urgent need to report to a health worker or facility. One of the indicators of the effectiveness of these informational efforts is to analyze the time between first onset of symptoms, the filing of a case report, and the hospitalization and isolation of all probable cases. Suspected Ebola patients in rural areas faced challenges in making it to a health facility due to distance, inadequate roads and transportation.

## Geographic and institutional factors affecting response to public health problems

Two factors affecting the response to public health problems in general and Ebola in particular will be explored in this thesis. One of these factors is health manpower shortages and the involvement of community health workers and volunteers to compensate for manpower shortages as well as to extend health education to local communities. Another factor to be explored is to what extent distance from health care facilities (HCF) affects the utilization of health services; this is very relevant to the control of Ebola as a key intervention is getting symptomatic persons to health care facilities equipped to isolate and care for Ebola patients, and doing this as quickly as possible. In addition, distance from a HCF affects not only the utilization of services by members of the community, but also the ability of members of the health workforce to reach these communities and patients.

### Community Health Workers and Response to Public Health Problems

The involvement of community health workers and volunteers has been advocated in many countries with inadequate health manpower. The Alma Ata Declaration of 1978, which declared the basic human right to health, stressed the importance of primary health care, including the participation of communities in the planning and implementation of health care, and urged bringing health care as close as possible to where people live and work. This declaration stressed the need for a range of health care workers, from physicians

and nurses to community workers and trained traditional practitioners, to respond to the expressed health needs of the community through an efficient referral system.[18]

In more recent years, in recognition of the significant shortages of specialized health workers in the health care systems of many countries, the World Health Organization has endorsed the concept of "task shifting": the process of delegation to move specific health care tasks from specialists to generalists.[19] For example, the implementation of directly observed treatment for TB often has a community health worker providing the medication to TB patients in their communities rather than having the patient go to a health facility and see a nurse or doctor for on-going treatment. The African Medical Research Foundation (AMREF) has urged African countries with health worker shortages to adopt a systematic approach to task shifting to improve health care coverage.[20]

Specific examples of the work of community volunteers have been described. For example, community volunteers were incorporated into the onchocerciasis program to administer ivermectin broadly across 16 endemic countries in sub-Saharan Africa; this project documented a 73% reduction in cases of infection after the community volunteers were used.[21] After the success and effectiveness of these Community Drug Distributors (CDD) many of these community volunteers were able to transition to local government support and are involved in a broader range of health activities, including malaria prevention and general health education. A study in Benin, West Africa found that community health volunteers were effective in identifying patients with Buruli ulcer and referring them to health facilities; about a quarter of all patients diagnosed were referred by these volunteers.[22] The presence of community health volunteers in two under-served districts

in Sierra Leone was associated with a significant increase in appropriate treatment of pneumonia in children and a decrease in traditional treatment for diarrhea in children.[23]

There are challenges and constraints with community health volunteers reported in the literature. For example, in Ethiopia, community volunteers are involved with polio surveillance; inconsistent training, inadequate collaboration with more formal health workers, and long travel time for volunteers who receive no incentives were documented as problems for community health volunteers.[24] Malawi has a long history of utilizing community level "health surveillance assistants." The lack of basic supplies and the need for routine re-supply was highlighted by a 2014 study in Malawi.[25] Another study in Malawi explored using these health surveillance assistants to provide anti-retroviral therapy (ART) to stable HIV infected patients; this study found that these assistants had difficulty correctly identifying complications of ART, including potentially severe side effects and toxicities; they also had difficulties correctly identifying which patients needed to be seen by trained clinicians.[26] Poor retention of community volunteers has also been identified as a problem. A study in Uganda recommended that continuation of services can be enhanced when the volunteers were selected by their communities, and when there was quality training and supervision.[27]

Liberia has a widespread system of community health workers, including various cadres. One such group is called "general Community Health Volunteers" (gCHV). Consistent with the Alma Alta Declaration of 1978, community health volunteers are elected by the community they serve, and therefore act as the final link between the national healthcare system, regional and local health care facilities, and individual communities. They bring health services as close as possible to the community while also serving as the first

resource in the referral network linking individuals with the formal primary health care system.

Distance from Health Facilities and Use of Health Services

The association between distance to health care facilities and utilization of health services has been widely studied. Research in Mozambique documented decreased use of health services when people had to walk more than one hour.[28] Pregnancy outcomes and distance to health facilities has been widely studied; a 2009 review found that in numerous studies, there are consistent results supporting the finding that increased distance from the facility is associated with reduced use of health services during pregnancy and delivery.[29] Research in Zambia that for women living within 1.9 kilometers of a health facility, there was a documented increased uptake of services to prevent mother to child HIV transmission; those living further had lower rates of service utilization.[30] In Tanzania, maternal mortality was found to increase with increased distance from health care facilities.[31] Also in Tanzania, increased child mortality was associated with living more than 5 kilometers from a health facility.[32] Long distances to health facilities and decreased use of health services has also been documented in Uganda.[33] Research in Rwanda found the increasing distances from health facilities was associated with lower rates of C-section and increased maternal mortality.[34]

A report on the use of Geographic Information Systems (GIS) to model theoretical walking times to clinics and assess the impact of distance on health utilization found in 2006 that in KwaZula-Natal, South Africa, there was a significant decline in utilization of clinic-based health care as travel times to these clinics increased. Homesteads within 30 minutes of

a clinic were 10 times more likely to access care at the clinic compared with homesteads in the 90 to 120 minute zone.[35]

In rural Liberia, increased distance to health facilities was found to be associated with decreased rates of children being taken for health services associated with fever as well as acute respiratory illness; children living further from health facilities were also less likely to receive de-worming treatment.[36] Prior to the 2014 /2015 Ebola outbreak in Liberia, the determinants of utilization of health care during the post-conflict era (after 2003) were studied; increased travel was associated with lower utilization of facility based health services in northern Liberia in 2008.[37]

In summary, well before the Ebola outbreak in Liberia, it was well documented elsewhere in Africa, and specifically in Liberia, that increased travel time and distance from healthcare facilities have a negative impact on health-seeking behavior and utilization of health services, especially those which are facility based. It could be expected that persons with Ebola symptoms living further from health facilities might be less able to receive a prompt diagnosis and treatment.

Addressing the complex issues of geographic access to health services, and the role of community health workers in bringing health services to rural, isolated, and remote areas requires a spatial understanding of the distribution of health services and health workers, population, and transportation networks. Geographic information systems provide powerful tools for understanding and analyzing these challenges in public health.

**GIS in public health and epidemiology**

GIS is increasingly a critical component of disease surveillance, epidemic response, and public health activities. While GIS has arguably been a component of epidemiological

investigations and public health responses since John Snow's pioneering work in cholera, the tools for collecting, managing, processing and visualizing geo-spatial data have only recently become widely available and used.

Multiple organizations now work to meet the demand for maps that visualize and distill information related to problems and crises ranging from damage assessments after natural disasters to distribution of disease. GIS can provide intuitive ways to both analyze and communicate complicated situations with many variables. This is important not only for the rapid response to an evolving crisis but also critical for preparation and mitigation of possible risks to health and wellbeing.

GIS as a tool in the Ebola response

The wide geographic spread of Ebola in 2014/2015 created a need for maps both for programmatic purposes, such as epidemiology and contact tracing, as well as a tool to communicate the seriousness of the epidemic to the broader world. Even at the earliest stages of the outbreak in Guinea in March 2014 the humanitarian organization Medicins sans Frontiers (MSF) used GIS to organize their initial response and contact tracing.[38]

There is an increasing appetite on the part of mass media for maps to describe and explain crises to the general public, and on the part of non-governmental organizations for planning and communicating their activities. The 2014/2015 West Africa Ebola epidemic occurred when tools for communicating and sharing geo-spatial information were available. In particular, the Humanitarian Digital Exchange (HDX), operated by the United Nations Office for Coordination of Humanitarian Affairs (OCHA), became a centralized repository for quantitative and geo-spatial information on the Ebola response.[39]

Another important resource is OpenStreetMap.org (OSM) where open source map data from a wide variety of sources has been compiled to create accurate and up-to-date maps, particularly in the developing world. Prior crises, in particular the Haiti earthquake in January 2010, had shown the remarkable power of volunteers to rapidly update maps based on satellite imagery. In West Africa, prior to the Ebola outbreak, there were limited accurate or up-to-date maps of the region, road networks, population distribution and infrastructure. This hampered the initial response to the outbreak in Guinea, which led to MSF to appeal for improved maps to the Humanitarian OSM Team (HOTOSM) which coordinates and activates a large cadre of volunteers around the world in up-dating OpenStreetMap.[38, 40]

**Bong County, Liberia: Background and Ebola epidemic**

Health Infrastructure in Bong County

The health system in Bong County is managed by a Health Team, which is composed of the focal persons managing various departments and projects, including community health, maternal and child health, surveillance, water and sanitation, and others. The Health Team is headquartered in Phebe Hospital which is located approximately 13 kilometers outside Gbarnga, the largest city in Bong County. Overall, Bong County is the third most populous county in Liberia with a population in 2014 of over 408,000.[41] In the north-central part of the country, Bong County shares borders with Guinea, and the major road leading from Guinea to Monrovia passes through Bong County. (see Figure 1) It is one of the lesser developed countries in Liberia with the majority of the population engaged in small scale agriculture. Bong also has the fourth largest city in Liberia (Gbarnga) and the presence of mining operations brings in migrant laborers.

Bong County has two main hospitals situated in Gbarnga (primarily serving the city's population) and Phebe, which serves as a referral hospital for the County. The Health Team oversees the activities of these 2 hospitals and 37 clinics distributed throughout the county, manages health manpower, and supervises public health activities in the county. In addition, multiple non-governmental organizations (NGOs) operate in the county, including International Medical Corps, CARE, MSF, Project Concern International (PCI), and others. The Bong County Health Team has the mandate to supervise and coordinate the work of these NGOs.

The first probable case of Ebola in Bong County was reported on March 30, 2014; this case is thought to be the first Ebola case in Liberia. The patient, a 14 year old male, was not tested for Ebola, was not hospitalized, and died. The first confirmed cases in Bong County were reported in the middle of July, 2014. By February, 2015, the Liberian Ministry of Health reported that there had been 150 confirmed cases, 38 probable cases, 417 suspected cases, and 159 deaths attributed to Ebola in Bong County.[42]

To respond to the outbreak, the Bong County Health Team, non-governmental organizations, and international agencies mobilized resources to educate the public on Ebola and practices to prevent transmission. Health workers were trained in infection prevention and identification of patients, and an Ebola Treatment Unit was set up outside of Gbarnga by the International Medical Corps on September 15, 2014, and a mobile lab to confirm diagnosis of Ebola was introduced.[43] Ebola community care centers were also constructed in the 8 health districts within the County.

General Community Health Volunteers and Community Responses to the Ebola Epidemic in Bong County

As described earlier, Liberia has a system to extend health services through community health workers, including general Community Health Volunteers. These community health workers supplement and support the work of professional health workers whose numbers are limited by health manpower shortages. For the most part, gCHVs are unpaid volunteers though sometimes when they conduct activities for an NGO, they may receive a small stipend or travel allowance. These volunteers, elected by their communities, are trained in basic public health practices. They receive trainings on specific conditions including malaria, acute respiratory infections, diarrhea, tuberculosis, and malnutrition, so that they can recognize and be consulted about common health issues and refer more serious cases to the nearest clinic. Other trainings concentrate on health outreach and education, such as organizing vaccination campaigns, and conducting community education on topics such as family planning, nutrition, water and sanitation, and distribution of insecticide treated bednets. They are also responsible for reporting on vital statistics such as births and deaths as well as conducting surveillance on communicable diseases such as measles and cholera.

As part of the national response to the Ebola epidemic in 2014, gCHVs were trained to give people in their communities health information about Ebola, how to recognize signs and symptoms, infection prevention measures such as hand washing and safe burial practices, and the importance of seeking early treatment. General CHVs report to a community health supervisor; all clinics have a staff member designated as the community health supervisor and all gCHVs in a catchment area meet at least once a month for a gCHV meeting. They often visit the clinic as part of their activities when referring patients for

medical services. The clinic also serves as a meeting point when gCHVs conduct community health mobilization and education activities as a team. A catchment area includes all of the villages whose population would normally go the clinic for services. This is dictated by distance and by geography such as rivers and hilly terrain. Road networks are often very circuitous; the majority of people in rural areas travel by foot or by motorbike taxis which use more direct paths than the roads to get to the clinic.

The remote nature of these communities and the gCHVs' status as volunteers also meant that the central health system had limited information on how many were active and where they worked. While not all community health supervisors originally came from the catchment area where they are now serving, they conduct field assessments and public health activities and have a good familiarity with the broader area where they are placed. Additionally, some clinic staff, such as registration clerks or immunization coordinators, are either current gCHVs who volunteer additional time at the clinic or have transitioned to a full-time, modestly paid position at the clinic.

In addition to community education about Ebola, these volunteers were expected to continue routine disease surveillance, as part of their normal activities. During the acute phase of the Ebola response, gCHVs were used by various NGOs as community mobilizers and contact tracers. In most cases, NGOs paid gCHVs for these activities although the Ministry of Health does not normally compensate gCHVs in any way. Because of the urgent need for additional health personnel, some NGOs rapidly recruited new people to serve as community health volunteers, though often these NGOs bypassed the normal process for recruitment which involved election at the community level to guarantee community trust.

This election was required for any community volunteer to be recognized as an official general community health volunteer.

Community leaders, along with the gCHVs, instituted quarantine and isolation practices in many communities, limiting travel into and out of many villages throughout the county, regardless of any suspected contact with Ebola patients. Many villages that remained Ebola-free credit these isolation practices with protecting the community. In some communities with documented Ebola outbreaks, strict quarantine measures were enforced by local leaders as well as health officials; this was documented to interrupt new transmissions.[14] The positive role that community health workers, in particular the wide network of gCHVs, contributed to the response to the epidemic was recognized by the Bong County Health Team. However, there was inadequate information regarding the number of active gCHVs and in particular, their geographic coverage of communities in the county.

**Project Background**

The need for accurate and detailed geographic information in Bong County relating to health facilities and the gCHV network was recognized by the Bong County Health Team.[44] Prior to 2014, map data, especially on rural infrastructure, in Liberia were out-dated and limited by multiple factors. The Liberian government was limited in its ability to update information on both infrastructure and populated settlements. Much of the data on settled areas came from the 1985 Census. The long civil wars in Liberia (1989-1997 and 1999-2003) had altered many settlement patterns as people fled areas of conflict. Much of the more recent data had come from the United Nations Peacekeeping Mission in Liberia (UNMIL) which has operated in Liberia since 2003.

As part of the Ebola response, significant effort was made in updating and improving maps to facilitate coordination between the various responding agencies, including the Liberian government, multi-lateral organizations such as the World Health Organization and UNMIL, international NGOs, foreign government agencies such as the US Centers for Disease Control and Prevention (CDC) and the US Department of Defense (DOD). For example, maps were used to plan the placement of Ebola Treatment Units (ETU) and Community Care Centers (CCC), based on population estimates, the location of roads that could be used by supply trucks during the rainy season, and suspected and projected location of disease clusters.

Thousands of volunteers around the world worked under the coordination of the Humanitarian OpenStreetMap Team to use satellite imagery to update OSM with information on roads and communities. Where good imagery existed, volunteers were able to map individual houses in communities as well as roads, tracks, and even foot paths going through the forest. (Much of Liberia remains forested.) This global effort was able to dramatically improve maps for much of Liberia, identifying the location and size of rural hamlets as well as recognizable landmarks such as churches, school buildings, and soccer fields. These volunteers, however, could not recognize, let alone fix, widespread problems with inconsistent place names for hamlets, villages and towns.

There were efforts to visualize the geographic spread of Ebola in Liberia but most of these condensed the data to the country or county levels. More detailed data were used to describe the epidemic at the district level but a combination of factors prevented accurate mapping at the sub-district level. In particular, there were problems with the lack of consistency in names, and the fact that the organizations and individuals who were

conducting mapping did not have the local language needed to mitigate around these problems. (See limitations section for further discussion of map issues.)

Request for GIS assistance on Health infrastructure and gCHVs

The Bong County Health Team wished to know how many gCHVs were still operating in mid-2015, particularly after the cessation of payment provided by international NGOs. There were anecdotal reports that some of the new gCHVs were being paid by more than one NGO, leading to distrust in reported numbers of gCHVs. The fact that many gCHVs work in rural hamlets (usually communities with 5 to 20 households) made it difficult for the Bong County Health Team to investigate and enumerate active gCHVs.

To address this problem, the Bong County Health Officer made a request to Project Concern International (PCI) for assistance in understanding the number and distribution of general Community Health Volunteers (gCHV). PCI responded by tasking me as a GIS intern to work with the Bong County Community Health Team and assist them to learn the geo-spatial location of their volunteers. The work conducted to assist the Bong County Health Team to understand the geographical location of all gCHVs, as well as the precise location of health facilities, is described in the Methods section.

**Research goal and aims**

To use accurate geo-spatial and temporal information to understand factors which may have influenced Ebola case distribution and outcomes in Bong County, Liberia.

Specific Aims of the research

1. To accurately map the location of all health facilities and general Community Health Volunteers in Bong County, Liberia

2. To geocode the recorded village of residence for confirmed and probable Ebola cases in Bong County, Liberia
3. To classify villages with Ebola cases in terms of rural isolation as measured by proximity to a healthcare facility
4. To analyze the relationship between distance to the nearest health facility and:
    a. Reported date of symptom onset for confirmed and probable Ebola cases
    b. Based on reported date of symptom onset, assess response in terms of hospitalization of confirmed and probable cases
    c. Assess outcome (death or survival) and calculate case fatality rate

**Methods**

Fieldwork and Data Sources

Travel was conducted in late June, 2015, to Monrovia, Liberia, for brief consultations with Project Concern International. Travel was then conducted to Bong County for meetings with the Bong County Health Team, specifically the Bong County communication health organizer. The Bong County Health Team indicated the need to have an accurate listing of all active gCHVs and the location where they were operating. Existing lists were known to be out-dated or incomplete, and in many cases, a very general "community" name was given as their location, rather than a specific and accurately named village. This meant that multiple gCHVs often appeared to share a single location (which is contrary to guidelines for their scope of work) and it was difficult to ascertain which specific villages had gCHV coverage and which villages were not currently being served by a gCHV.

Travel was conducted in July and August, 2015, to each health facility in Bong County. Thirty-five days (35) were spent driving to these 39 health facilities which are spread

out throughout the county. Lists of gCHV were confirmed and updated at each health facility. Although formal lists of gCHVs were incomplete and in some cases not updated, it was found that clinics had multiple staff who were very familiar with the gCHVs, where they lived, and the many small hamlets and villages within the catchment area where they serve. Thus, a complete and updated listing of all gCHVs, as well as their area of work, was compiled with the assistance of clinic staff.

The Bong County Health Office had maps of the county but these maps were out-dated or inaccurate and missing some critical information. The Bong County Health Team had made a request to the local Liberia Institute for Statistical and Geographic Information Services (LISGIS) for a map of all clinics and other health infrastructure within the county. The local LISGIS did not have the resources, such as vehicles and fuel, to do field collection of GIS data, specifically latitude and longitude points collected using Global Position Satellite (GPS) network, in order to create this map. Additionally, lack of access to the internet also inhibited the knowledge of and use of tools and resources such as OpenStreetMap.

Mapping of Bong County and Health Care Facilities

Up to date map information on Liberia is maintained on the Humanitarian OpenStreetMap Team (HOTOSM.org) wiki. [40] This includes shapefiles that can be easily downloaded and used for the creation of custom maps. These data were imported into QGIS and organized into appropriate base layers. The map of Bong County which was created from these is seen in Figure 2. There is varying degrees of detail with some sections of the county having a great deal of detailed information down to the outline of individual houses. Slightly less detailed areas would still include the outline of settled areas, prominent

buildings outside of the settled area, such as schools or churches, especially in relation to the road network. Other areas had very little details, with just labeled points for different communities without any other cartographic information such as the roads or paths.

Using existing maps and lists of all health facilities in Bong County, a preliminary layer of health facilities was created, using a combination of best guess match of place names to the OSM data on places, and reported driving directions to each clinic. Subsequently, field travel was conducted to each of the 37 clinics and 2 hospitals in the 8 health districts in the county. GPS coordinates for each clinic compound were recorded using an Android tablet. These coordinates were used to update the health facility layer.

Mapping of gCHVs

The next step in mapping was to identify and approximate the location of each of the gCHVs in Bong County, to respond to the original request of the Bong County Health Team. At each of the 39 health facilities visited, meetings were conducted with the clinic Officer in Charge (OIC) and the community health gCHV supervisor, who was the primary source of information on gCHVs and who is the person who maintains records of the gCHVs associated with that facility. Although the 2 hospitals have sporadic electricity, none of these clinics had computers or electricity and none of the facilities had electronic records relating to gCHVs. Records of monthly meetings with gCHVs were kept in each facility, though there are no permanent lists of gCHVs and basic demographic information about them, including locations.

As part of the data collection exercise, discussions were held with the gCHV supervisor, as well as with additional staff familiar with the gCHVs and the catchment area, along with gCHVs who happened to be at the facility at the time of the site visit. The gCHV

supervisor and the OIC were often personnel assigned to the facility from elsewhere in Liberia, and in some cases did not have as detailed information about the catchment area. In many cases, however, lower level staff at the facility, such as clerks and orderlies, were former gCHVs, and therefore had detailed knowledge that supplement the information provided by the OIC. Further, gCHV supervisors conduct regular field visits throughout the catchment area and are quite familiar with the area, and were able to identify other clinic staff who had better geographic knowledge.

An Excel document that listed gCHVs and their village was created based on the existing gCHV from the county. In discussion with facility staff and a review of locally held hand-written records, the list was updated with new gCVHs not yet included in the record supplied by the county health team; some of these gCHVs had been active for years and may have been recorded on other lists but the lack of a centralized, up-datable registry meant that many gCHVs were missing from the county lists. All of the gCHVs known to be active reported by facility staff were recorded with spelling of the community or hamlet commonly used by the clinic staff. In addition, the name of the community as it occurred on maps was recorded in the database. In many cases, this led to 3 different place names that were associated with a single gCHV.

Participatory mapping

In order to compile accurate lists of gCHVs associated with each facility, handwritten lists prepared at the facility level were merged with the electronic list received from the Bong County Health Team. Every effort was made to record the specific location where the gCVH lived, rather than the general community name used to describe a collection of several

villages or hamlets where the gCHV worked, or the most prominent local village in that gCHVs sphere of operation.

I then engaged in a participatory process to map the location of active gCHVs. Using the map prepared in QGIS along with a map of Liberia on a tablet using the OSMAnd+ app as back-up, I showed a map of the catchment area to the staff. An initial search for the facility reported place name was conducted and if a match was found, the staff were consulted for confirmation or correction. When a place name could not be found or there was uncertainty of a match, a participatory process was employed where the combination of roads and paths was described by the staff with as much detail about the route through intermediary communities. The route described was then followed on the map in QGIS with any other cartographic information used to confirm locations or prompt for more detail. Describing alternative routes to the village or routes from that village to further villages was used to confirm the accuracy of locations.

Based on this process, I was able to identify the villages and hamlets where gCVHs were stationed and geo-locate them in QGIS. This updated map was then discussed with staff at the facility to confirm accuracy. We also discussed how the data collected would be used by the County Health Team as well as how accurate maps and GIS analysis could be used analyze and inform public health responses. An example used would be an NGO engaged in assessing the functional status of previously dug wells. This NGO, theoretically, could now ask the County Health Team for contact information for the closest gCVHs to each well to be assessed. I demonstrated to the local staff how GIS could match different sets of information, such as a list of wells and a list of gCVHs, even where they do not share a common attribute such as being in the same village.

Mapping of Confirmed and Probable Ebola Cases

The information officer of the Bong County Health Team provided me with the Ebola case lists for the county. This included a total of 748 listings. Initial review and cleaning of the data found a number of records that contained inadequate data to be classified; these 14 records were dropped. The MOH listing was as inclusive as possible and included a large number of "suspect" cases, including most reported deaths without a confirmed cause of death as well as many patients who reported any Ebola-like symptoms, including fever, nausea, vomiting, joint pain, bleeding, general malaise, and other flu like symptoms. Of the 734 cases with adequate data, 371 (51%) had a record of laboratory results and 363 had no recorded laboratory results. Five of the records with no recorded lab result had the comment "discharged due to negative test" in the record. An additional 41 were classified as "not a case". Of the 317 suspected and probable cases with no recorded lab results, 37 were classified by the MOH as probable cases as they had confirmed contact with known Ebola cases and are included in my analysis of confirmed and probable cases. The remaining 280 suspect cases with no recorded lab results had incomplete data for them to be confidently considered an Ebola case.

Of the 371 with recorded laboratory results, 237 had negative lab results and are considered confirmed negative patients and are not included in this analysis. 134 had a confirmed positive laboratory result and are included in the analysis, along with the 37 cases described above who were considered probable cases. Thus, 171 records (23% of the total listings) were included in this analysis as confirmed or probable cases. Of these 171, it was possible to geocode the village of residence for 156 cases. These decisions are illustrated in Figure 3.

In addition, there are 3 cases with missing data on onset of symptoms but have a date of hospitalization and confirmed laboratory results. In order to include these cases in the analysis, the date of hospitalization has been used as a proxy for date of symptom onset.

The method to geolocate confirmed and probable Ebola cases with more precision than residence by health district involved matching the recorded village of residence to known place names. The inconsistency and variability of place names and naming conventions both in the case listings and place names listed in other geospatial databases required the creation of a process to match the recorded village name to a recorded place name. My experience in the field as well as the geospatial information gathered to map the gCHVs provided a database of place names that was both locally produced and included the variants in names for a single village. For example, in geolocating a specific gCHV as many as five different spellings and names of villages were recorded. I manually cleaned the place names in the Ebola case listings for consistency of naming. In many cases both the neighborhood and larger town was recorded; the most precise was used. For example, a case reported to live in Gbarnga/Lelekpayea was assigned to the fixed village of residence of Lelekpayea in the health district of Gbarnga.

Geolocating the village of residence was done by searching for matches in the gCHV data set as well as the official place name data set from the Liberian Institute of Statistical and Geographic Information Services (LISGIS) which also includes geographic coordinates. To address the inconsistency in naming conventions, specifically the inconsistent inclusion of "town" or "ta" in place names, the search for matches was additionally done with both variants of place names with these suffixes as well as removal of these suffixes. There are 2,825 place names in the LISGIS data base for Bong County. Of the 15 confirmed or probable Ebola cases that cannot be geolocated, two had no village of residence listed, and

of the remaining 13, there were no matches between the village name listed and the extensive LISGIS database and no obvious similar name in the district. Therefore these cases are not included in any mapping to be presented in the results section. However, these cases will be included in the analysis of the epidemic in Bong County.

Methods to Calculate Case Fatality Rates

Case fatality rates were calculated based on standard method of number of deaths divided by number of confirmed and probable cases. In terms of calculating CFR over various time periods, because there is often a rapid progression from symptom onset to acute illness to death (in some cases), it is reasonable to assume deaths occurred not long after symptom onset, so the date of symptom onset was used as a proxy for date of death. Because of the small number of cases in July (6), October (13) and December (6), to calculate case fatality rates over time I combined the number of cases for July and August (total cases = 48), September and October (total cases = 67), and November and December (total cases = 52).

**Findings related to the Distribution of Health Resources**

Distribution of Health Districts, Health Care Facilities and Population:

There are 12 administrative districts in Bong County. Some of these districts are combined to form the 8 health districts in Bong County which largely follow district lines. The largest population (approximately 98,000 population) resides in Jorquelleh health district which includes the only city in the county, Gbarnga. The least populated health district is Zota, with an estimated population of 25,000. The health districts in Bong County, their populations, the number and type of health facilities in each district, and the average number of gCHVs assigned to healthcare facilities is presented in Table 1. The number of facilities

per health district varies from 3 to 9. The geographic position of health care facilities in Bong County is seen in Figure 4.

General community health volunteers:

The number of gCHVs in each health district is shown in Table 1, along with the number of health facilities in that district. The number of gCHVs per health district varied from a low of 43 to a high of 113. The number of gCHVs per health facility ranged from a low of 4 to a high of 33. Thirteen (33%) of health care facilities had 6 to 10 gCHVS, eight facilities (21%) had 11 to 15 gCHVS, and twelve facilities (31%) had 16 to 20 gCHVs. One facility had only 5 gCHVS; five facilities had over 20 gCHVs. There was significant variability between the different health districts with a mean number of gCHVs per facility being as low as 8.2 in one health district while another health district had a mean of 20.3 gCHVs per facility. The geographic position of the village of residence of each gCHVs is presented in Figure 5.

**Findings related to the Ebola Outbreak in Bong County**

Distribution by Week of Onset of symptoms:

The first case of Ebola in Bong County was reported on March 31, 2014 though symptom onset was recorded as March 21. This case resulted in death but no additional transmission were associated with this case; it is unknown whether this case was a person who had traveled to Bong County from another county. The next case in Bong County did not appear until July. When analyzing the course of the epidemic over time, I will limit the analysis to the 170 cases which occurred from July through December, 2014. In addition, this analysis will be limited to those considered confirmed or probable, as described in the

Decision Tree. Date of symptom onset is used for analysis of the epidemic over time as case report date was found to be less reliable as many cases were reported on the same day.

The histogram of cases by date of symptom onset, Figure 6, shows relatively few cases in July (6), sharp increase in cases in August (42) and September (54), then a decline in October (13), with a spike in cases in November (46), and another sharp decline to 6 cases in December. There were no cases reported in Bong County after December 19, 2014. The distribution of cases is also seen on Figure 7 which presents the same data but in the form of a curve.

Figure 8 shows the number of cases differentiated by confirmed or probable, by week of symptom onset. This shows that the proportion of "probable" cases declined and the proportion of confirmed cases increased as the epidemic progressed; this probably reflects the increasing availability of laboratory testing. Changes in the epidemic over time also reflect the establishment on September 15, 2014, of the Ebola Treatment Unit at Phebe Hospital, which is the main county hospital.

Figure 9 is a scatter plot of Ebola cases, both confirmed and probable, by date of symptom onset with their distance in kilometers from the nearest health care facility. This plot indicates that 5 kilometers is a reasonable cut-off distance to differentiate between those with more access to a HCF and those with less access.

There was a spike of cases in November, as seen in the density curve (Figure 10) which displays date of symptom onset over time, comparing those living 5 or less kilometers from a HCF and those living more than 5 kilometers from a HCF. Although there was a decline in cases among those living closer to a HCF after September, the low but persistent occurrence of new cases in areas closer to HCF in the last three months of the year re-

inforce the need for on-going surveillance, especially when there were new cases elsewhere in the country.

Almost all of the cases in November (41 of 42, 98%) occurred in persons more than 5 kilometers from a HCF. Further, the scatter plot (Figure 9) indicates that most of these cases occurred in and around two villages, as 30 cases lived in or near Taylor Ta and 8 lived in or near Bomo Ta. These two rural clusters accounted for 38 of 42 (90.5%) cases in Bong County in November, 2014. More discussion of clusters may be found in Appendix One.

Hospitalization of confirmed and probable Ebola cases:

Overall, out of the 170 confirmed and probable Ebola cases in Bong County from July to December 2014, 109 were hospitalized, 48 are listed as not hospitalized, and there is missing data on hospitalization for 13 cases. As seen in Figure 11, hospitalization rates increased dramatically over the course of the epidemic, from 19 of 48 of patients (40%) hospitalized in July and August to 36 patients of 67 patients (54%) during the months of September and October. All but one of the 52 patients (98%) with symptom onset in November and December were hospitalized. This reflects both the establishment of the Ebola Treatment Unit on September 15 as well as extensive public education on the importance of hospitalization and isolation of cases.

Of cases with data on date of onset, hospitalization, and distance from a HCF, 58% of patients lived 5 or less kilometers from a HCF were hospitalized, compared with 84% of those living more than 5 kilometers from a HCF, as seen in Figure 12. This is initially counter-intuitive, as it would seem that persons living near a HCF would be more likely to be hospitalized. However, it appears that these different hospitalization rates reflect time and the availability of services, as the more remote cases occurred later in the epidemic, after the

ETU was established and after the intense public education campaigns about the importance of isolating and hospitalizing anyone with symptoms of Ebola.

Case Fatality Rates in Bong County:

In Bong County, there were 70 deaths out of 171 patients, for a case fatality rate (CFR) of 41%. A comparison of CFRs based on time, hospitalization rates, and distance from a HCF, as shown in Table 2. There was little difference in the CFR between patients who were hospitalized; 43 deaths among 102 hospitalized patients or a CFR of 42% compared with 21 deaths among the 54 patients not hospitalized, with a CFR of 39%. There were also very similar CFRs among patients who lived within 5 kilometers of a HCF (CFR = 40%) and those who lived more than 5 kilometers from a HCF (CFR = 43%).

The stability of the death rate in Bong County probably reflects the basic nature of Ebola virus disease and the limited impact of interventions on the rate of death. The overall CFR in the 2014/2015 West Africa Ebola outbreak was reported to be 11,315 deaths among 28,637 cases, for a CFR of 39.5%, very similar to the rate of 41% observed in this data set from Bong County.

**Limitations**

Definition of Cases:

I have used a specific method to select cases to be included in this analysis. Based on this method, the cases I have included as confirmed were truly confirmed on the basis of a positive lab test. Those included as "probable" were not lab confirmed; however, they were listed as probable and had known contact with an Ebola case. This reduced the total of cases to 171, whereas the total listed in Bong County records was 748, though this included 237 with a confirmed negative lab result. More details on the method to select confirmed cases

can be found in the Decision Tree, Figure 3. It is possible that there were some listings who had Ebola but the record was inadequate to include them as a probable case.

Inconsistencies in case listings:

A careful review of the 171 confirmed and probable cases revealed some inconsistencies, some of which appear to be data entry errors. An example of inconsistency is cases listed as "not hospitalized" but also having a date of hospitalization. My assumption was that there is a greater chance of a data error on a yes/no variable compared to an actual date, so these cases were in fact considered to be hospitalized.

Missing Data:

There were missing data in many records; most cases were missing information on at least one variable. For categorical yes/no variables, such as hospitalization, missing data probably had a greater impact on the count of "not hospitalized" relative to hospitalized, and therefore the hospitalization rates reported in this analysis may be an over-estimate of hospitalization. However, the categorical variable of alive or dead was filled in for all cases, so the case fatality rates are probably reflective of the epidemic in Bong County. The number of cases with missing data is indicated in the tables.

Mapping of Ebola Cases:

It was not possible to geo-locate 15 cases out of the 171 analyzed. Additionally, the lack of consistence and specific addressing means that the village name recorded for someone may instead refer to the greater community rather than the specific hamlet. These community names often come from the nearest large village that is on a more established road. Geolocating these cases to that village would in many cases significantly reduce the

calculated distance from the nearest health facility. This may have resulted in an under-count of cases considered to have low access to HCF.

Another issue is that many people might work and stay much of the time in a larger village but also have a home in a rural area where their family might live and where they farm a small plot of land. It is unknown which of these place names (rural or less rural) would be recorded and where a person might go with the onset of symptoms. A likely example of this situation is the significant discrepancy between the number of cases geolocated to Mawah in my analysis, which is 8 confirmed and two probable. This is lower than the number of cases (13 confirmed and 9 probable) in a published description of the Mahwah cluster.[14] Thus, the number of confirmed and probable cases in my analysis, particularly in certain rural clusters may be an under-report of the confirmed and probable Ebola cases identified in these clusters.

General Community Health Volunteers (gCHVs):

The listing and geolocation of gCHVs is based on the situation as it existed in July/August 2015. Some of these gCHVs were new recruits and were not active as a formal gCHV during the outbreak, though many of them were active in response activities. Additionally, many contact tracers and community mobilizers were recruited from the existing pool of gCHVs, and thus worked outside of their community. This uncertainty about the number, locations and activities of gCHVs during the outbreak means that it is impossible to measure the actual impact of gCHVs on the course of the outbreak in Bong County.

**Discussion:**

These findings suggest that controlling the Ebola outbreak was facilitated and possibly more effective in more urban communities in Bong County. Persons living in these communities not only have easier access to health care facilities but they are also more easily served by such interventions as health education, community mobilization and outreach, prompt responses such as ambulances to transport possible cases to health care facilities and burial teams to conduct safe burials.

People living in rural communities appear to have been protected at the early stages of the epidemic (July to September) when most cases occurred in urban areas. The decline in new cases in urban areas is quite visible after September, highlighting the effectiveness of interventions to control the epidemic. However, it is likely that there was lower penetration of these interventions in more isolated communities. It is also quite likely that high risk community behaviors persisted longer in rural communities than in more urbanized communities. These high risk community behaviors included lack of hand washing stations, home care of sick persons and participation in unsafe traditional burials, which include washing and touching of dead bodies.

Hospitalization rates increased significantly over time in Bong County; by the end of the outbreak in Bong County, all cases were hospitalized. However, this did not seem to lower case fatality rates, probably due to the fact that hospital care was supportive and addressed complications such as dehydration, but hospital care could not offer any curative treatments. In addition to caring for the patient, hospitalization also served to isolate the patient in a setting where there were protective supplies and training of health care workers on how to avoid transmission in the healthcare setting. When patients were cared for at home and not hospitalized there was significant risk of transmission to family members and

caregivers. Thus, the increasing rates of hospitalization no doubt contributed to the control of Ebola in Bong County. The last case occurred on December 19, slightly more than three months after the establishment of the Ebola Treatment Unit on September 15, 2014.

Case fatality rates remained stable over time, hovering around 40%, and case fatality rates did not appear to be correlated with distance from a healthcare facility or hospitalization. This is probably due to the fact that there was no treatment available for Ebola in Liberia at the time, and the case fatality rates reflect the basic nature of this disease. However, there appears to be a slight decline in CFR with time; CFR declined from a high of 48% in the period of July and August to 36.5% in November/December. As almost all cases in November and December were hospitalized, this decline in CFR may reflect the increasing skill of health workers to provide life-saving supportive care in hospitals. All of the last 47 cases in Bong County were hospitalized and only 14 died, a CFR of 29.7%, much lower than the overall CFR of 41% for Bong County.

The effectiveness of community education about Ebola may be associated with the decline in new cases in areas within 5 kilometers of a healthcare facility, where people likely had access to both mass media (primarily radio) as well as messages from health extension workers such as the general Community Health Volunteers (gCHVs). As people and communities are more remote, there are challenges for penetration of both mass media and the more personalized health education that can be delivered by cadres such as gCHVs. These findings should be useful to public health officials in Bong County and elsewhere in terms of re-inforcing the urgent need in rural and remote communities for health education and interventions to prevent the spread of infectious diseases. The current coverage of gCHVs in Bong County, where there are hundreds of rural villages and communities served by gCHVs, strongly suggests that penetration of health education to these communities is

achievable. Additional training of cGHVs in disease surveillance and community level infection control measures may empower gCHVs and the remote communities they serve to protect themselves from the spread of infectious diseases and facilitate early detection and rapid response to future outbreaks.

**References**


1. World Health Organization. *Ebola Situation Report - 30 December 2015*. 2015; Available from: http://apps.who.int/ebola/current-situation/ebola-situation-report-30-december-2015.
2. Dixon, M.G., et al., *Ebola viral disease outbreak--West Africa, 2014*. MMWR Morb Mortal Wkly Rep, 2014. **63**(25): p. 548-51.
3. World Health Organization, *Ebola Virus Disease Fact Sheet No. 103*. 2014, WHO.
4. Lamunu, M., et al., *Containing a haemorrhagic fever epidemic: the Ebola experience in Uganda (October 2000-January 2001)*. Int J Infect Dis, 2004. **8**(1): p. 27-37.
5. O'Brien, P., *Fearing fear itself: Why aid donors must act now to stop the Ebola outbreak in West Africa*, in *Politics of Poverty*. 2014, Oxfam America.
6. Lindblade, K.A., et al., *Decreased Ebola Transmission after Rapid Response to Outbreaks in Remote Areas, Liberia, 2014*. Emerg Infect Dis, 2015. **21**(10): p. 1800-7.
7. Bazeyo, W., et al., *Ebola a reality of modern Public Health; need for Surveillance, Preparedness and Response Training for Health Workers and other multidisciplinary teams: a case for Uganda.* Pan Afr Med J, 2015. **20**: p. 404.
8. Borchert, M., et al., *Ebola haemorrhagic fever outbreak in Masindi District, Uganda: outbreak description and lessons learned.* BMC Infect Dis, 2011. **11**: p. 357.
9. Nyenswah, T., et al., *Initiation of a ring approach to infection prevention and control at non-Ebola health care facilities - Liberia, January-February 2015*. MMWR Morb Mortal Wkly Rep, 2015. **64**(18): p. 505-8.
10. Manguvo, A. and B. Mafuvadze, *The impact of traditional and religious practices on the spread of Ebola in West Africa: time for a strategic shift.* Pan Afr Med J, 2015. **22 Suppl 1**: p. 9.
11. Nyenswah, T., et al., *Controlling the last known cluster of Ebola virus disease - Liberia, January-February 2015*. MMWR Morb Mortal Wkly Rep, 2015. **64**(18): p. 500-4.
12. Nielsen, C.F., et al., *Improving burial practices and cemetery management during an Ebola virus disease epidemic - Sierra Leone, 2014*. MMWR Morb Mortal Wkly Rep, 2015. **64**(1): p. 20-7.
13. Kobayashi, M., et al., *Community Knowledge, Attitudes, and Practices Regarding Ebola Virus Disease - Five Counties, Liberia, September-October, 2014*. MMWR Morb Mortal Wkly Rep, 2015. **64**(26): p. 714-8.
14. Nyenswah, T., et al., *Community quarantine to interrupt Ebola virus transmission - Mawah Village, Bong County, Liberia, August-October, 2014*. MMWR Morb Mortal Wkly Rep, 2015. **64**(7): p. 179-82.
15. World Health Organization. *The Ebola outbreak in Liberia is over*. WHO statement: 9 May 2015; Available from: http://www.who.int/mediacentre/news/statements/2015/liberia-ends-ebola/en/.
16. World Health Organization, *Ebola Situation Report - 15 July 2015*. 2015, WHO.

17. World Health Organization, *Ebola Situation Report - 25 November 2015* 2015, WHO.

18. United Nations, *Declaration of Alma-Ata*, in *International Conference on Primary Health Care*. 1978: Alma-Ata, USSR.

19. World Health Organization, *Task shifting to tackle health worker shortages*. 2007, WHO.

20. African Medical Research Foundation. *Amref's Position Statement On Task Shifting.* Available from: http://amref.org/amref/en/info-hub/amrefs-position-statement-on-task-shifting-/.

21. Brown, H., *Community workers key to improving Africa's primary care.* Lancet, 2007. **370**(9593): p. 1115-7.

22. Barogui, Y.T., et al., *Contribution of the community health volunteers in the control of Buruli ulcer in Benin.* PLoS Negl Trop Dis, 2014. **8**(10): p. e3200.

23. Yansaneh, A.I., et al., *Influence of community health volunteers on care seeking and treatment coverage for common childhood illnesses in the context of free health care in rural Sierra Leone.* Trop Med Int Health, 2014. **19**(12): p. 1466-76.

24. Dinku, B., A. Kumie, and F. Bisrat, *Linking community volunteer surveillance focal persons with health extension workers on polio surveillance.* Ethiop Med J, 2013. **51 Suppl 1**: p. 71-6.

25. Kunkel, A.G., E.S. Van Itallie, and D. Wu, *Optimal distribution of medical backpacks and health surveillance assistants in Malawi.* Health Care Manag Sci, 2014. **17**(3): p. 230-44.

26. Tweya, H., et al., *'Task shifting' in an antiretroviral clinic in Malawi: can health surveillance assistants manage patients safely?* Public Health Action, 2012. **2**(4): p. 178-80.

27. Ludwick, T., et al., *Poor retention does not have to be the rule: retention of volunteer community health workers in Uganda.* Health Policy Plan, 2014. **29**(3): p. 388-95.

28. Anselmi, L., M. Lagarde, and K. Hanson, *Health service availability and health seeking behaviour in resource poor settings: evidence from Mozambique.* Health Econ Rev, 2015. **5**(1): p. 62.

29. Gabrysch, S. and O.M. Campbell, *Still too far to walk: literature review of the determinants of delivery service use.* BMC Pregnancy Childbirth, 2009. **9**: p. 34.

30. Escamilla, V., et al., *Distance from household to clinic and its association with the uptake of prevention of mother-to-child HIV transmission regimens in rural Zambia.* J Acquir Immune Defic Syndr, 2015.

31. Hanson, C., et al., *Maternal mortality and distance to facility-based obstetric care in rural southern Tanzania: a secondary analysis of cross-sectional census data in 226 000 households.* Lancet Glob Health, 2015. **3**(7): p. e387-95.

32. Kadobera, D., et al., *The effect of distance to formal health facility on childhood mortality in rural Tanzania, 2005-2007.* Glob Health Action, 2012. **5**: p. 1-9.

33. Musoke, D., et al., *Health seeking behaviour and challenges in utilising health facilities in Wakiso district, Uganda.* Afr Health Sci, 2014. **14**(4): p. 1046-55.

34. Sudhof, L., et al., *Local use of geographic information systems to improve data utilisation and health services: mapping caesarean section coverage in rural Rwanda.* Trop Med Int Health, 2013. **18**(1): p. 18-26.

35. Tanser, F., B. Gijsbertsen, and K. Herbst, *Modelling and understanding primary health care accessibility and utilization in rural South Africa: an exploration using a geographical information system.* Soc Sci Med, 2006. **63**(3): p. 691-705.

36. Kenny, A., et al., *Remoteness and maternal and child health service utilization in rural Liberia: A population-based survey.* J Glob Health, 2015. **5**(2): p. 020401.

37. Kruk, M.E., et al., *Population preferences for health care in liberia: insights for rebuilding a health system.* Health Serv Res, 2011. **46**(6pt2): p. 2057-78.

38. Timo Lüge, M.-C.s.G.U.C., *GIS Support for the MSF Ebola Response in Guinea 2014*. 2014.

39. HDX, *West Africa: Ebola outbreak*. 2015, OCHA.

40. Humanitarian OpenStreetMap Team. *2014 West Africa Ebola Response*. 2015; Available from: http://wiki.openstreetmap.org/wiki/2014_West_Africa_Ebola_Response.

41. LISGIS, *Population 2008, 2014 by County, District, Clan and Households, Liberia 260914*, L.I.o.S.a.G.-I.S. (LISGIS), Editor. 2014.

42. Ministry of Health Liberia, *Liberia Ebola Daily Sitrep no. 270 for 9th February 2015*, M.o. Health, Editor. 2015.

43. International Medical Corps, *International Medical Corps Opens Liberia's Sixth Ebola Treatment Unit, Bringing New Hope to Liberians*. 2014, International Medical Corps.

44. Sumo, M.K., *Personal communication with the Community Health Coordinator regarding need for GIS mapping of health resources in Bong County.* 2015.

**Tables**

Table 1: Population, Number of Health Facilities and gCHVs by Health District

| | Total Population 2014 estimate | Number of HCFs | Number of gCHVs | Average number of gCHVs per HCF |
|---|---|---|---|---|
| Fuamah | 35289 | 3 | 47 | 15.7 |
| Jorquelleh | 96881 | 5 | 63 | 12.6 |
| Kokoyah | 28948 | 5 | 69 | 13.8 |
| Panta Kpaai | 51939 | 9 | 74 | 8.2 |
| Salala | 53402 | 3 | 61 | 20.3 |
| Sanoyeah | 37135 | 3 | 55 | 18.3 |
| Suakoko | 79922 | 6 | 113 | 18.8 |
| Zota | 24780 | 5 | 43 | 8.6 |
| Total | 408296 | 39 | 525 | 14.5 |

Table 2: Case fatality rates by hospitalization, isolation, and time.

| | Number of cases | Number of Deaths | Case Fatality Rate |
|---|---|---|---|
| **Hospitalized** | | | |
| No | 48 | 19 | 0.396 |
| Yes | 109 | 45 | 0.413 |
| unknown | 13 | 5 | 0.385 |
| **Isolated from HCF** | | | |
| <= 5km to HCF | 94 | 38 | 0.404 |
| > 5km to HCF | 61 | 26 | 0.426 |
| undetermined | 15 | 5 | 0.333 |
| **Month of symptom onset** | | | |
| July | 6 | 5 | 0.833 |
| August | 42 | 18 | 0.429 |
| September | 56 | 20 | 0.357 |
| October | 13 | 7 | 0.538 |
| November | 46 | 17 | 0.37 |
| December | 7 | 2 | 0.286 |
| **Bi-Monthly symptom onset** | | | |
| July - August | 48 | 23 | 0.479 |
| September - October | 69 | 27 | 0.391 |
| November - December | 53 | 19 | 0.358 |
| **Overall** | | | |
| Total | 170 | 69 | 0.406 |

**Figures:**

Figure 1: Map of Counties in Liberia

Figure 2: Map of administrative districts in Bong County, showing Towns and Villages and Major roads

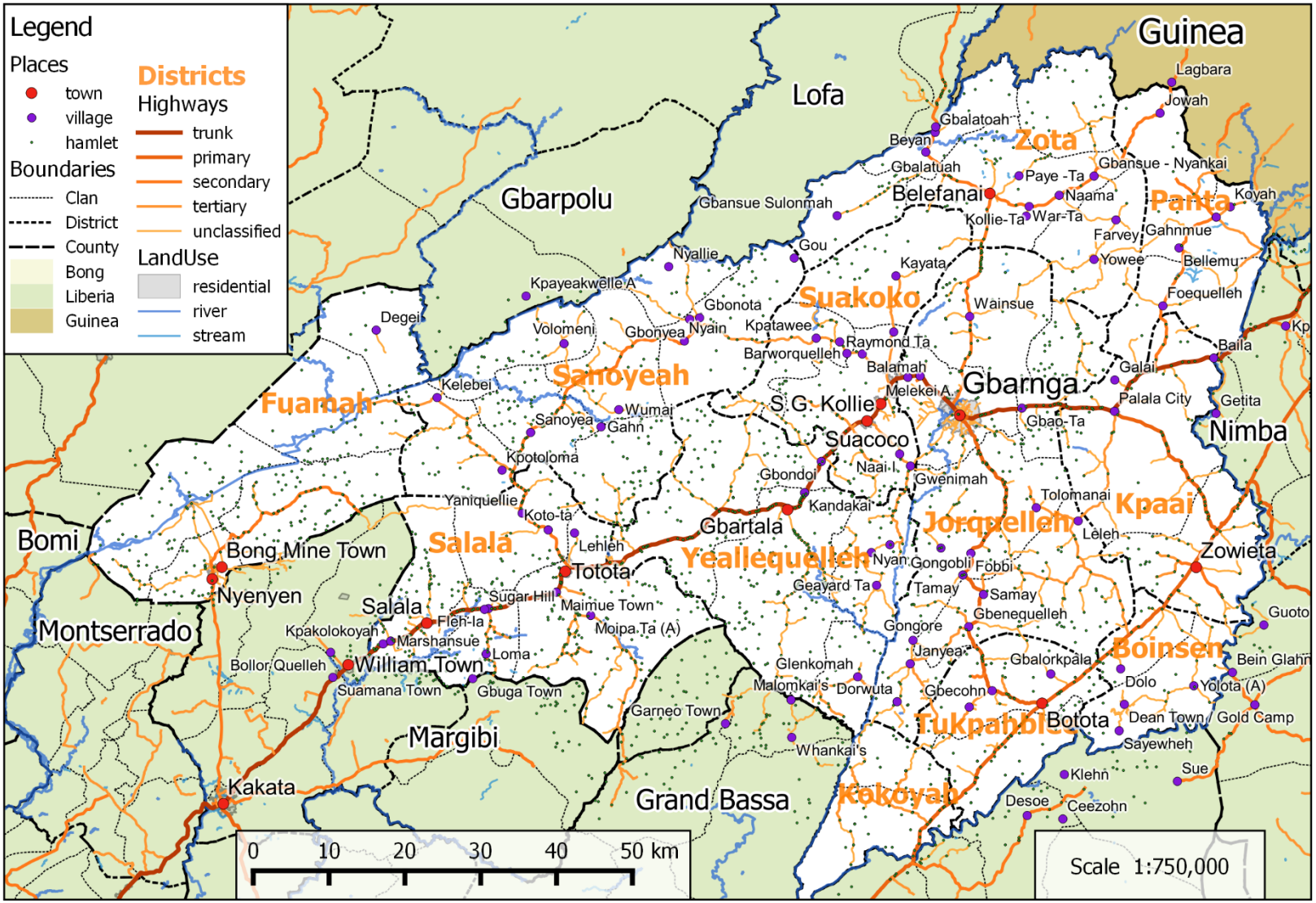


Figure 3: Decision Tree for inclusion or exclusion of possible Ebola cases

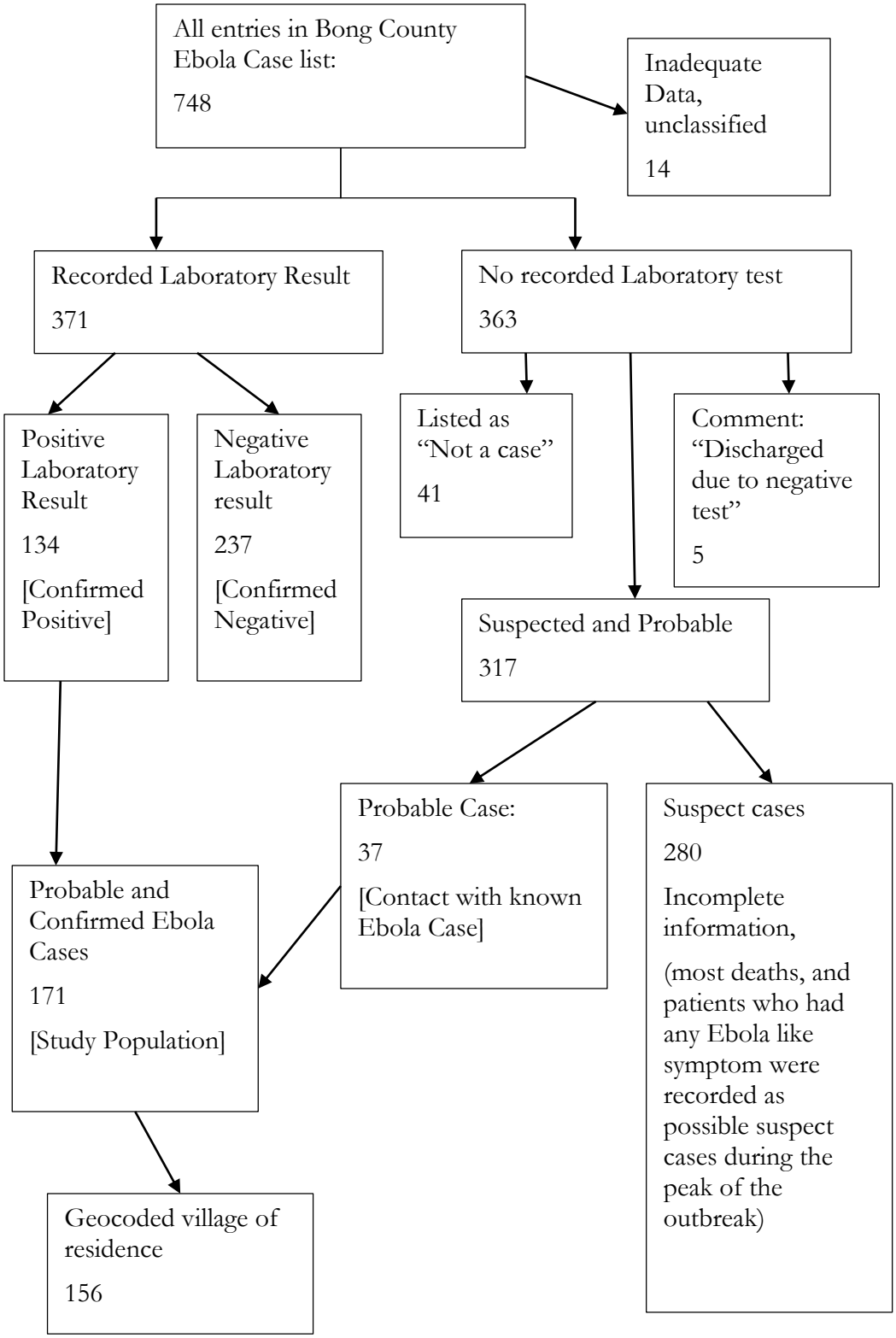


Figure 4: Map of Health Facilities in Bong County showing the Health Districts

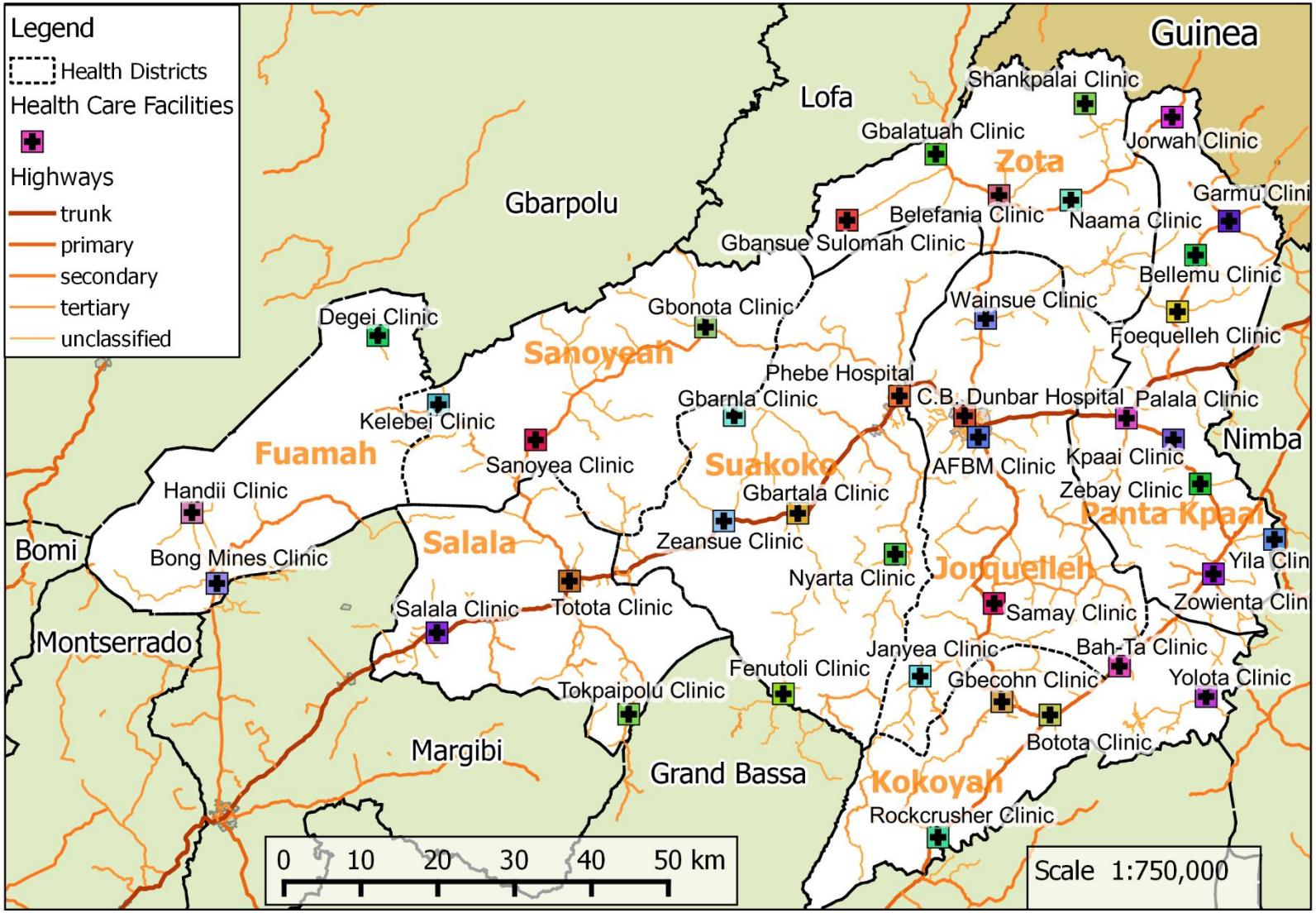
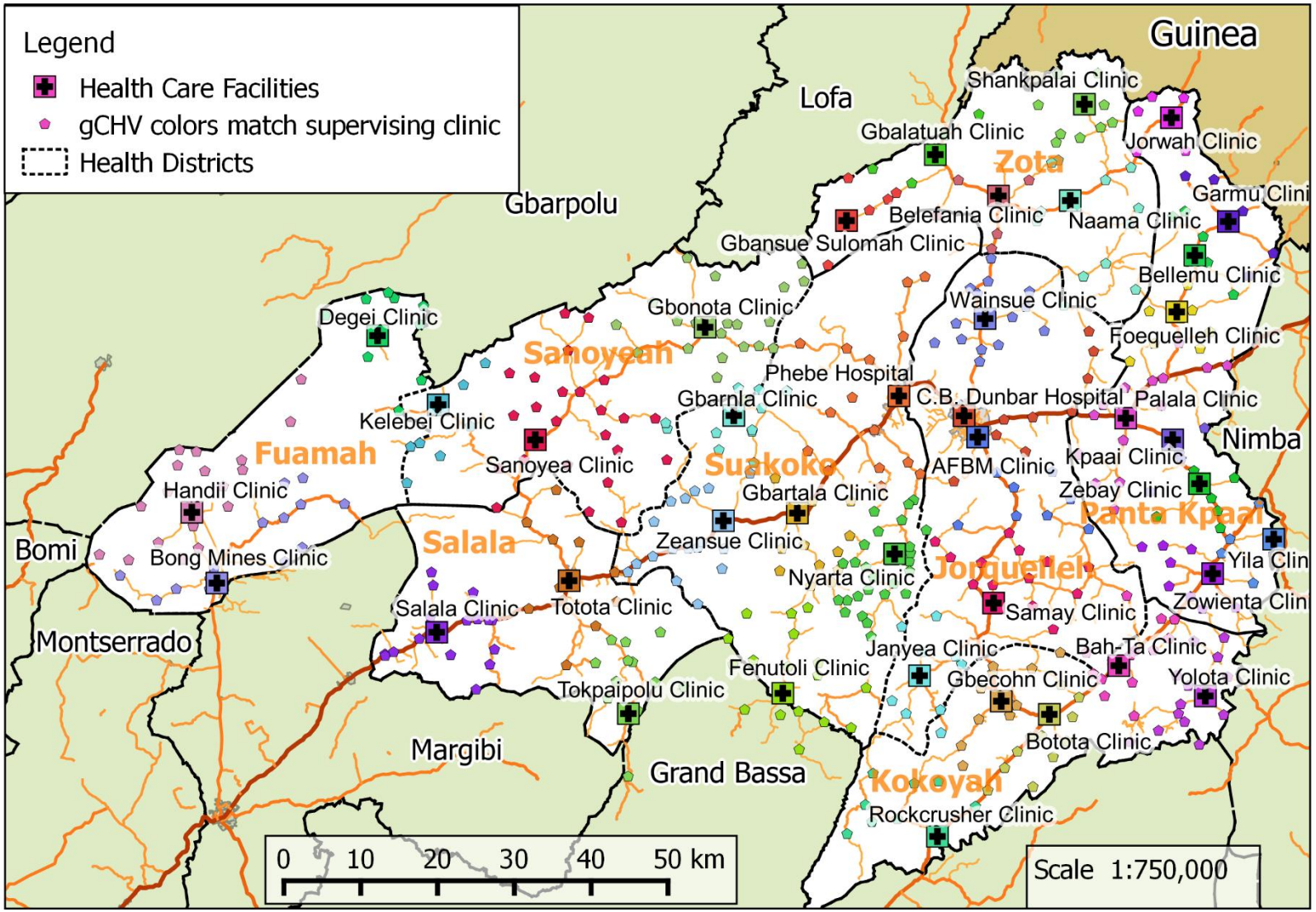


Figure 5: Map of gCHVs and supervising HCF in Bong County



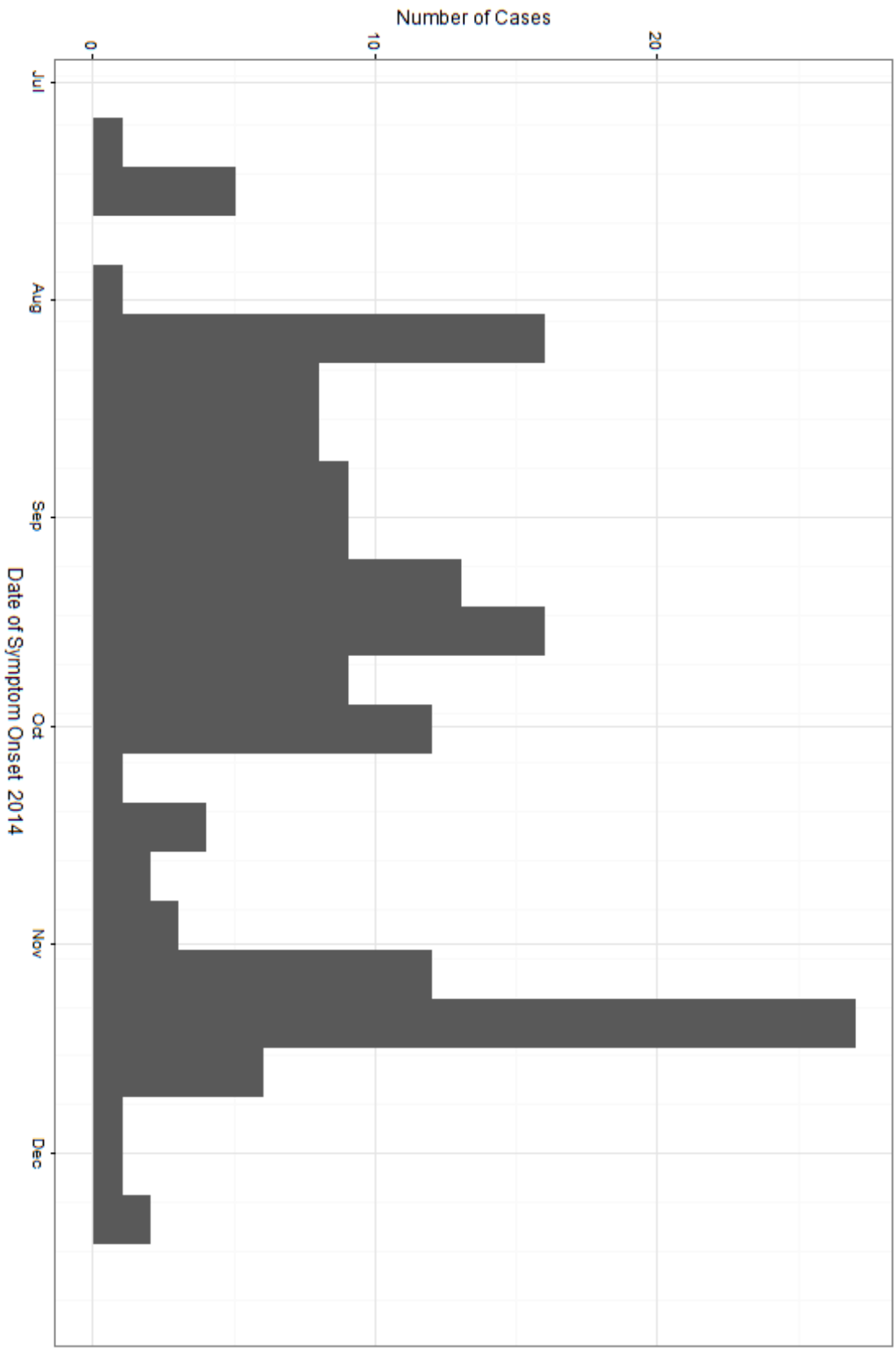



Figure 6: Histogram of Ebola cases by date of symptom onset; N=170

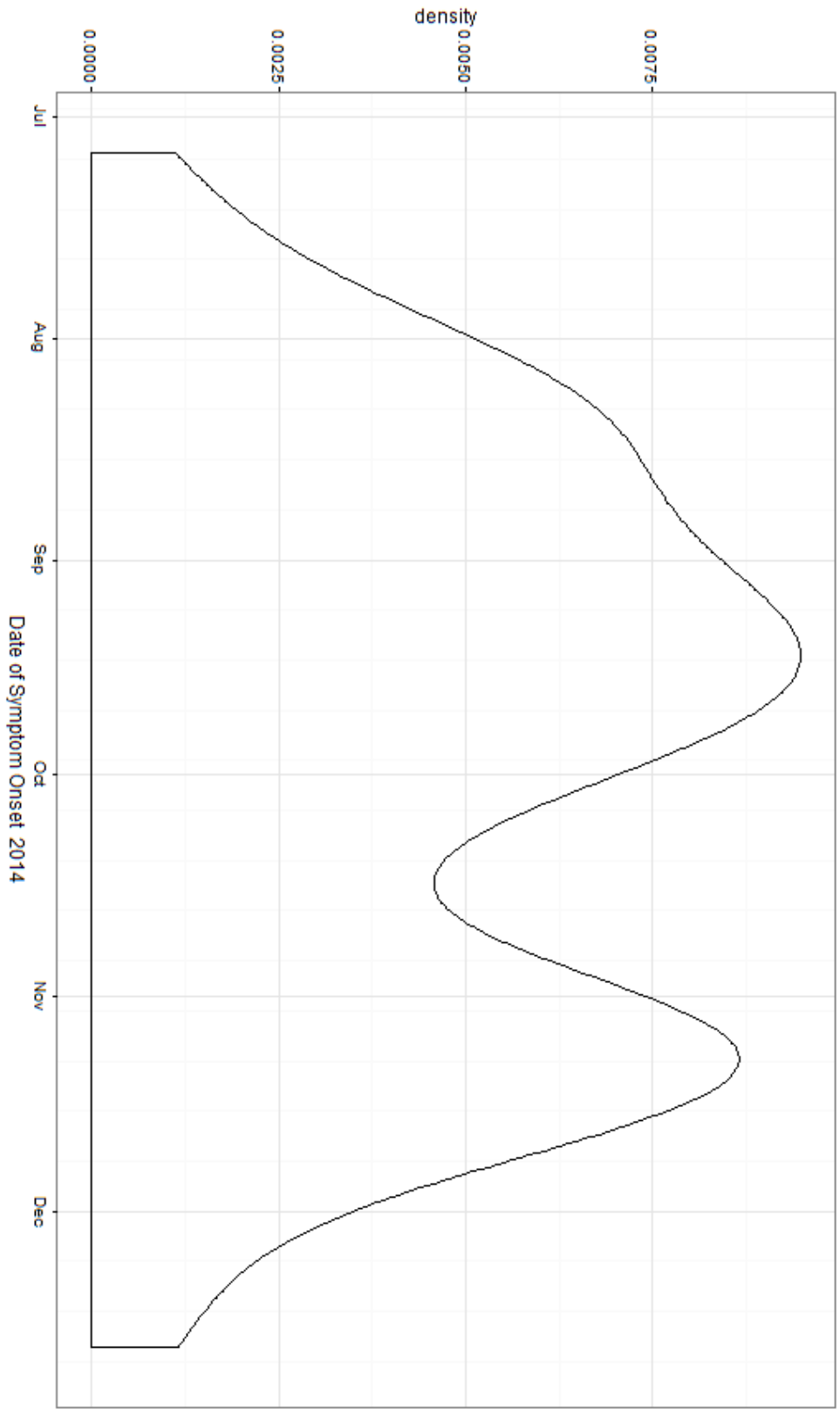



Figure 7: Density plot of Ebola cases by date of symptom onset

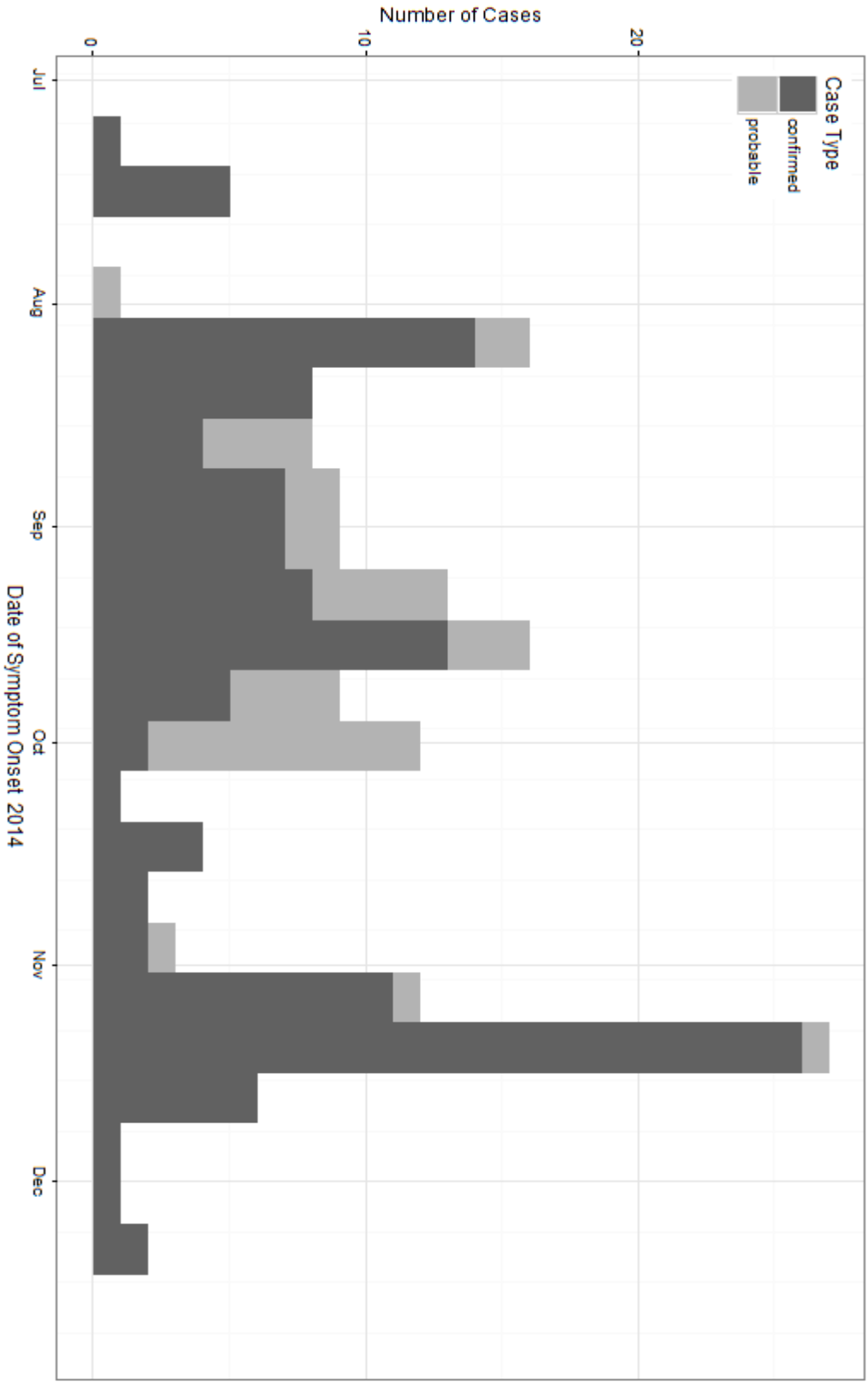



Figure 8: Histogram of Ebola cases by date of symptom onset and case classification

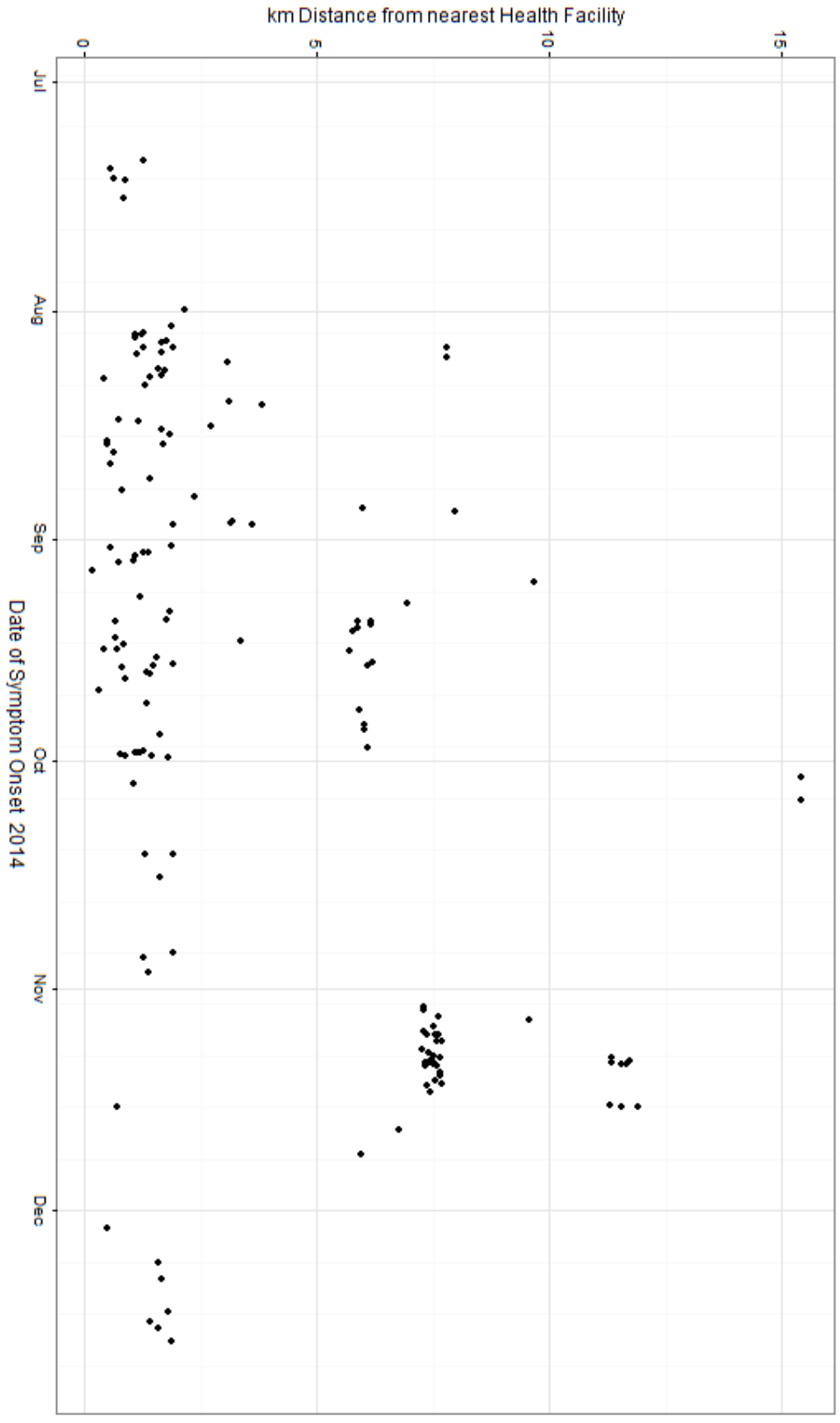



Figure 9: Scatter plot of Ebola cases by date of symptom onset and distance from HCF; N=155

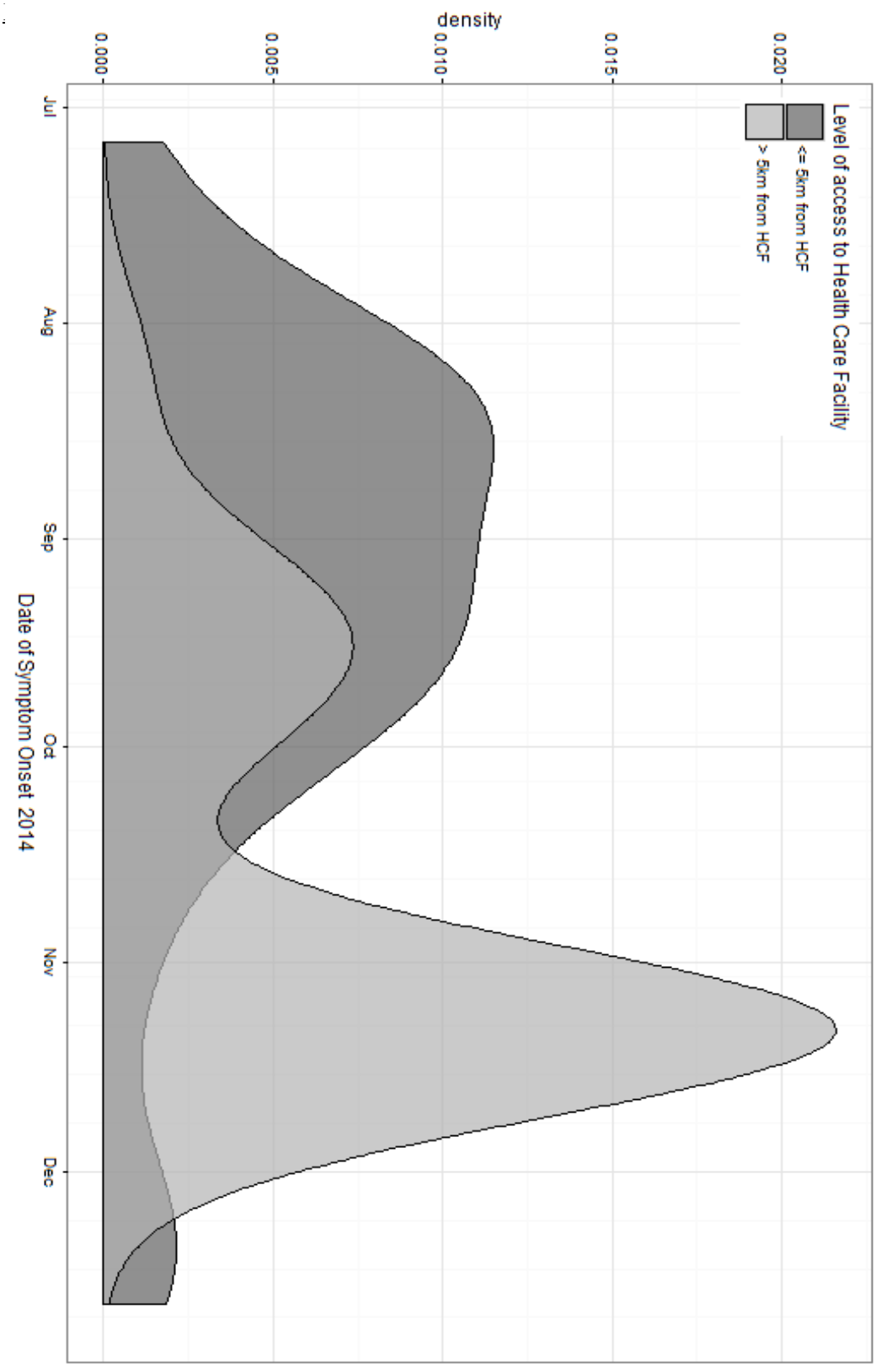



Figure 10: Ebola cases by date of symptom onset and distance from HCF; N=155

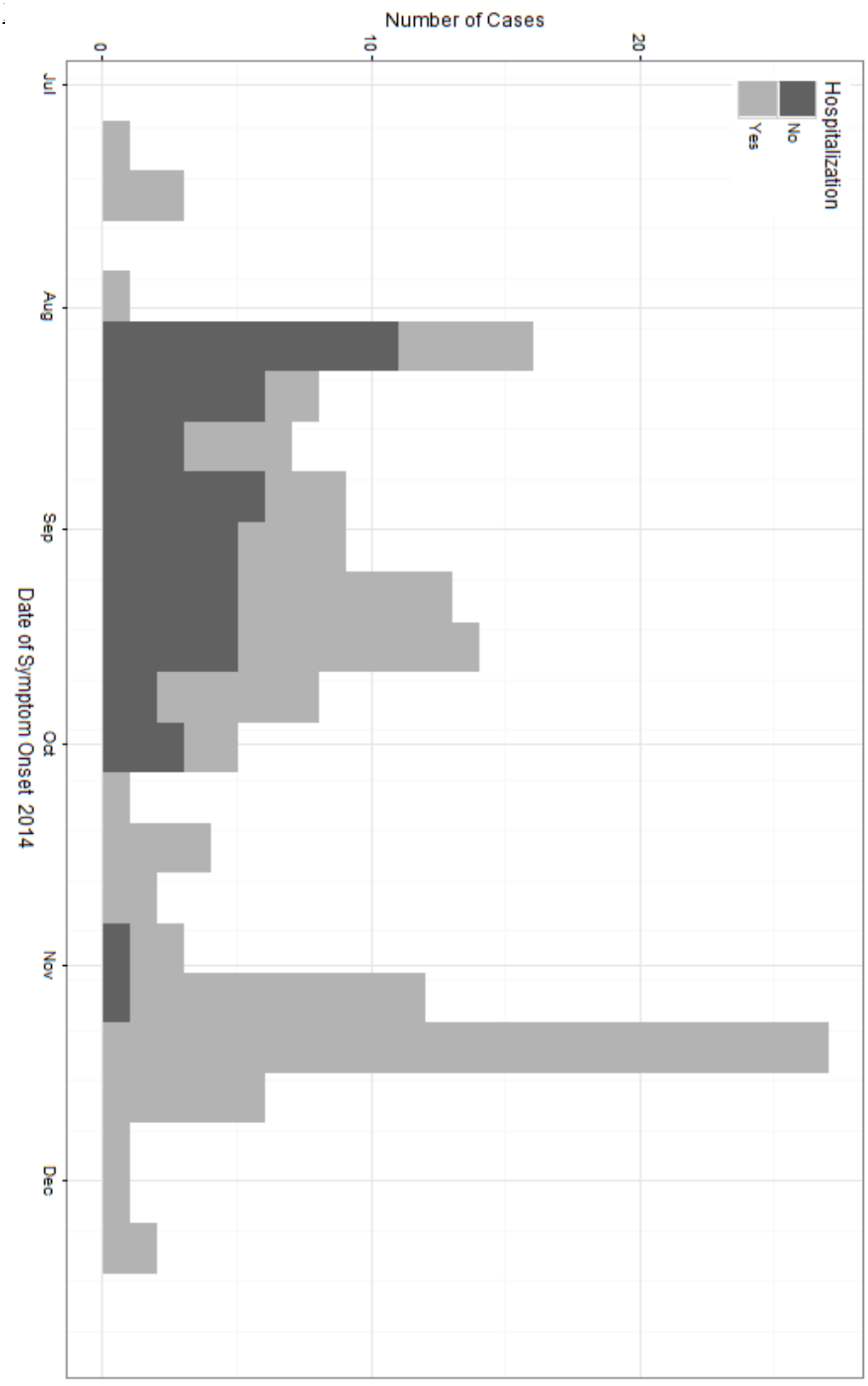



Figure 11: Histogram of Ebola cases by date of symptom onset and hospitalization

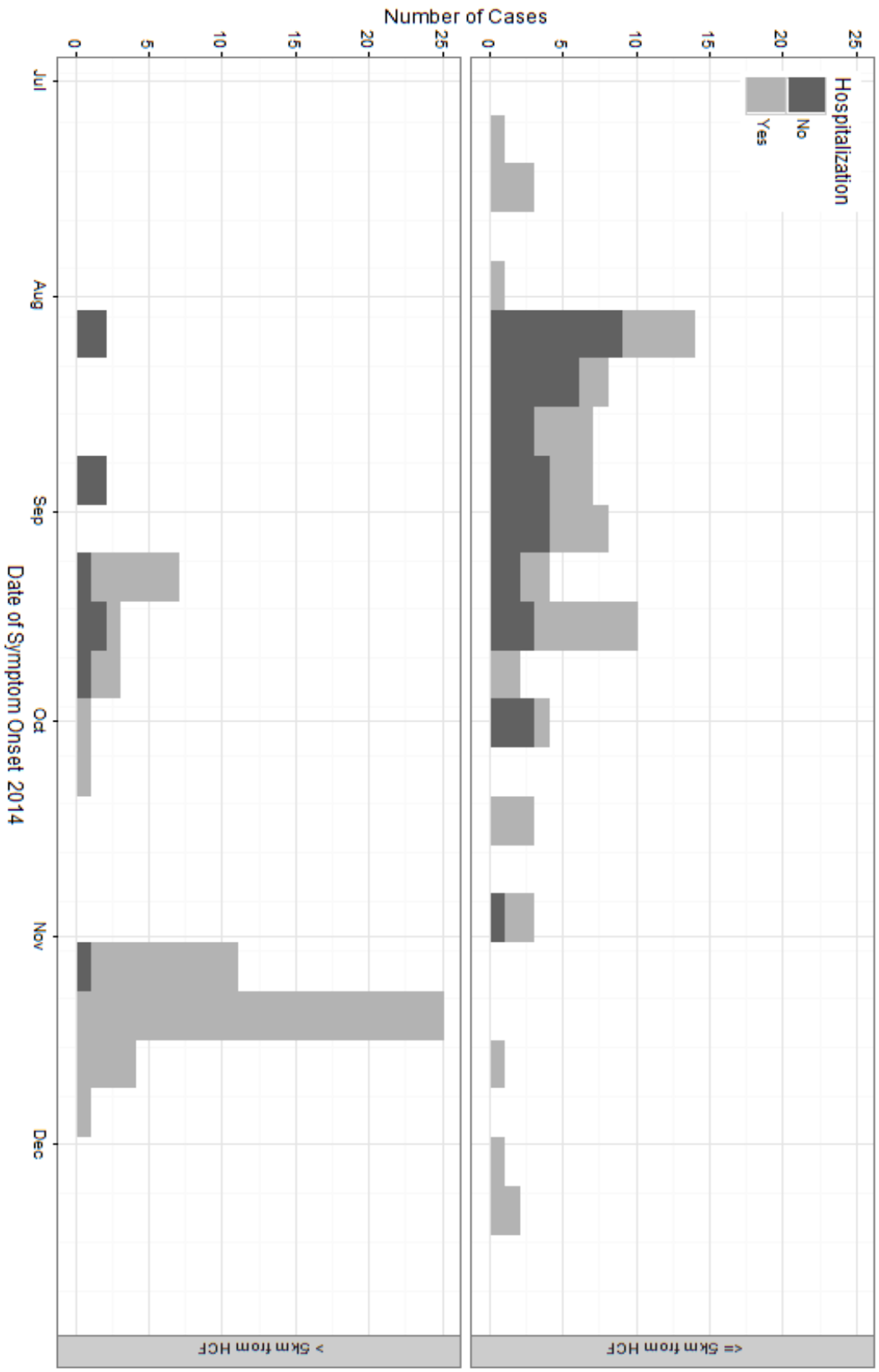



Figure 12: Distribution of hospitalization rates with comparison by access to HCF

**Appendix: Definition of Ebola Virus Disease Cluster and/or outbreak**

In the literature reviewed for this analysis, various terms have been used to describe cases which appear to be linked either through documented contacts, geographical location, or time, as follows:

Cluster used in Emerging Infectious Diseases: Authors describe 10 cases that appear to be linked by contacts. (EID journal July 20, 2015 (author Tolbert Nyenswah et al)

Cluster used by CDC in May 15 2015 MMWR to describe the "last known cluster" in Liberia, January to Feb 2015. In this instance, 21 cases were epidemiologically linked to one index case; these were family members, neighbors, community members, one healthcare worker and one herbalist.

Cluster used by CDC in relation to Legionnaire's Disease: 2 or more cases with apparent geographic or time links

Outbreak used by CDC: In the Feb 27 2015 MMWR, CDC listed a total of 12 outbreaks in remote areas of Liberia; 2 of these were in Bong County (Tayla-ta and Bomota). In both of these cases, the standard spelling used in the County was "Taylor Ta" and Bomo Ta. In addition, CDC reported on another outbreak in Bong County, the community of Mawah, which is spelled consistently with standard use in the County.

Cluster as used in this analysis: based on the case reports and geolocation information, my database confirms the outbreaks or clusters in Taylor-ta, Bomo-Ta, and Mawah, although the final number of cases is not the same as reported by the CDC. These discrepancies reflect the complexities of accurate record keeping, differences in village names, and no doubt many other issues. In addition to these 3 clusters in remote areas, there appears to be a cluster of cases in one neighborhood of Gbarnga, the main town in Bong County.