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SOCIAL NETWORK ANALYSIS OF CELLPHONE SURVEILLANCE DATA FOR EBOLA IN SIERRA LEONE

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Abstract

Aim: To explore and visualize the connectivity of suspected Ebola cases and surveillance callers who used cellphone technology in Moyamba District in Sierra Leone for Ebola surveillance, and to examine the demographic differences and characteristics of callers who make more calls as well as more likely to make at least one positive Ebola call.

Methods: Surveillance data for 393 suspected Ebola cases (192 males, 201 females) were collected from October 23, 2014 to June 28, 2015 using cellphone technology. UCINET and NetDraw were used to explore and visualize the social connectivity between callers and suspected Ebola cases. Poisson and logistic regression analyses were used to determine the factors associated with the number of Ebola surveillance calls made and the likelihood of making at least one positive surveillance call respectively.

Result: The entire social network structure was comprised of 393 ties with 745 nodes covering 253 villages. In multivariable analysis, holding other covariates in the model constant, female gender (AOR=0.33, 95% CI [0.14, 0.81]) was associated with decreased odds of making at least one positive Ebola surveillance call compared to male gender. Also, holding other variables in the model constant, female gender (IR= 0.63, 95% CI [0.49, 0.82]) was associated with making fewer Ebola surveillance calls compared to male gender.

Conclusion: Social network visualization can be used to analyze syndromic surveillance data for Ebola collected by cellphone technology and can yield unique insights. This study show that men made more Ebola surveillance calls than women, and were also more likely to make at least one positive Ebola surveillance call than women.

Introduction

Ebola virus disease (EVD) was first identified in 1976 in Zaire but more cases of the disease have been reported in other countries in recent times (Sarwar, Sitar, & Ledgerwood, 2011). EVD generates pathogenic febrile illnesses and is naturally transmitted by animal or vector hosts such as fruit bats, monkeys and chimpanzees (Hong et al., 2014). The disease is caused by one of the following four distinct hemorrhagic fever viruses (HFVs) family: *Flaviviradae, Arenaviradae, Bunyaviradae, and Filoviradae*. The genus *Ebolavirus* of the family *Filoviradae* was responsible for the 2014 West African Ebola outbreak. *Ebolavirus* has 5 different virus strains: Sudan virus, Tai Forest virus, Reston virus, Ebola virus, and Bundibugyo virus. The 2014 outbreak is the largest so far and recorded more than 20,000 cases and 10,000 deaths (Zawilinska & Kosz-Vnenchak, 2014).

Among the countries greatly affected by the 2014 EVD outbreak was Sierra Leone (Dallatomasina, 2015). The first confirmed EVD case in Sierra Leone was reported on 27th May 2014. The country's preparedness for an EVD outbreak was lacking prior to the 2014 West African Ebola outbreak. Sierra Leone's EVD response involved the formation of an Ebola technical task force that was responsible for EVD surveillance, case identification, case tracking and monitoring.

Ebola case and contact tracing, patient treatment and management, and the effective response to both patients and the community have been shown to be effective for EVD surveillance in the past (Tambo & Xiao-Nong, 2014). EVD surveillance in West Africa includes a series of actions such as correct coordination between Ebola case isolation and treatment, contact tracing and follow-up of each contact for 21 days after exposure (Pandey et al., 2014). Sierra Leone leveraged cellphone technology to assist with its EVD surveillance.

Cellphone technology has revolutionized disease surveillance by serving as a channel through which people reveal their public health concerns, locations, and movements. In Haiti, public health experts successfully predicted the spatial evolution of the 2010 cholera outbreak using cellphone calls and SMS messages obtained from more than 2 million mobile phone SIM cards (Bengtsson et al., 2015).

Following the 2014 Ebola outbreak, researchers in West Africa called for the use of routine syndromic surveillance systems that rely on data supplied via cellphones. Researchers also recommended the use of cellphones for relaying surveillance data from communities affected by an EVD outbreak to peripheral health centers (Ansumana, Bonwitt, Stenger, & Jacobsen, 2014). In Guinea, smartphones were used to communicate real-time surveillance data for contact tracing and case identification during the 2014 West Africa EVD outbreak (Sacks et al., 2015). Given the surge in global cellphone usage and the increasing popularity of cellphone-based epidemiological surveillance more research is needed to explore its efficiency and community uptake. Furthermore, few studies have taken advantage of the network-like data generated from cellphone-based surveillance in which callers and cases are interconnected through a web of calls.

This study used social network analysis to evaluate Ebola surveillance data collected in Sierra Leone by cellphone technology. Specifically, this study used network analysis to (1) explore and visualize the connectivity between suspected Ebola cases and callers who used cellphone technology for Ebola surveillance, and to determine the outdegree centrality for multivariable analysis (2) to examine demographic differences in surveillance callers who used the cellphone surveillance system; and (3) to determine the characteristics of callers who were

more likely to make at least one positive Ebola surveillance call (i.e., those who called about suspected cases that were subsequently confirmed to be Ebola positive).

Methods

Study setting and participants

Surveillance data were collected from Moyamba District in southern Sierra Leone from October 2014 to June 2015 using cellphones. The district is approximately 6,902 sq/km with a population of 258,506 (Sierra Leone 2004 Population Census, 2014). In 2014 the population of Sierra Leone was estimated to be 6,315,627 of which approximately 4,215,000 (70%) had cellphones (Global Resources and Information Directory, 2015). The Moyamba District Health Manager Team (MDHMT) Ebola Taskforce, in collaboration with Action Contra la famine (ACF), started cellphone-based syndromic surveillance for Ebola in October 2014. Specifically, community members in Moyamba District were encouraged to call the MDHMT Ebola surveillance hotline to report suspected Ebola cases (dead or alive). Community members who called the center provided their names, telephone number, and the village in which they were residing. The caller also provided the name of the person that they suspected to have Ebola and the person's sex, age and the village of the person that they suspected to have Ebola. The caller could call about any person, regardless of their age, gender, or ethnicity. Within 24 hours of receiving a call, the MDHMT Ebola Taskforce would dispatch a Community Health Officer and Ebola contact tracers to the location of the person suspected to have Ebola and transfer him/her to an Ebola treatment center for diagnosis. If the suspected Ebola case was deceased his/her body was transferred to the local mortuary for safe burial. Deceased persons however were not tested for Ebola.

This study involves an analysis of the Ebola surveillance data collected by the MDHMT Ebola Taskforce from October 2014 through May 2015. The dataset for analysis included callers' names, their telephone numbers, and their village of residence, as well as the cases' name, sex, and location (village), whether the person was sick or dead at the time the surveillance call was made, and if there were sick or dead people at the residence of the suspected Ebola case at the time the call was made to the MDHMT call center. The dataset also included the Ebola lab result for suspected Ebola cases. There were 353 surveillance callers and 393 suspected Ebola cases, including one caller who subsequently became a suspected Ebola case. By cross-referencing names and demographic characteristics of callers and cases, a whole network covering the entire surveillance period was constructed and the connectivity of callers and cases was determined. This study used UCINET software (Borgatti, 2002) to analyze the network of callers and suspected Ebola cases. Specifically, UCINET was used to compute degree centrality. Degree centrality is the number of ties or contact a node has within a network (Freeman, 1979). NetDraw (Borgatti, 2002) was also used to visualize the network components in order to depict the social ties among callers and suspected Ebola cases. The analysis was also used to estimate the number of calls made by each caller; this estimate served as the outcome in the multivariate analysis.

Analysis

SAS 9.2 version (SAS, 2011) was used for descriptive statistical analysis of the characteristics of the callers and suspected Ebola cases. Summary statistics obtained from exploratory data analysis provided the initial understanding of the nature and strength of the relationship among the various characteristics of callers and suspected Ebola cases. Poisson and

logistic regressions were used to determine the factors associated with the number of Ebola surveillance calls made and the likelihood of making at least one positive Ebola surveillance call respectively. Specifically, Poisson regression was used to determine the gender difference in the number of Ebola surveillance calls made controlling in the model for the week in which the surveillance call was made, and the Ebola prevalence of the village in which calls were made. Logistic regression was used to determine the gender difference associated with making at least one positive Ebola surveillance call, controlling in the model for the week in which Ebola surveillance calls were made, whether the person for whom the Ebola surveillance call was made was sick or dead, and the Ebola prevalence of the village in which calls were made.

Ethics and privacy

The University of Kentucky Institutional Review Board reviewed the protocol for the secondary analyses described in this capstone and determined that it met federal criteria to be exempt.

Results

Descriptive characteristics of suspected Ebola cases

Surveillance data for 393 suspected Ebola cases (192 males, 201 females) were collected from October 23, 2014 to June 28, 2015 using cellphone technology. The descriptive characteristics of suspected Ebola cases, callers, status of Ebola suspected cases, lab results and type of call are presented in Table 1. The average age of the suspected Ebola cases was 23.5 years (standard deviation=29.5). Three hundred and twenty-four (82.4%) of the suspected Ebola cases were reported sick at the time data was collected while 69 (17.6%) were deceased. Two

hundred and twenty (68%) of the sick suspected Ebola cases were females while 104 (32%) were

males. Twenty-five (8%) of the sick suspected Ebola cases were later confirmed as infected with

Ebola, 295 (91%) were tested negative for Ebola while 4 (1%) had unknown infections.

Descriptive characteristics of surveillance callers

Three hundred and fifty-three callers reported syndromic surveillance data for Ebola for

the period under review. Three hundred and one (85.3%) of the callers were males while fifty-

two (14.7%) were females. Three hundred and thirty-six (95.2%) callers made one call while

seventeen (4.8%) made multiple calls. Of the multiple callers; 14 made two calls, one made 3

calls, one made 10 calls, and another made 13 calls.

Of the 353 callers; twenty-two (2 females and 20 males) reported suspected Ebola cases

with 100% efficiency (i.e., all the calls made were later confirmed to be Ebola positive). Three

male callers made two calls each with one call for each resulting in one confirmed Ebola case

(i.e. 50% efficiency). All other callers had 0% efficiency (i.e., every suspected Ebola case about

whom they called tested negative).

Descriptive characteristics of calls

Three hundred and ninety three calls (male=341, females=52) were made by 353 callers

using cellphone technology for Ebola syndromic surveillance from October 23, 2014 to June 28,

2015 (Table 2). Men made fewer (16.7%) surveillance calls about dead suspected Ebola cases

compared to women (17.3%). Majority (83.3%) of the calls made by men were about sick

suspected Ebola cases. The percentage of men making at least one positive Ebola surveillance

call was nearly twice (6.8%) as high than that for women (3.7%).

Social network analysis

UCINET software was used to construct a network showing the connectivity between Ebola surveillance callers and Ebola suspected cases for the entire surveillance period. The entire network was comprised of 745 nodes with 393 ties covering 253 villages. Dyads (i.e., single calls) composed the largest proportion of the network components. For clarity, dyads were removed for the visualization in Figure 1. Figure 1 shows the network comprising 45 nodes and 33 ties (i.e. calls) between Ebola surveillance callers and positive Ebola cases. The largest component in the network has a size of 13 and the majority of other components in the network are triads (19 triplets).

Factors associated with number of calls

Multivariable analysis was done using Poisson regression and the results are presented in Table 3. There was a gender difference in the number of Ebola surveillance calls made. Men made more Ebola surveillance calls than women ($p<0.01$). In multivariable analysis, adjusting for other variables in the model, female gender (IR= 0.63, 95% CI [0.49, 0.82]) was associated with decreased incidence of making Ebola surveillance calls than male gender. The goodness-of-fit chi-squared test for the Poisson regression was 420.690 (df =389, p=0.13) which indicates that the regression model fits the study data well.

Factors associated with making at least one positive call

Logistic regression was used to do multivariable analysis to examine the likelihood of an Ebola surveillance call yielding a positive Ebola laboratory result and the results are presented in

Table 4. There was a gender difference in the likelihood of making at least one positive Ebola surveillance call. Women were less likely to make at least one Ebola positive call compared to men (p=0.01). Holding other covariates in the model constant, the odds ratio estimate for the gender difference (reference group: males) is 0.33 (95% CI [0.14, 0.81]). This indicates that women were significantly less likely to make at least one positive Ebola surveillance call than men holding other covariates in the model constant (95% CI [0.14, 0.81]).

Discussion

Ebola syndromic surveillance data collected by cellphone technology in Sierra Leone was analyzed by visualizing the connectivity of 353 callers and 393 suspected Ebola cases using network analysis. Adjusting the other covariates in the model, women made fewer Ebola surveillance calls than men (IR=0.63, 95% CI [0.49, 0.82]). From multivariable analysis, women were significantly less likely to make at least one positive Ebola surveillance call than men holding other covariates in the model constant (AOR = 0.33, 95% CI [0.14, 0.81]).

To my knowledge no study has investigated the association between gender, number of Ebola surveillance calls made during an Ebola outbreak, and the likelihood of making at least one positive surveillance call. The reasons for men in Sierra Leone making more surveillance calls than women may be attributed to the higher gender gap in literacy. Forty-five percent of men in Sierra Leone are educated compared to 26% for women ("Sierra Leone 2008 Demographic and Health Survey," 2008). This higher gender literacy gap makes men more likely to be employed than women. Sierra Leonean women like their counterparts in Guinea and Liberia experience significant gender-based discrimination in terms of employment and education (Smith et al., 2015). This gender-based difference in terms of employment and

education also means high property-ownership gap between men and women in Sierra Leone. Sierra Leonean women are 43% less likely than their men to own house, television, computers and a cellphone (Bhandari, 2011). Because of these reasons men Sierra Leone were able to make more surveillance calls than women.

Men in Sierra Leone were more likely to make at least one positive surveillance call than women probably due to their increased ability to accurately identified signs and symptoms of Ebola than women. This advantage by men may have been acquired from years of academic and practical clinical training. There are almost twice as many educated men than women in Sierra Leone ("Sierra Leone 2008 Demographic and Health Survey," 2008). Studies have shown that greater experience obtained from years of academic training and clinical practice is associated with post predictive value accuracy in syndromic surveillance (Cadieux et al., 2012).
In syndromic surveillance, post predictive value or positive predictive value is the probability of disease given a positive syndromic surveillance test.

Some limitations to this network analysis study are the lack of complete background and accurate information about the people who are in the network. It is possible that community members who called the MDHMT Ebola surveillance team on behalf of suspected Ebola cases may not have provided sufficient, complete or accurate information regarding the suspected Ebola cases about whom they were calling. It is also possible that MDHMT Ebola surveillance team officers may have incorrectly recorded the names of the callers, suspected Ebola cases or both. Few variables were available for use in the multivariate analysis using Poisson and logistic regressions. It is also possible that there were confounders that were unmeasured in the study and were unaccounted for in the models. The presence of such unmeasured confounders may have also interfered in the result obtained from the models.

Another limitation to this study is the failure to use zero-truncated Poisson regression for multivariable analysis. The zero-truncated Poisson regression is used for count data model studies in which the value zero cannot occur. From the Ebola surveillance data used in this study it is clear that zero cannot occur during the surveillance period since the data was collected during the peak period of Ebola surveillance in Moyamba District and hence active Ebola surveillance was going on. In the future, it will be appropriate to run a zero-truncated Poisson regression to determine the association between the week of Ebola surveillance, gender and Ebola prevalence in the village with the number of Ebola surveillance calls made using cellphone technology. However, in spite of these assumed limitations, health policy and decision makers should not be dissuaded from employing the use of social network analysis to assist with outbreak surveillance and investigation during infectious disease outbreaks.

In conclusion, findings from this study show that men are more active in making Ebola surveillance calls using cellphone technology than women, and that men were also more likely to make at least one positive Ebola surveillance call than women. This study also shows that simple network visualization of surveillance data provides a better understanding of the distribution of suspected Ebola cases during outbreak of the disease. Social network analysis could help outbreak investigators and disease intervention specialists to control and managed disease outbreak by connecting suspected Ebola cases to each other and to surveillance officers. Such analysis could also help to identify those people in a community that are at high risk. Also, the combination of cellphone technology with user-friendly and open-source social network software will provide an important adjunct to the traditional measures of epidemiologic surveillance. The ability to analyze the social network of suspected cases during disease outbreak in near or real

time may greatly help to decide the best use of disease control resources. This study underscores

the need to develop, improve and utilize available tools for outbreak investigation and control.

Table 1. Descriptive characteristics and status of suspected Ebola cases and callers, lab result

and type of call

Characteristics	n (%)
Suspected Cases (n=393)	
Sex	
Male	192 (48.9)
Female	201(51.2)
Status	
Sick	324 (82.4)
Dead	69 (17.6)
Lab result (among 324 sick suspected Ebola cases)	
Positive	25 (8)
Negative	295 (91)
Unknown	4 (1)
Village Ebola prevalence – median (interquartile range)	0 (0)
Callers (n=353)	
Sex	
Male	301(85.3)
Female	52 (14.7)
Number of calls per person - median (interquartile range)	1 (0)
One call	339 (93.9)
Two or more calls	54 (6.1)

Table 2. Distribution of status of suspected cases, lab results, number and percentages of

positive and negative calls by gender of callers

Characteristics	Male	Female
Number of calls	341	52
Number of positive calls	23	2
Call Status of suspected cases - n(%)		
Sick	284(83.3)	43(82.7)
Dead	57(16.7)	9(17.3)
Lab result (for 327 sick suspected Ebola reported calls)		
Positive	23(8.1)	2(4.7)
Negative	261 (91.9)	41(95.3)
Number of dead suspected cases not tested	57(16.7)	9(17.3)
Number who made at least one positive call	23(6.8)	2(3.7)

Table 3. Multivariate analysis of factors associated with the number of Ebola surveillance calls

Characteristic	IR	95% CI	p-value
Female versus male gender	0.63	(0.49, 0.82)	<0.01*
Village Ebola prevalence	0.95	(0.88, 1.02)	0.17
Week	0.90	(0.89, 0.91)	<0.0001*

IR= Incidence ratio; CI=Confidence interval
* $p<0.05$

Table 4. Multivariate analysis of factors associated with making at least one positive Ebola

surveillance call

Characteristic	Adjusted OR	95% CI	p-value
Female versus male gender	0.33	(0.14, 0.81)	0.01*
Week (1 unit change in week)	1.05	(0.96, 1.15)	0.31
Sick versus dead status	0.52	(0.17, 1.54)	0.24

OR= Odds ratio; CI=Confidence interval
* $p<0.05$

Figure 1. Network showing connectivity of callers who made multiple calls and suspected Ebola cases for Moyamba District from October 2014 to June 2015
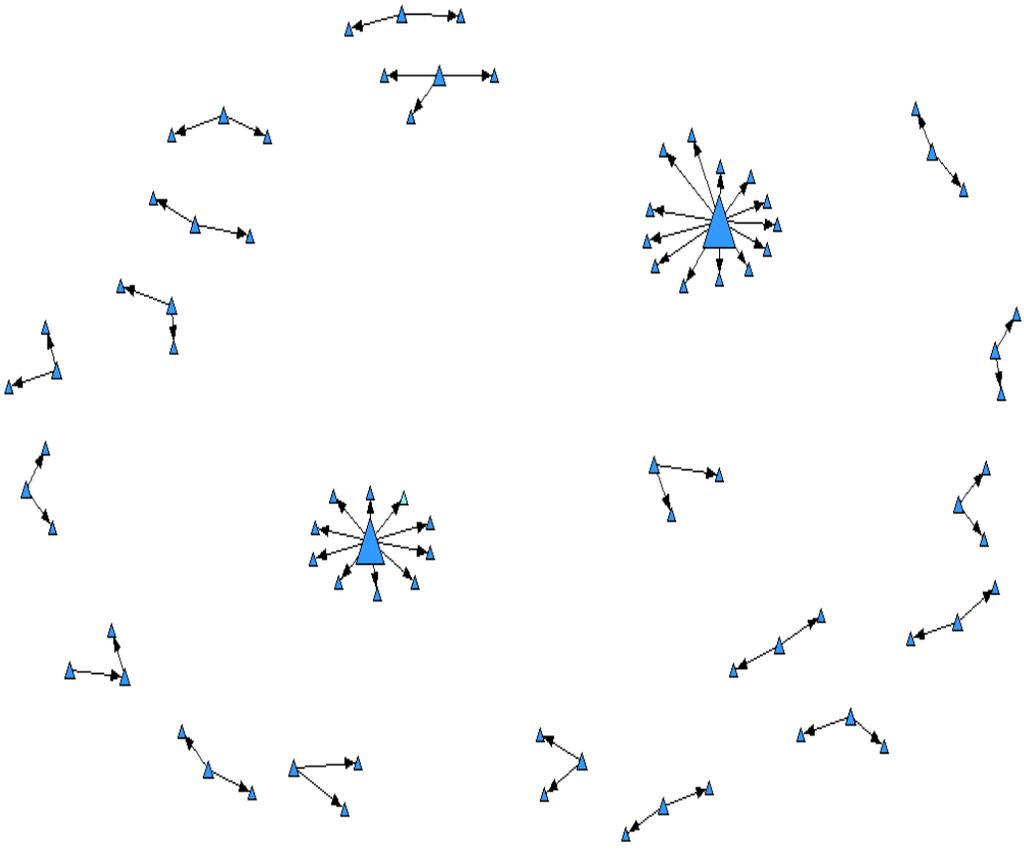
*Arrows showing outgoing surveillance calls to positive and suspected Ebola cases

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Biosketch

Jia is a Fulbright Fellow from Sierra Leone. He holds an MSc in Environmental Biology (Njala University), postgraduate certificate in Tropical Community Medicine and Health, (University of Sierra Leone), a certificate in Field Surveillance for Disaster (University of Michigan, USA) and a BSc degree in Biology and Education (University of Sierra Leone). His first M.Sc. thesis research in 2005 involved a two-month placement program at the laboratory of the Germany- funded TB/Leprosy Control Hospital now incorporated into the Sierra Leone National Reference Laboratory at Lakka western Sierra Leone. His MSc research investigated the treatment outcomes of TB patients in the HIV/AIDS era in Sierra Leone which was later published.

In 2010, Jia was among 25 participants who attended a WHO/UNESCO sponsored international E-Resources National Leaders course organized in Sierra Leone. He has also participated in several workshops, conferences, field trips and seminars on tropical infections, HIV/AIDS, water quality, sanitation and wastewater management practices in The Gambia, Liberia, Egypt, South Africa and in his home country Sierra Leone.

Jia is a lecturer currently on study leave from Njala University in Sierra Leone where he teaches a number of courses in public health, environmental biology, general biology, nursing and environmental science for more than seven academic years. He has also taught several health and natural science courses at the Cuttington University in Liberia from 2007 to 2009.