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Counting indirect crisis-related deaths in the context of a low-resilience health system: the case of maternal and neonatal health during the Ebola epidemic in Sierra Leone

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Abstract: While the number of direct Ebola-related deaths from the 2013-16 West African Ebola outbreak has been quantified, the number of indirect deaths, resulting from decreased utilisation of routine health services, remains unknown. Such information is a key ingredient of health system resilience, essential to adequate allocation of resources to both “crisis response activities” and “core functions”. Taking stock of indirect deaths may also help the concept of health system resilience achieve political traction over the traditional approach of disease-specific surveillance.

This study responds to these imperatives by quantifying the extent of the drop in utilisation of essential reproductive, maternal and neonatal health services in Sierra Leone during the Ebola outbreak by using interrupted time-series regression to analyse HMIS data. Using the Lives Saved Tool, we then model the implication of this decrease in utilisation in terms of excess maternal and neonatal deaths, as well as stillbirths.

We find that antenatal care coverage suffered from the largest decrease in coverage as a result of the Ebola epidemic, with an estimated 22 percentage point decrease in population coverage compared to the most conservative counterfactual scenario. Use of family planning, facility delivery and post-natal care services also decreased but to a lesser extent (-6, -8 and -13 p.p. respectively). This decrease in utilisation of life-saving health services translates to 3,600 additional maternal, neonatal and stillbirth deaths in the year 2014-15 under the most conservative scenario. In other words, we estimate that the indirect mortality effects of a crisis in the context of a health system lacking resilience may be as important as the direct mortality effects of the crisis itself.

Key messages:

- Rapid evaluation of the indirect maternal, neonatal and stillbirth mortality impact of a crisis affecting health service utilisation is feasible using HMIS data and the Lives Saved Tool.
- The indirect mortality effects of the 2014 Ebola epidemic in the context of a health system lacking resilience, may be at least as important as the direct mortality effects of the crisis itself.

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Counting indirect crisis-related deaths in the context of a low-resilience health system: the case of maternal and neonatal health during the Ebola epidemic in Sierra Leone

Introduction

The 2013-16 Ebola epidemic in Guinea, Liberia and Sierra Leone was one of the most high profile communicable disease outbreaks of this century. In total there were 28,600 confirmed, probable and suspected cases across the three countries, with an associated 11,300 deaths between December 2013 and January 2016 (WHO 2016). In Sierra Leone, nearly 4,000 people died from more than 14,000 cases (CDC 2016) between May 2014 and January 2016 .

In addition, many people are likely to have died from causes other than Ebola as a consequence of being unable to access the health system during the crisis. The pre-existing, chronic lack of resilience within the Sierra Leone health system meant that patients and some health workers were justifiably too afraid of infection to access routine health services during the outbreak (Nam et al. 2016). Furthermore, scarce resources in the health system were diverted to address the crisis and to screen and manage suspected and confirmed cases as well as manage growing numbers of contacts. Parpia et al. (2016) estimate that a decrease in utilisation of health services of 50% would have caused 2,800 excess deaths from malaria, HIV/AIDS and tuberculosis in Sierra Leone, nearly three quarters of the direct Ebola deaths in the country.

Rapid and rigorous evaluation approaches to count these indirect deaths are essential to developing resilient health systems in the future. Kruk and others have defined health systems resilience as the ability to effectively respond to a crisis while maintaining core functions (Kruk et al. 2015). Rapidly available information on the mortality impact of a crisis, both direct and indirect, is essential for making resource allocation choices between "crisis response" activities and "core functions". Adequate estimates of the indirect mortality of Ebola are politically important, potentially helping to shift the discourse away from disease-specific surveillance to resilience across the entire health system. This is particularly important given the fact that the countries most affected by Ebola are widely recognised as having suffered from extremely weak health systems prior to the outbreak, which not only made them vulnerable to the epidemic that followed, but also caused much suffering in its own right (Kieny et al. 2014).

Few indirect mortality estimates from the Ebola outbreak have been proposed. While the Parpia paper cited above provides helpful estimates, it models the number of deaths based on utilisation scenarios rather than actual utilisation data. Evans et al (2015) model changes in mortality rates based on health worker deaths caused by Ebola and a coefficient translating human resource availability into mortality rates, an approach that requires extremely strong and contestable assumptions. In the area of maternal and child health, several estimates of reduced utilisation have been put forward, but none translate this into a mortality impact (Iyengar et al. 2015; Jones and Ameh 2015; Quaglio et al. 2016; Ribacke et al. 2016; Streifel 2015).

Based on work conducted in the context of a UNFPA-funded rapid response evaluation during Sierra Leone's 2014 Ebola outbreak, this study presents an innovative method to rapidly quantify the indirect maternal, neonatal and stillbirth deaths resulting from crisis-related drops in utilisation of health services. Our approach quantifies drops in utilisation by using interrupted time-series regression to analyse health service statistics; converts this drop in utilisation to changes in population coverage of key interventions using recent Demographic Health Survey data; and models the implication of changes in the coverage of key interventions for maternal and neonatal mortality using the Lives Saved Tool (Futures Group 2016).

This study focuses on maternal, neonatal and stillbirth deaths. While these deaths only make up part of the indirect mortality burden, investigating the number of indirect deaths among pregnant women, newborns and stillbirths is especially important for a number of reasons. Firstly, they were particularly vulnerable to being denied care as a consequence of the outbreak. Providers were concerned about contracting Ebola from pregnant women with unknown Ebola status in situations where the risk of contamination from delivery was high (Black 2014; Dynes et al. 2015; Milland and Bolkan 2015). Reports also indicate that antepartum bleeding was often ascribed to Ebola rather than to more common causes (Butler 2014). Secondly, many women were not receiving the quality care they needed even before the outbreak (Statistics Sierra Leone, Ministry of Health and Sanitation, and ICF Macro 2014; Witter et al. 2016) due to a chronically under-resourced health system (O'Hare 2015). Deficiencies in human resources for health (UNFPA, ICM, and WHO 2014) and other systemic weaknesses, including a lack of implementation of International Health Regulations (Kieny et al. 2014; Streifel 2015), all contributed to the lack of capacity prior to the outbreak. Maternal and neonatal health therefore presents an ideal case study to investigate the implications of inadequate health system resilience.

Data and Methods

Data

Data on primary care health service utilisation, as recorded by the Health Management Information System (HMIS), was provided by the Sierra Leone Ministry of Health and Sanitation (MoHS). Ethics approval was granted on 15th December 2014 from the Sierra Leone Ethics and Scientific Review Committee. The data enumerates the number of patients attending each type of health service, in each month between April 2011 and December 2014, in each of Sierra Leone's 13 districts. 3.2% of the HMIS data points were missing due to lack of data submission by the district, including no data for Kambia and Western Area districts on women's second dose of Intermittent Preventive Therapy for malaria. Where data were missing from a district for a specific month, these were left missing in the analysis so as not to affect the overall trend in service use. Data were analysed for the following health services:

- family planning visits for new and continuing clients,
- pregnant women's fourth antenatal care visit,
- pregnant women's second tetanus toxoid vaccination,
- pregnant women's second dose of Intermittent Preventive Therapy for malaria,
- institutional delivery, and
- mothers' postnatal care visit within 48 hours of the birth.

These services were chosen from the wider range of services recorded in the HMIS as they relate to maternal and neonatal health and form part of the interventions included in the Lives Saved Tool.

All population data were obtained from the 2015 Revision of the World Population Prospects (United Nations Department of Economic and Social Affairs 2015). The baseline population coverage estimates for each health service studied were obtained from the Sierra Leone 2013 Demographic Health Survey (DHS) dataset, a nationally representative survey that reports key population coverage indicators on reproductive, maternal and child health, using stratified random sampling (Statistics Sierra Leone, Ministry of Health and Sanitation, and ICF Macro 2014). Use of maternal health services is reported for births within the 5 years prior to the survey, and average coverage can be calculated for specific time periods as needed. Population weights were used when estimating service coverage to account for the differential chances of selection into the survey.

For the Lives Saved Tool (Futures Group 2016) mortality modelling, the Spectrum/Lives Saved Tool default data was used, except for:

- the baseline and future coverage levels of the health services under study, obtained from the 2013 DHS and our own analysis detailed below;
- 2012 child mortality estimates, obtained from the UN Inter-Agency Group for Child Mortality Estimation's database;
- 2012 maternal mortality estimates, obtained from the WHO, UNICEF, UNFPA and World Bank 2015 maternal mortality estimates;
- 2012 stillbirth estimates, obtained from the 2016 Lancet Stillbirth Series (Lawn et al. 2016; Statistics Sierra Leone, Ministry of Health and Sanitation, and ICF Macro 2014; UN Inter-agency Group for Child Mortality Estimation n.d.; WHO et al. 2015).

Methods for Analysis

The study's analytical approach can be summarised in Figure 1 and as follows. We first assessed whether there had been a statistically significant change in the level or trend of utilisation of the selected key maternal and neonatal health services in the aftermath of the Ebola outbreak. In order to understand the impact of this change in utilisation on maternal and neonatal mortality, it was necessary to convert this change in utilisation, i.e. in the number of people using a health service, to a change in coverage, i.e. the share of the population using a health service. Dividing the number of recorded visits in the HMIS by the number of people in need of a given health service was not appropriate for obtaining population coverage estimates, since the HMIS underestimates the number of actual health visits (Options Consultancy Services 2015). Assuming, however, that the (in)accuracy of the HMIS remained constant over time, and that drops in the utilisation of primary care services were representative of decreases in utilisation across all levels of care, one can estimate post-Ebola population coverage by applying the change in the number of HMIS visits caused by the Ebola outbreak to a baseline, pre-Ebola level of population coverage. One can also estimate population coverage in that year under a counterfactual scenario by assuming that pre-Ebola trends in utilisation would have continued (or remained constant) in the absence of the outbreak. The impact on mortality can then be estimated by inputting the estimated levels of population coverage under the post-Ebola impact scenario and under the post-Ebola counterfactual scenario into the Lives Saved Tool and taking the difference in the number of deaths between the two scenarios. The details of the approach outlined here are presented below.

Figure 1: Summary of method

In Sierra Leone, the epidemic began on the 25th May 2014 and the last case was diagnosed on the 14th of January 2016 (Government of Sierra Leone Ministry of Health 2014; World Health Organisation 2017). By the beginning of July 2014, 252 cases had been confirmed (WHO 2014). In this study, the start date of the Ebola outbreak is designated as June 2014, as a compromise between the time when a few cases had been identified and the point where it became clear that a significant crisis was under way. This assumption was tested through sensitivity analyses using May and July as alternative start dates for the epidemic. The fit of the models detailed below was best for a June 2014 start date. Results of the sensitivity analysis are available upon request from the authors.

We used a segmented linear regression with month-year and district fixed effects to estimate whether there were any changes in the level or trend of utilisation of reproductive and maternal health services as a consequence of the Ebola outbreak (Lagarde 2012). The impact of the outbreak on health utilisation is not allowed to vary at the district level. The first reason for this is to remove some of the district-level noise in the HMIS data. The second reason is that there is no baseline mortality data at the district level, such that the Lives Saved Tool analysis can only be run at the national level. Our approach controls for the rainy season's impact on utilisation (Streifel 2015), any other seasonal changes in utilisation caused, for example, by harvest time, the school year, or seasonal changes in fertility (Dorelien 2016), the underlying trend prior to the outbreak (Lagarde 2012). The specification is as follows:

$$Y_{it} = \theta + \beta_1 preslope_t + \beta_2 eboladrop_t + \beta_3 changeslope_t + \beta_4 rain_{it} + \beta_4 outlier_{it} + \varphi_t + \delta_i + \varepsilon_{it}$$

Where Y_{it} is the number of people using a given health service in a given month-year *t* and district *i*; θ is a constant; *preslope* is a variable equal to one in the first month of data and increasing by one unit in each subsequent month; *eboladrop* is a dummy equal to one if the month is June 2014 or later and zero otherwise; *changeslope* is equal to zero if the month is prior to June 2014, equal to one if the month is June 2014, and increases by one unit in each month after June 2014; *rain* is a dummy equal to one if the district is located in a zone (Northern, Southern or Eastern) that experienced at least one period of 10 days with cumulative rainfall above 100mm, according to the USGS FEWS NET Data Portal (USGS and USAID n.d.); *outliers* are dummies equal to one if the observation is an outlier, as described below; φ is a fixed effect for month-year; δ is a fixed effect for district. Standard errors are clustered at the district level in order to address heteroskedasticity and any remaining within-district error correlation over time.

The coefficients of interest are:

- β_1, which estimates the trend in the utilisation of health services prior to the Ebola outbreak;
- β_2, which estimates the one-off drop in utilisation at the point of the outbreak, in June 2014; and
- β_3, which would capture any change in the utilisation trend after the start of the Ebola outbreak.

Due to the imperfect nature of HMIS data, a number of outliers were observed. Data points were labelled as outliers if they were statistically "unusual" (studentised residual higher than an absolute value of two) and if they had influence on the estimated coefficients (defined as a high Cook's distance statistic compared to other data points). Each outlier was allocated a dummy in order to discount that observation in the calculation of coefficients. 3.8% of available data points were excluded following outlier analysis.

Once the regression model was estimated, the next task was to calculate average levels of annual utilisation two years prior to the Ebola outbreak (June 2012-May 2013)[1] and in the year after the Ebola outbreak (June 2014-May 2015). We calculated average annual utilisation

[1] Except for family planning, where the survey questions report <u>current</u> use of contraception as opposed to use of services in the past. Therefore the baseline period was defined as June 2013 – October 2013, during which fieldwork for the DHS was conducted.

two years prior to the outbreak, instead of the year immediately before, in order to match the change in utilisation to the DHS baseline, which only has data up to September 2013. Outliers were dropped and out-of-sample predictions created between January and May 2015, for which HMIS data was not available.

Four scenarios were created for the year after the Ebola outbreak. In the "Impact 1" scenario, the negative trend observed between June and December 2014 is extended until May 2015. In the "Impact 2" scenario, the observed post-Ebola trend is maintained up until December 2014, after which we assume all subsequent levels of utilisation are equal to those observed in December 2014. In the "Counterfactual 1" scenario, the pre-Ebola trend is assumed to continue unabated until May 2015. In the "Counterfactual 2" scenario, it is assumed that utilisation would have remained at the same level as May 2014 from June 2014 onwards (see Figure 2).

Figure 2: Visualisation of the four scenarios for antenatal care

The average levels of annual utilisation for each scenario and each health service were divided by the number of live births for that year, except for family planning visits, where the number of visits was divided by the number of women of reproductive age in that year. We then calculated the change between the 2012-13 average number of visits per population and the 2014-15 average number of visits per population in each of the four scenarios. This change was then applied to the baseline population coverage level of the key interventions in order to obtain estimated coverage levels for the post-Ebola year (June 2014-May 2015) under each of the four scenarios. The baseline population coverage of key MNH interventions was estimated using DHS data for births taking place between June 2012 and May 2013.

Finally, baseline and post-Ebola population coverage for the six health services were inputted into the Lives Saved Tool (LiST) v.5.46 (Futures Group 2016) in order to estimate the excess maternal, neonatal and stillbirth mortality that resulted from lower utilisation of reproductive and maternal health services. Following LiST assumptions, levels of coverage for some non-modelled interventions affecting maternal deaths, neonatal deaths or stillbirths, were pegged to the modelled interventions (e.g. it is assumed that neonatal thermal care is provided for all facility deliveries); where the coverage for a given intervention was not assumed to be pegged to that of another intervention, coverage was set at the DHS estimated coverage for that intervention, for births occurring in 2012, for all years and all scenarios; where there was neither a pegging assumption nor DHS data, coverage was left as zero for all years and all scenarios. LiST assumptions are available in the 2017 LiST manual and upon request from the authors (Futures Group 2017).

LiST calculates changes in the number of maternal, neonatal and stillbirth deaths as a result of changes in the coverage of a given set of essential reproductive and maternal health interventions. Within the model, the population coverage of different interventions affects mortality rates for specific causes of death or risk factors, according to the effectiveness values associated with each intervention. The number of deaths is calculated in the model by applying these new mortality rates, associated with different causes of death, to the projected number of live births or number of children in different age groups (Winfrey, McKinnon, and Stover 2011). The indirect deaths caused by the reduction in health service utilisation in the year after the outbreak were calculated as the difference between the number of deaths estimated by the model in the post-Ebola utilisation scenarios and the number of deaths estimated in the counterfactual scenarios.

Results

As shown in Table 1 by the coefficients on *time*, there was a positive trend in the utilisation of key reproductive and maternal health services in primary care facilities prior to the Ebola outbreak. For example, prior to the outbreak, there was an average increase of 12 new postnatal care clients per month between April 2011 and June 2014. As of June 2014, all of these services experienced a negative and significant drop in utilisation, as shown by the coefficient on *ebola*. This one-time drop in utilisation ranged from the equivalent of just over two years' worth of progress in the case of tetanus toxoid vaccination (TT2) (146=5.7*25.6 months), to 8 months' worth of progress in the case of facility delivery and postnatal care (PNC). After June 2014, utilisation continued to drop in the case of antenatal care services (ANC4), facility delivery, and postnatal care, with negative trends (post-Ebola trend = *time-changeslope*) significant at the 1% level. While the number of clients accessing family planning, tetanus toxoid vaccination, and intermittent preventive therapy also continued to drop in the months following the Ebola outbreak, the trend is significant only at the 10% significance level for family planning (FP clients) and malaria prevention in pregnancy (IPT2), and insignificant for tetanus toxoid vaccinations. This implies that we can be less certain about the post-Ebola trend in utilisation for family planning and malaria prevention, and that there is no statistical evidence that utilisation of tetanus toxoid vaccinations continued to drop after June 2014.

Table 1: Interrupted time-series model of the decrease in utilisation of health services during the Ebola epidemic

As described in the methods, we used the model above to predict average levels of utilisation in the year June 2012-May 2013 and in the year June 2014-May 2015 under four scenarios: Impact 1, Impact 2, Counterfactual 1, and Counterfactual 2. We then divided the average number of predicted clients in each year, scenario and health service by the relevant population variable (births or women of reproductive age). We subsequently calculated the change in utilisation between the years 2012-13 and 2014-15. This percentage change, which is scenario and health service-specific, was then applied to population coverage estimates for 2012-13 (calculated using DHS 2013 data) in order to obtain predicted coverage values for the year 2014-15 in each scenario and health service. The results are displayed below in Table 2, with the last two columns showing the impact of the epidemic according to the most extreme combination of scenarios (Impact 1 vs. Counterfactual 1) and the most conservative combination (Impact 2 vs. Counterfactual 2).

Table 2: Percentage of the population accessing each of six health services under different scenarios

The results show that Impact 1 and Impact 2 predicted coverage values are systematically lower than the 2012-13 estimates, due to the post-outbreak drop in the level and trend of utilisation. Impact 1 is lower than Impact 2 as it assumes that the downward trend continued past December 2014, while Impact 2 assumes that the December 2014 utilisation level continued until May 2015. The counterfactual coverage values, however, are higher than the 2012-13 values because these scenarios portray the hypothetical situation whereby the pre-outbreak trend would have continued in the absence of the epidemic (counterfactual 1), or remained as high as it was in May 2014 (counterfactual 2).

Across health services, we see that antenatal care coverage (ANC4) and the share of pregnant women accessing malaria prevention therapy (IPT2) suffered from the largest decrease in coverage as a result of the Ebola epidemic. Taking the most conservative combination of scenarios (Impact 2 and Counterfactual 2), the coverage of antenatal care and intermittent preventative treatment of malaria in pregnancy would have been 22 percentage points and 18 percentage points higher, respectively, in the absence of the outbreak. Tetanus toxoid vaccination and postnatal care were also significantly affected (-15 p.p. and -13 p.p. respectively), while family planning and facility deliveries suffered a decrease in coverage of -6 p.p. and -9 p.p. respectively. 95% confidence intervals for average levels of utilisation in the HMIS data (not shown) resulted in less than one percentage point difference in population coverage and did not greatly affect the mortality estimates. These are available on request from the authors.

Changes in the coverage of essential, life-saving health services resulted in a high number of excess deaths. Depending on whether we assume that the observed decline in utilisation stopped after December 2014 or continued until May 2015, as well as the extent of improvements in coverage had the outbreak not occurred, the total number of indirect maternal, neonatal and stillbirth deaths in the first year of the outbreak is between 4,900 and 3,600 deaths (rounded to the nearest 100). The most conservative estimate is close to the number of deaths attributed directly to Ebola itself, of about 4,000 over the entire period of the Ebola outbreak (CDC 2016). A large proportion of these deaths is due to reductions in family planning services, which caused more women and newborns to experience a risky birth.

Table 3: Estimates of maternal and neonatal deaths and stillbirths in Sierra Leone due to the fall in utilisation of essential MNH services

Discussion

Before the Ebola outbreak hit Sierra Leone in May 2014, significant progress had been made in achieving higher coverage of maternal and newborn health (MNH) services, even though maternal mortality remained high due to poor quality care (Witter et al. 2016). The percentage of facility-based deliveries doubled between 2008 and 2013 (from 25% to 54% of live births); almost all pregnant women (97%) received at least one antenatal care visit by a skilled provider (compared to 87% in 2008); and the proportion of women receiving a postnatal check-up within two days of delivery increased to more than two thirds (from 56% in 2008 to 73% in 2013) (Statistics Sierra Leone, Ministry of Health and Sanitation, and ICF Macro 2009, 2014).

Yet the severe setbacks in utilisation suffered during the latest crisis demonstrate that the health system achieving these gains was not resilient. Large falls in the numbers of client visits during the month of the outbreak highlight the immediate and catastrophic knock-on effect of the containment efforts on the rest of the health system. This was compounded by further reductions in service utilisation over the first year of the epidemic, with each of the six services analysed showing ongoing falls. We find that antenatal care coverage suffered from the largest decrease in coverage as a result of the epidemic, with an estimated 22 percentage point decrease in population coverage compared to what would have happened in the absence of the outbreak, under the most conservative scenario combination. Use of family planning, facility delivery and post-natal care services also decreased by a significant extent (-6, -9 and -13 p.p. respectively). This decrease in utilisation of life-saving health services translates to a conservative estimate of 3,600 indirect maternal, neonatal and stillbirth deaths in the year 2014-15. In other words, we estimate that the number of maternal, neonatal and stillbirth deaths caused by decreased utilisation in the year following the outbreak is equivalent to the number of direct Ebola deaths in the country over the entire period of the epidemic.

While no other study has estimated maternal and neonatal deaths caused by changes in service utilisation, two other studies surveyed emergency obstetric facilities to estimate changes in utilisation across the country. Jones et al (Jones and Ameh 2015) find that BEmONC deliveries, CEmONC deliveries, ANC and PNC visits decreased respectively by 31%, 37%, 18% and 22% between May and November 2014. Ribacke (2016) found that the number of hospital deliveries and C-sections declined by 20% when comparing Jan-May 2014 relative to late 2014-2015. Our findings are comparable although it is important to note that while these studies are using more reliable, researcher-collected data, their before-after comparison fails to take into account underlying trends and seasonal variations. Our use of interrupted time-series regression controls for seasonal changes in utilisation, the underlying trend prior to the outbreak, and enables one to examine the ongoing impact on utilisation up to one year after the outbreak (Lagarde 2012).

Despite this study's rigorous methodology, there are a number of limitations. The study has assumed that the quality of the HMIS data remained constant over time. However it is possible that the accuracy of HMIS was improving prior to the Ebola outbreak, accounting for some of the improvements seen in the pre-Ebola period, and that the accuracy of HMIS records deteriorated during the epidemic. Regarding pre-Ebola improvements, a comparison of the 2008 and 2013 DHS shows substantial, real improvements in coverage, lending support to the positive trends seen in the HMIS data. In terms of the post-Ebola decrease in utilisation, available data suggests that data completeness for 2014 remained at 80% (Options Consultancy Services 2015). Evidence from researcher-collected data (Jones and Ameh 2015; Ribacke et al. 2016) and qualitative research on women and health workers' attitudes to care-seeking and provision during the outbreak further supports our findings (Nam et al. 2016). Other imperfections in the HMIS data have been somewhat mitigated through the exclusion of outliers and influential points in the regression analysis. It is also important to note that this study assumes that the decrease in utilisation of maternal and neonatal services from primary health facilities is representative of the decrease in utilisation for all types of health facilities, including hospitals.

The reduction in the utilisation is converted to mortality through the use of the LiST tool. While this tool has been extensively validated (Friberg et al. 2010; Hazel et al. 2010; Larsen, Friberg, and Eisele 2011), the number of estimated deaths depends on the tool's demographic assumptions, as well as on baseline mortality rates and causes of death, which are themselves only best estimates. Given the lack of more accurate information, this analysis has prioritised transparency by adopting default LiST assumptions where required. Effectiveness values of the interventions included in LiST assume high levels of quality of care, which are unlikely to prevail in practice. Furthermore, the lack of data on non-modelled interventions, resulting in either pegging the level of coverage to modelled interventions or setting coverage to zero, is likely to have over-estimated the number of indirect deaths.

Conversely, the long-term indirect effects of the outbreak on maternal and neonatal health have not been estimated by this study. It is not yet known how quickly the health system can recover from the Ebola epidemic, but clearly it will be difficult to rapidly bounce back to pre-Ebola levels due to the loss of health workers (Evans, Goldstein, and Popova 2015).

Conclusion

Our results show that the indirect mortality effects of a crisis in the context of a health system lacking resilience may be at least as important as the direct mortality effects of the crisis itself. This study also presents an innovative method to rapidly quantify the indirect maternal, neonatal and stillbirth deaths resulting from crisis-related drops in health service utilisation. Conducting such an evaluation within different sectors of the population will aid in directing limited resources to areas where they are most needed. In particular, we hope this approach can help health systems stay "aware", the first dimension of health systems resilience, described by Kruk as "an up-to-date map of human, physical, and information assets that highlight areas of strength and vulnerability" (2016, 1911).

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Figure 1: Summary of method

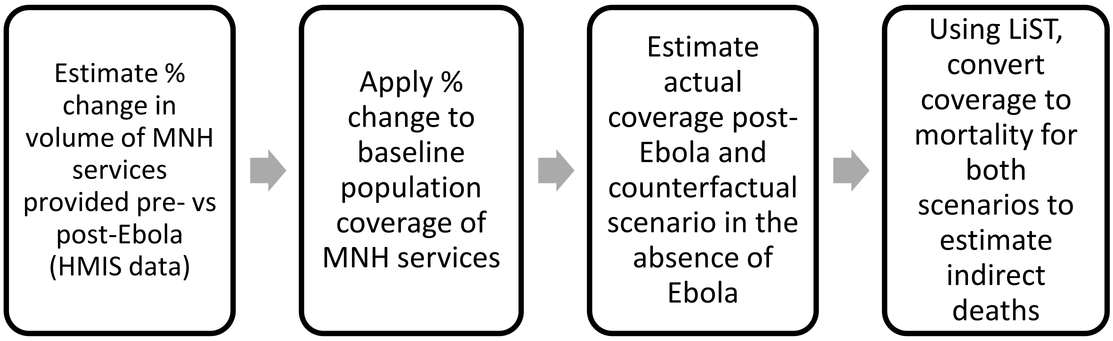

Figure 2: Visualisation of the four scenarios for antenatal care

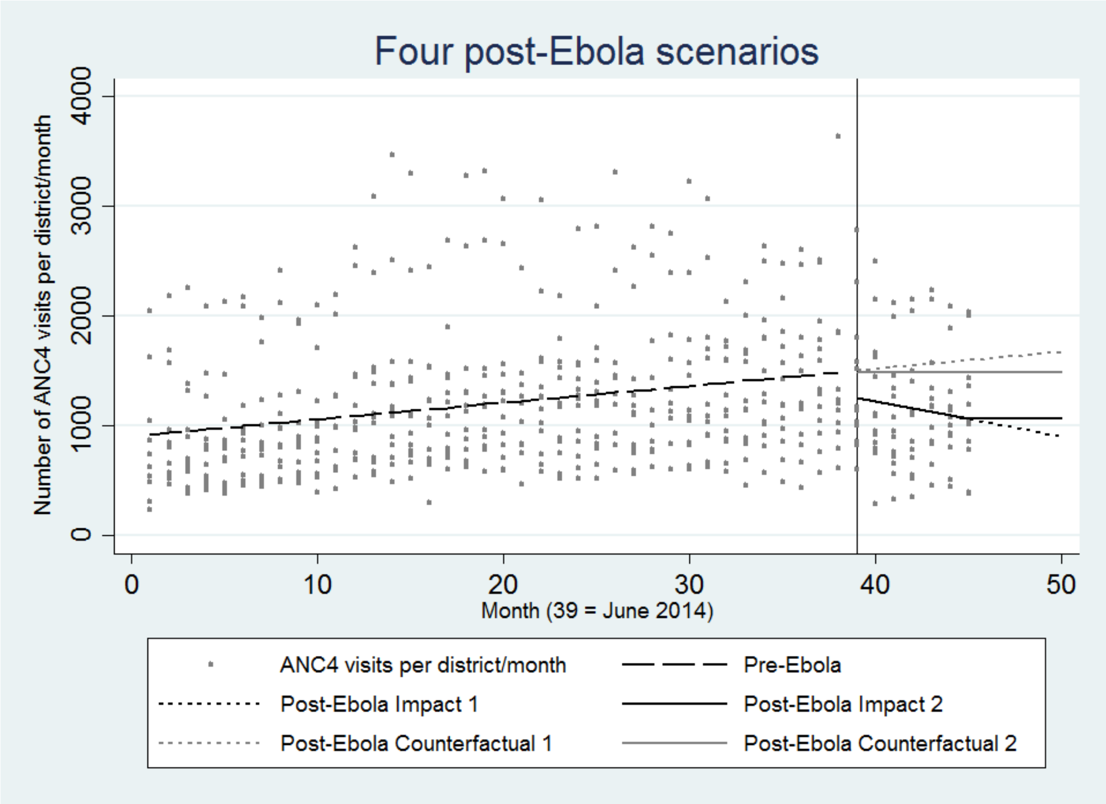

Table 1: Interrupted time-series model of the decrease in utilisation of health services during the Ebola epidemic

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	FP clients	ANC4	TT2	IPT2	Delivery	PNC
preslope	85.53***	15.36***	5.728**	14.81***	8.85***	12.27***
	(13.07)	(2.323)	(1.894)	(3.581)	(1.349)	(1.762)
eboladrop	-1,165**	-201.3***	-146.3***	-236.6**	-74.50**	-99.94**
	(520.5)	(42.45)	(39.53)	(74.80)	(34.05)	(34.12)
changeslope	-135.3*	-47.52***	-15.91	-25.32*	-28.94***	-33.88***
	(64.07)	(14.28)	(13.37)	(12.53)	(8.877)	(10.19)
rain	449.7*	-2.736	-13.05	-23.61	-41.54**	-18.57
	(247.1)	(18.26)	(22.21)	(23.14)	(14.73)	(12.57)
Constant	2,232***	905.5***	1,006***	810.9***	973.3***	846.3***
	(322.5)	(47.45)	(38.50)	(76.31)	(29.51)	(36.00)
Observations	557	560	563	473	559	557
R-squared	0.162	0.377	0.123	0.333	0.264	0.432
Nb of districts	13	13	13	11	13	13
District FE	YES	YES	YES	YES	YES	YES
Month-Year FE	YES	YES	YES	YES	YES	YES
Outlier dummies	YES	YES	YES	YES	YES	YES

NB: for IPT2, data in the districts of Kambia and Western Area were not available. Clustered standard errors in parentheses. FE = Fixed effects.

*** p<0.01, ** p<0.05, * p<0.1

Table 2: Percentage of the population accessing each of six health services under different scenarios

	Pre-Ebola ('12-'13)	Impact 1 ('14-'15)	Impact 2 ('14-'15)	CFT 1 ('14-'15)	CFT 2 ('14-'15)	= [Impact 1 – CFT 1]	= [Impact 2 – CFT 2]
FP clients	22.1	17.1	17.3	25.7	23.6	-8.6	-6.3
ANC4	74.2	64.8	67.2	95.5	89.5	-30.7	-22.2
TT2	86.0	76.6	77.6	95.6	92.6	-19.0	-15.0
IPT2	71.6	68.0	68.9	93.6	87.3	-25.6	-18.4
Delivery	57.4	54.4	55.7	67.4	64.4	-13.0	-8.7
PNC	68.3	66.0	67.7	85.8	80.7	-19.8	-13.0

NB: CFT = Counterfactual

Table 3: Estimates of maternal and neonatal deaths and stillbirths in Sierra Leone due to the fall in utilisation of essential MNH services

	Indirect deaths	
	=[Impact 1 – CFT 1]	=[Impact 2 – CFT 2]
Maternal deaths	714	549
Neonatal deaths	2,992	2,161
Stillbirths	1,230	883
TOTAL	**4,936**	**3,593**
% excess deaths due to FP reductions	42%	44%

NB: CFT = Counterfactual; FP = Family planning