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Franck Ale, M. Eugenia Riccio, Yves Katuala, Théophile Maloko, Georges Tonamou, Etienne Gignoux, Iza Ciglenecki & Jonathan Polonsky

Measles epidemic in Yakusu Health Zone, Democratic Republic of Congo, 2018–2019: a retrospective observational study

Franck Ale[1†], M. Eugenia Riccio[2†], Yves Katuala[1], Théophile Maloko[3], Georges Tonamou[4], Etienne Gignoux[5], Iza Ciglenecki[2], Jonathan Polonsky[5,6*]

[1] Médecins Sans Frontières, Abidjan, Côte d'Ivoire

[2] Médecins Sans Frontières, Geneva, Switzerland

[3] Ministry of Public Health, Tshopo, Democratic Republic of the Congo

[4] Médecins Sans Frontières, Kinshasa, Democratic Republic of the Congo

[5] Epicentre, Paris, France

[6] Geneva Centre of Humanitarian Studies, University of Geneva, Geneva, Switzerland

* Corresponding author: Jonathan.Polonsky@epicentre.msf.org

† These authors contributed equally

Abstract

Background

A large measles outbreak occurred in Yakusu Health Zone, Democratic Republic of the Congo, between January 2018 and June 2019. We aimed to estimate the magnitude, mortality burden, and vaccination coverage of this epidemic, and to evaluate whether the reactive mass vaccination campaign reached previously unvaccinated children.

Methods

We conducted a retrospective two-stage cluster household survey to estimate the attack rate (AR), case fatality ratio (CFR), mortality rates, and vaccination coverage. We extrapolated survey-weighted estimates to the population of Yakusu to estimate true outbreak size. Kaplan-Meier survival analysis characterised the temporal distribution of post-measles mortality. Geospatial analyses described the spatial distribution of vaccination coverage and attack rates, and Spearman rank correlation quantified the spatial relationship between routine and campaign coverage at the cluster level.

Results

Among 8,968 individuals surveyed, 1,390 (15.5%, 95% CI: 13.2–17.8) reported measles during the recall period. The estimated true outbreak size was 22,068 cases (95% CI: 18,785–25,351), suggesting routine surveillance detected only 27.9% of cases. Among children under 5 years, the AR was 45.7% (95% CI: 39.6–51.9) and the 31-day CFR was 4.9% (95% CI: 3.4–6.3). Among infants under 1 year, survival at 31 days post-onset was only 78.7%, with deaths continuing to accrue beyond this point, reflecting a distribution of onset-to-death intervals that extends beyond the standard attribution cutoff.

Routine EPI and campaign vaccination coverage were each approximately two-thirds of the target population (68.2% and 67.7%, respectively). Among children vaccinated during the campaign, 81.6% had already received routine EPI vaccination, while only 39.8% of previously unvaccinated children were reached. EPI and campaign coverage were strongly spatially correlated at the cluster level (Spearman $\rho = 0.59$, $p < 0.001$).

Conclusions

This was a severe epidemic with high attack rates and case fatality, particularly among infants. The reactive vaccination campaign, implemented more than one year into the outbreak, overwhelmingly reached children already vaccinated through routine services while failing to reach the majority of unvaccinated children. Reactive campaigns in similar settings should prioritise identifying and reaching unvaccinated populations through improved microplanning and spatial targeting, rather than maximising total doses administered.

Keywords: Measles, Disease Outbreaks, Mass Vaccination, Vaccination Coverage, Retrospective Studies, Health Surveys, Mortality

Introduction

Measles was historically a major contributor to child morbidity and mortality globally prior to the widespread implementation of a highly effective vaccine [1]. Following enormous progress in measles elimination in the latter years of the 20th century, measles incidence continued to decrease considerably in the 21st century, from 145 to 17 cases per million people between 2000 and 2021 [2]. This progress was accompanied by a concomitant decline in annual measles-related deaths, from an estimated 761,000 to 128,000, averting an estimated 56 million deaths [2].

Despite these achievements, measles epidemics persist, particularly in sub-Saharan Africa [2, 3]. Between 2018 and 2019, the Democratic Republic of the Congo (DRC) experienced one of the largest measles outbreaks ever recorded, with 311,471 reported cases, driven by low vaccination coverage, inadequate surveillance, and a strained healthcare system [4]. Access to healthcare in the DRC is severely constrained by economic barriers, with out-of-pocket costs representing a major

obstacle to care-seeking and vaccine uptake, particularly in remote provinces [5–7]. Médecins Sans Frontières (MSF), in collaboration with the DRC Ministry of Public Health (MoH), responded to this crisis by reinforcing surveillance, providing free medical care, and conducting vaccination campaigns.

Yakusu Health Zone (HZ), Tshopo province, was one of the most affected areas. Between 1 January 2018 and 30 June 2019, 6,150 measles cases (attack rate [AR]: 4.3%) and 152 measles-attributable deaths (case fatality ratio [CFR]: 2.5%) were reported in a population of 142,379 (Figure 1).

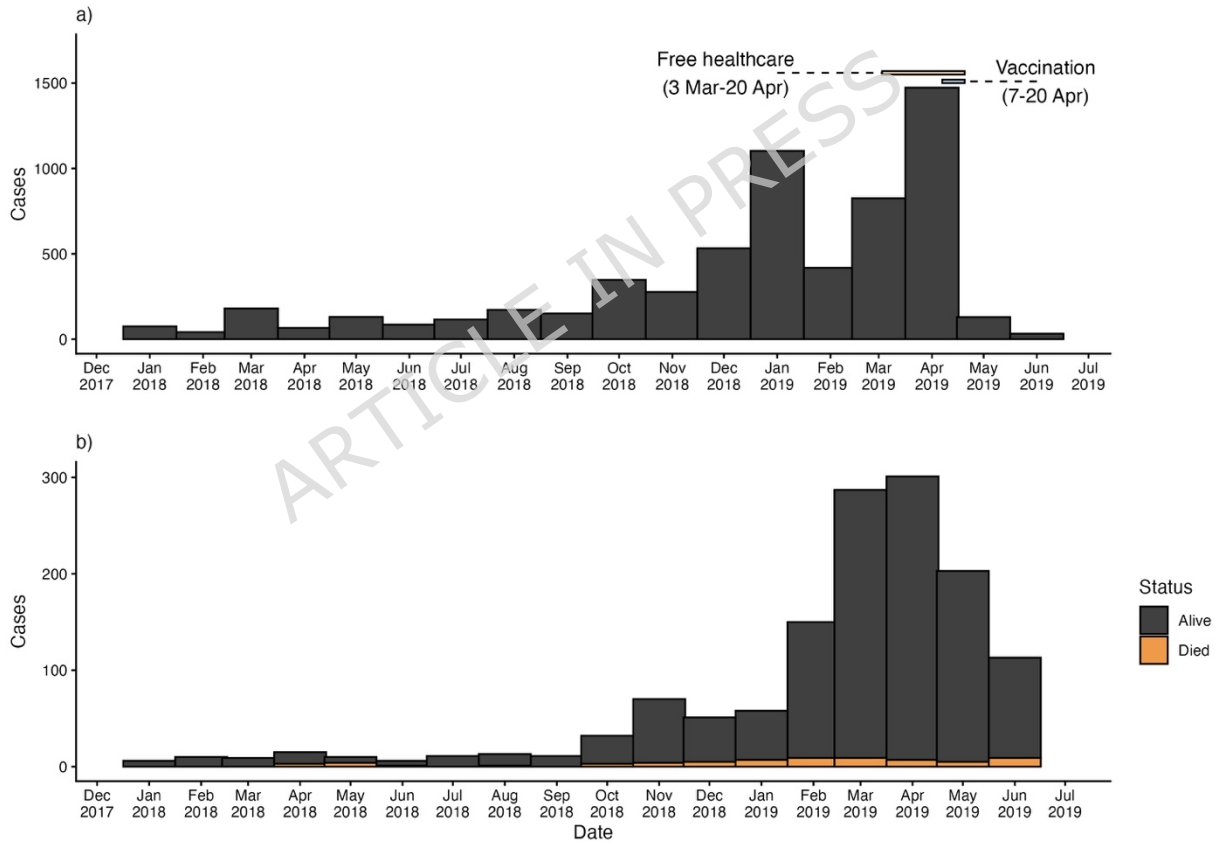

Figure 1: Measles epidemic curves by surveillance method, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019. Panel a depicts monthly case counts from routine surveillance; panel b shows cases ascertained retrospectively,

stratified by vital status. Intervention periods are marked: free healthcare provision (3–20 Mar 2019) and supplementary immunisation activities (7–20 Apr 2019).

During the peak of the epidemic, between 3 March and 20 April 2019, MSF supported the MoH by providing free treatment to a total of 2,615 patients (Figure 1 panel a). Additionally, between 7 and 20 April 2019, MoH conducted a mass vaccination campaign (MVC) targeting all children aged 6–59 months.

Due to limited access to healthcare, weak disease surveillance systems, and incomplete health records leading to under-attribution of measles as cause of death [5, 8], the reported AR and CFR were likely substantially underestimated. Reactive mass vaccination campaigns are the primary response tool in such settings, but their effectiveness depends on reaching previously unvaccinated children, something that is rarely evaluated at the individual level. Previous work in DRC has suggested that vaccination coverage may be associated with proximity to health facilities [9, 10], raising the possibility that reactive campaigns may systematically miss the same remote populations that routine services fail to reach.

There is also growing evidence that measles may increase mortality beyond the acute illness itself, through prolonged suppression of immune memory that leaves children vulnerable to secondary infections for weeks to months after recovery [11, 12]. If substantiated in outbreak settings, this would imply that the conventional 31-day attribution window used to define measles-attributable deaths underestimates the true mortality burden.

This study aimed to document the impact of the outbreak by estimating the AR, CFR, measles-specific proportional mortality (MSPM), and daily mortality rates for both the overall population and children under 5 years. Additionally, we assessed

the degree to which the reactive vaccination campaign reached previously unvaccinated children, and examined the sensitivity of measles mortality estimates to the choice of attribution window.

Methods

Study design and setting

This was a cross-sectional two-stage cluster survey, conducted in Yakusu HZ from 2 to 9 July 2019. The target population was any person residing for at least four weeks in Yakusu HZ during the recall period (from 1 January 2018 until the date of data collection).

Sampling method

Households were chosen using two-stage cluster sampling as recommended by WHO [13]. At the first stage, 40 clusters were selected with a probability proportional to the size of the village or quarter from which the cluster was selected. At the second stage, 25 households were selected by randomly generating GPS points within the perimeter of the village or quarter from which the cluster was selected. When the perimeter of the village or quarter was unknown or incorrect, a systematic random sample was used instead. In villages where there were fewer than 25 households, all households were selected for inclusion. Tablets provided to each surveyor team were equipped with OsmAnd software [14] to identify the household closest to each randomly generated GPS point. Subsequent households were selected based on proximity to the prior household using a defined protocol.

Data collection

A questionnaire was developed specifically for this study. Information was collected on demographic characteristics, measles vaccination and infection status, and, where appropriate, access to healthcare and cause of death, for all individuals.

Surveyors underwent a 3-day training on household selection, obtaining informed consent, and conducting the survey through practical exercises and role play. A pilot study was conducted outside of the survey target area to test and adapt the survey material to the local context. Interviews were conducted in Lingala or Swahili, the local languages.

Community leaders and heads of households were informed about the survey several days before the planned site visits. On the interview date, eight teams of two surveyors each visited the selected households, explained the survey objectives to the primary respondent, and obtained informed consent. If consent was provided, all household members were included. Participation refusals were recorded in logbooks. Data were collected on mobile devices using KoBoCollect software [15].

Main definitions

A measles case was defined as any individual with the following symptoms: maculopapular rash during at least 3 days, fever ≥38°C (or warm to the touch), and cough or upper respiratory tract infection or conjunctivitis. A measles-specific death was defined as any death occurring within 31 days of onset of measles symptoms [13]. We also examined mortality over an extended 90-day window, comparing all-cause mortality rates between measles cases and non-cases to assess whether excess mortality persisted beyond 31 days.

Routine Expanded Programme on Immunisation (EPI) in DRC provides a single dose of measles-containing vaccine at 9 months of age. Older children and adults have been vaccinated through routine EPI during infancy, during supplementary immunisation activities or previous outbreak responses, or may have acquired natural immunity through prior infection. The MVC targeted all children aged 6–59 months.

Data analysis

Measles AR was calculated as the number of measles cases divided by the number of persons included in the survey during the recall period. CFR was calculated as the number of measles-specific deaths divided by the number of measles cases. MSPM was calculated as the number of measles-attributable deaths divided by the total number of deaths recorded. AR, CFR, and MSPM were expressed as percentages.

All-cause and measles-specific mortality rates, expressed as deaths per 10,000 person-days, were estimated as the number of deaths divided by the total person-time at risk. Person-time at risk depended on time spent in the household: for participants present throughout the recall period, the full recall period was used; for those who migrated in or out, half the total recall period was used; and for those born or who died during the recall period, the actual dates were used.

All analyses were performed for all individuals and separately for children under 5 years. Additionally, analyses were stratified by three periods to evaluate the impact of MSF intervention: Phase 1 (pre-MSF; 1 Jan 2018 – 2 Mar 2019), Phase 2 (MSF intervention; 3 Mar – 20 Apr 2019), and Phase 3 (post-MSF; 21 Apr – 30 Jun 2019).

To describe risk factors associated with measles infection and mortality, we fitted log-Poisson multilevel regression models with random effects at cluster and

household levels. We included sex, age group, and EPI vaccination status as explanatory variables. In the univariate analysis, all variables were tested for association with the outcome, and those with $p < 0.1$ were included in the multivariate analysis. As vaccination status is correlated with age (both EPI and the campaign targeted young children), we also conducted a sensitivity analysis fitting the mortality model without age to assess whether vaccination became significant in the absence of this potential confounder.

To characterise the temporal distribution of post-measles mortality and provide formal justification for examining mortality beyond 31 days, we estimated time from symptom onset to death using Kaplan-Meier methods, stratified by age group (<1 year, 1–4 years, ≥5 years).

To assess whether the reactive vaccination campaign reached previously unvaccinated children, we cross-tabulated individual EPI and MVC vaccination status among the target population (aged 6–59 months) with known status for both. We calculated the proportion of campaign recipients who had already received EPI, and the proportion of EPI-unvaccinated children reached by the campaign.

Estimates of the true number of cases and deaths in Yakusu HZ were calculated by applying the survey-weighted AR and CFR to the estimated population size. Confidence intervals for extrapolated estimates were derived by applying the lower and upper bounds of the survey-weighted AR and CFR to the population denominator. The proportion of cases detected by the surveillance system was calculated as the number of reported cases divided by the estimated total.

Measles vaccination coverage was estimated as the proportion of individuals reporting having received any dose of the vaccine (by vaccination card or by parental recall), separately for routine EPI and the MVC.

Geospatial analyses were conducted to describe the spatial distributions of EPI and campaign coverage and measles AR among children aged 6–59 months. To formally quantify the spatial relationship between routine and campaign coverage, we calculated a Spearman rank correlation between cluster-level EPI and MVC coverage estimates. Point pattern datasets were created using the R package spatstat [16], applying cluster-specific estimates to the geographic coordinates of each cluster. These data were smoothed using a Gaussian kernel function and visualised as heat maps [17].

All analyses were performed using R statistical software [18], with the survey package used to account for the cluster survey design.

Results

Sample description

A total of 1,101 households were selected for participation, of which 1,080 (98.1%), comprising 8,968 individuals, consented to participate. The median age was 14 years (IQR: 5–28), with approximately one-fifth (21.6%, 95% CI: 20.6–22.5) of the population aged under 5 years. The male-to-female sex ratio was 1.01 (95% CI: 0.96–1.06).

Over three-quarters of participants (6,955, 77.6%) were present in the household throughout the entire recall period, while 496 (5.5%) joined and 657 (7.3%) left

during the recall period. There were 724 births and 313 deaths during the recall period (Table 1).

<<Table 1 placed here>>

Measles cases

After having the standard measles case definition explained to them, 1,390 participants reported having had measles (Table 2), with a temporal distribution that closely matched that described by the routine surveillance data (Figure 1 panel b). The overall AR was 15.5% (95% CI: 13.2–17.8) and the under-5 AR was 45.7% (95% CI: 39.6–51.9) (Table 3). Among children with known vaccination status, ARs were 56.0% (95% CI: 47.3–64.7) among the unvaccinated and 33.3% (95% CI: 27.9–38.6) among those vaccinated by either EPI or the campaign.

<<Tables 2 and 3 placed here>>

In a multivariate analysis, children under 5 years had a substantially higher risk of becoming a case (RR: 2.5, 95% CI: 2.1–2.9), while individuals who had received vaccine through either routine EPI or the campaign had a lower risk (RR: 0.80, 95% CI: 0.68–0.93). Approximately 84.5% of cases had at least one other case in their household, and 79.4% (95% CI: 74.1–84.6) had sought healthcare, predominantly at government health facilities (90.6% of those seeking care).

Mortality

Of the 1,390 measles cases, 78 deaths were reported in total; of these, 64 had known dates of both symptom onset and death. Among these 64, 48 died within 31 days of onset, yielding an overall CFR of 3.5% (95% CI: 2.4–4.5). Among children under 5, the CFR was 4.9% (95% CI: 3.4–6.3), and among infants under 1 year it

was 19.5% (95% CI: 12.1–26.9) (Table 3). When the attribution window was extended to 90 days, 62 deaths were captured, with the overall CFR rising to 4.5% (95% CI: 3.4–5.5) and the under-5 CFR to 6.3% (95% CI: 4.7–7.9). Among the 64 deaths with known onset and death dates, the median time from symptom onset to death was 27.5 days (IQR: 4.75–38.25; range: 0–161), with a substantial proportion of deaths occurring beyond 31 days.

All-cause crude mortality rate (CMR) was 0.72 per 10,000 person-days (95% CI: 0.61–0.82), while the under-5 mortality rate (U5MR) was 1.51 per 10,000 person-days (95% CI: 1.19–1.84) (Table 4). Among 313 deaths, 48 (15.3%, 95% CI: 10.9–19.8) were attributable to measles within 31 days of onset. Among children under 5, measles accounted for 43 of 122 deaths (35.2%, 95% CI: 26.0–44.5).

When the attribution window was extended to 90 days, 62 deaths were captured (CFR: 4.5%, 95% CI: 3.4–5.5), an increment of 14 deaths beyond the 31-day definition. This increment likely reflects the tail of the acute mortality distribution rather than a distinct period of late excess mortality: the median time from symptom onset to death was 27.5 days (IQR: 4.75–38.25), indicating that a substantial proportion of deaths from the acute illness itself occurred just beyond the 31-day cutoff. In an age-adjusted log-Poisson model with cluster-level random effects, measles case status was strongly associated with mortality in the first 31 days (RR: 41.0, 95% CI: 6.2–104, $p < 0.001$), but cases who survived beyond 31 days had lower subsequent mortality than non-cases (RR: 0.46, 95% CI: 0.26–0.84, $p = 0.011$), consistent with survivor selection (depletion of the most vulnerable individuals from the case population during the acute phase).

Kaplan-Meier analysis confirmed that deaths continued to accrue well beyond 31 days post-onset (Figure 2). Age-stratified curves revealed marked differences in survival: at 31 days, survival was 78.7% (95% CI: 69.6–89.0) among infants under 1 year, 96.7% (95% CI: 95.5–98.0) among children aged 1–4 years, and 98.9% (95% CI: 98.0–99.9) among those aged 5 years and over. Mortality continued beyond day 31 across all age groups, with infant survival declining further to 73.6% by day 90, meaning that nearly one quarter of infants with measles died within three months of symptom onset.

The 31-day CFR varied across outbreak phases: 5.0% in the pre-intervention period, 1.9% during the intervention period (3 March to 20 April 2019), and 3.9% in the post-intervention period.

In a univariate log-Poisson regression with random effects at cluster and household levels, age was the only variable significantly associated with mortality at $p < 0.1$ (Supplementary Table S1). The multivariate model therefore included only age, and estimates were unchanged from the univariate analysis. Children aged 1–4 years had approximately one-fifth the risk compared with infants under 1 year (RR: 0.22, 95% CI: 0.09–0.55, $p < 0.001$), while this risk was substantially lower still among those aged 5 years and over (RR: 0.056, 95% CI: 0.01–0.22, $p < 0.001$). Sex, EPI vaccination status, other household cases, and care-seeking were not significantly associated with mortality (Supplementary Table S1). In a sensitivity analysis excluding age from the model (to address confounding between age and vaccination status), EPI vaccination showed a non-significant trend towards protection (aRR: 0.60, 95% CI: 0.30–1.21), though the small number of deaths (n = 48) limited statistical power to detect an independent effect.

Table 4: Summary of mortality measures, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019.

Measure	Overall (95% CI)	Under 5 (95% CI)	Under 1 (95% CI)
All-cause mortality rate (per 10,000 PD)	0.72 (0.61–0.82)	1.51 (1.19–1.84)	5.36 (4.04–6.98)
MSPM, 31-day (%)	15.3 (10.9–19.8)	35.2 (26.0–44.5)	27.3 (19.5–35.0)
90-day mortality rate, cases (per 10,000 PD)	1.03 (0.76–1.31)	9.25 (6.98–12.0)	46.7 (27.7–73.9)
90-day mortality rate, non-cases (per 10,000 PD)	0.66 (0.56–0.76)	6.60 (5.06–8.47)	12.5 (8.77–17.3)
90-day mortality rate ratio (per 10,000 PD)	1.58 (1.12–2.22)	1.40 (0.98–2.01)	3.73 (2.12–6.58)

PD: person-days; MSPM: measles-specific proportional mortality.

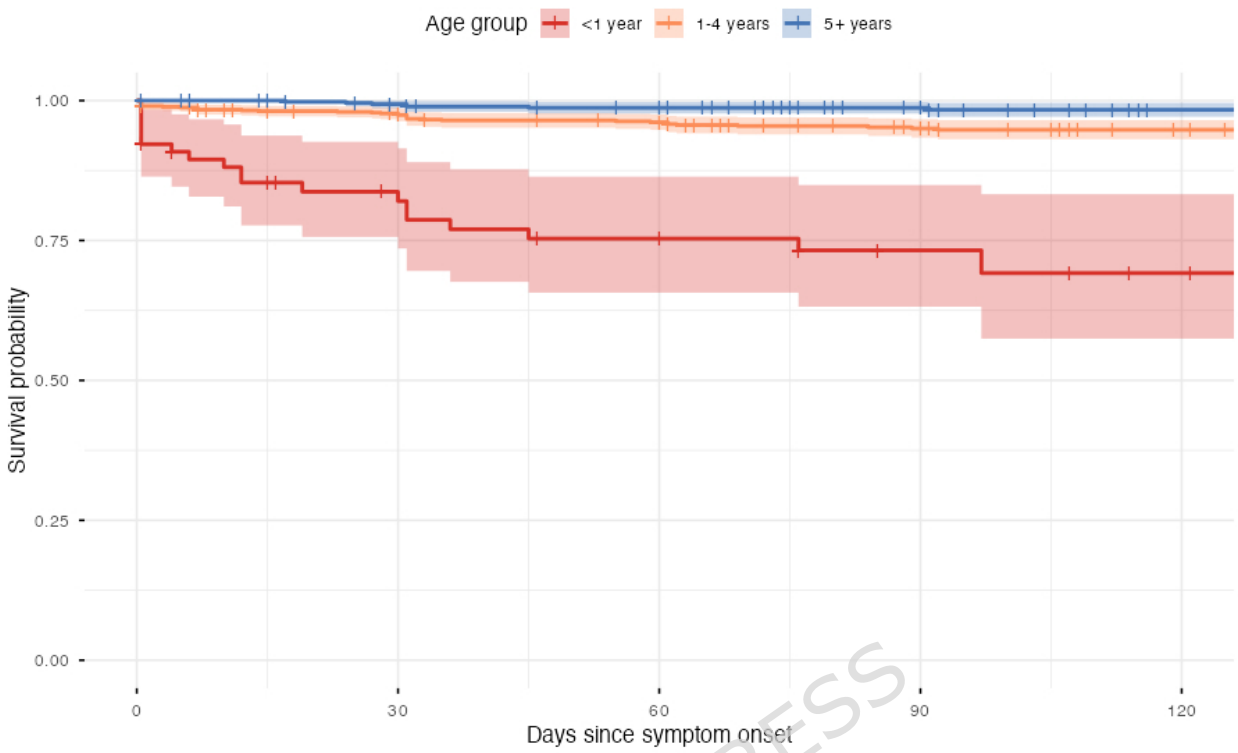

Figure 2: Kaplan-Meier survival curves from symptom onset among measles cases, stratified by age group, Yakusu Health Zone, Tshopo Province, DRC, January 2018 – June 2019. Shaded areas represent 95% confidence intervals. Risk table shown below.

Estimated outbreak size and surveillance sensitivity

Extrapolating the survey-weighted AR to the population of Yakusu HZ (142,379), the total number of cases was estimated at 22,068 (95% CI: 18,785–25,351) and the total number of deaths at 762 (95% CI: 460–1,130). This suggests the routine surveillance system detected 27.9% of cases and 19.9% of deaths. Among children under 5, estimated cases numbered approximately 14,035 and deaths approximately 683, with similar proportions detected by surveillance.

Vaccination coverage

Among the target population for vaccination (children aged 6–59 months), 68.2% (95% CI: 62.2–74.1) reported having been vaccinated through routine EPI, and 67.7% (95% CI: 61.6–73.8) reported being vaccinated during the MVC, of whom only 10.8% (116/1,079) could be verified by vaccination card. The proportion vaccinated by either EPI or the campaign was 82.1% (95% CI: 78.0–86.1), only marginally higher than coverage from each source alone. Overall, 53.5% (95% CI: 46.8–60.3) of the target age group reported having been vaccinated through both EPI and the campaign.

Among children with known status for both EPI and MVC, the overlap between routine and campaign vaccination was substantial (Table 5). Over half (56.1%) had received both EPI and campaign doses, while 19.2% had received neither. Among children vaccinated during the campaign, 81.6% had already received routine EPI vaccination. Conversely, among children who had not been vaccinated through routine EPI, only 39.8% were reached by the campaign.

Table 5: Cross-tabulation of EPI and mass vaccination campaign (MVC) status among children aged 6–59 months with known status for both, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019.

	MVC vaccinated	MVC not vaccinated	Total
EPI vaccinated	56.1%	12.1%	68.2%
EPI not vaccinated	12.7%	19.2%	31.8%
Total	68.8%	31.2%	100%

Geospatial analyses

There was a high degree of spatial overlap in vaccination coverage by EPI and MVC among children under 5 years, with pockets of low coverage in the west and centre of the HZ (Figure 3). EPI and campaign coverage were strongly positively correlated at the cluster level (Spearman $\rho = 0.59$, $p < 0.001$), confirming that the campaign largely reached the same geographic areas as routine EPI.

Prior to the campaign, the AR was greatest in the peripheral areas of the HZ, while after the campaign the spatial distribution of cases was approximately the inverse of the vaccination coverage, concentrated in those areas with lowest coverage (Figure 3).

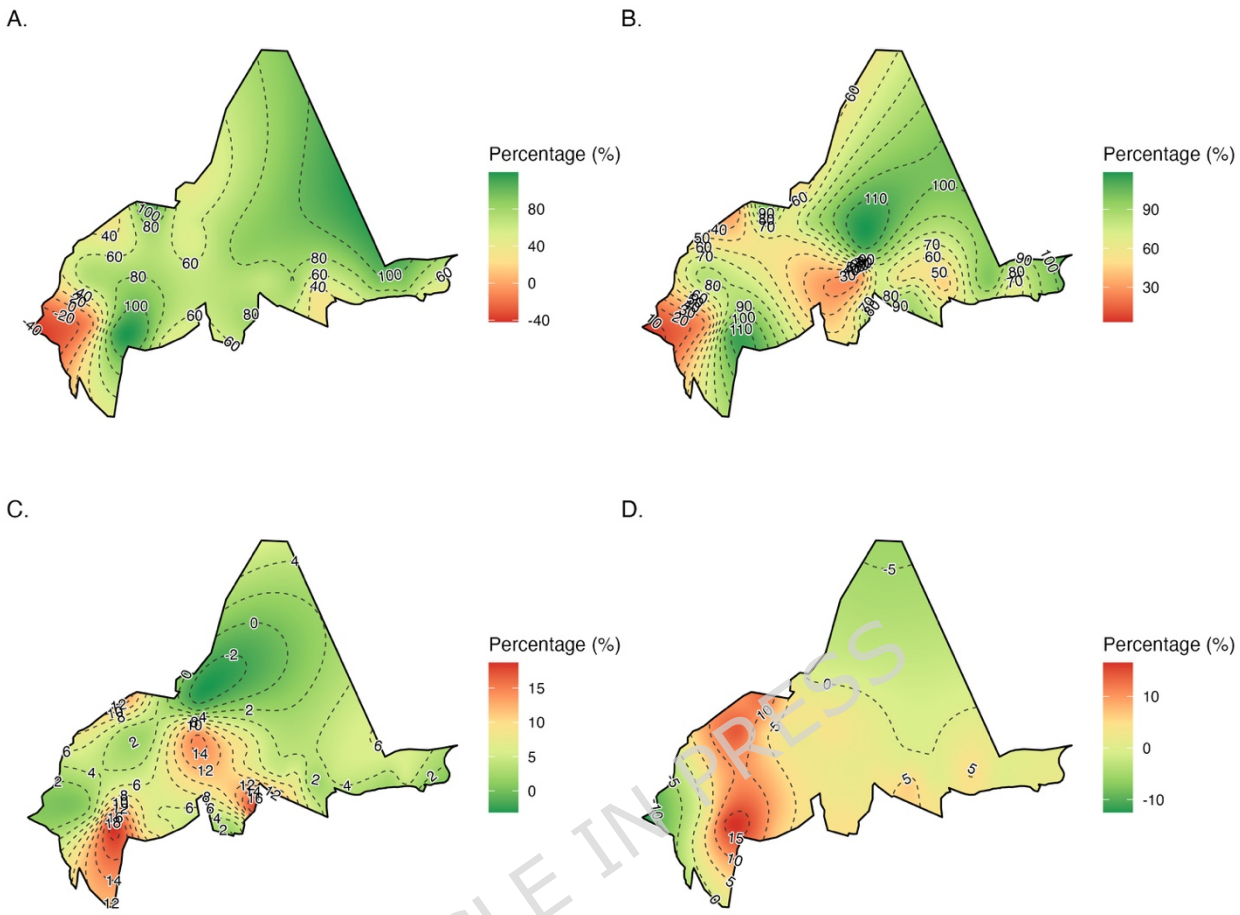

Figure 3: Geospatial distribution of the proportion of children aged under 5 years having received measles vaccine during (a) routine EPI and (b) mass reactive vaccination campaign, and of the measles attack rate (c) before and (d) after the campaign, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019.

Discussion

In this study, we described key aspects of a large measles outbreak associated with high mortality in Yakusu HZ, DRC. We observed markedly high community attack rates among children under 5 years compared with previously reported measles epidemics in DRC and other sub-Saharan African countries [8, 19–24]. Roughly two-

thirds of cases occurred among children under 5 years, with an AR approaching 50%. Measles was the leading cause of death among children under 5 years, with a CFR that was much higher than reported in routine data, and comparable to that observed in neighbouring Aketi HZ [25]. Among infants under 1 year, approximately one in five with measles died within 31 days.

Extending the attribution window from 31 to 90 days captured 14 additional deaths, raising the CFR from 3.5% to 4.5%. To determine whether these late deaths reflected ongoing measles-related excess mortality or simply the tail of the acute illness, we compared age-adjusted mortality rates between cases and non-cases in each period separately. Excess mortality among cases was overwhelmingly concentrated in the first 31 days, with no evidence of continued excess between days 32 and 90; indeed, cases who survived past day 31 had lower subsequent mortality than non-cases (RR: 0.46, 95% CI: 0.26–0.84), consistent with survivor selection. The additional deaths in the wider window are therefore better explained by the distribution of onset-to-death intervals (median 27.5 days, IQR 4.75–38.25), which places a proportion of acute deaths just beyond the 31-day boundary, than by a distinct late mortality signal. Although immune amnesia has been shown to increase susceptibility to secondary infections for months following measles in other contexts [11, 12], we found no evidence of such an effect here, though the small number of late deaths limits our ability to exclude one. In practical terms, the 31-day definition captures the large majority of measles-attributable deaths, but inevitably misses some that fall in the tail of what is a continuous process.

While being vaccinated through either routine EPI or the campaign was associated with a reduced risk of measles infection (RR: 0.80, 95% CI: 0.68–0.93), the campaign overwhelmingly reached children who had already been vaccinated

through routine EPI. Among campaign recipients, 81.6% had already received routine vaccination. Conversely, only 39.8% of children who had not been vaccinated through routine EPI were reached by the campaign. This pattern was spatially consistent: EPI and campaign coverage were strongly correlated at the cluster level (Spearman $\rho = 0.59$, $p < 0.001$), indicating that the campaign was delivered in the same areas, and largely to the same children, as routine services. This is a recognised challenge in reactive vaccination campaigns [20, 26], but the magnitude of the overlap documented here is striking. While we were unable to assess the role of distance from health facilities directly, the spatial overlap between EPI and campaign coverage is consistent with previous work in DRC suggesting that vaccination uptake decreases with distance from health centres, with campaigns reaching accessible populations but missing remote communities.

The observation that 59.3% of measles cases had been previously vaccinated does not indicate vaccine failure. Rather, it reflects the fact that approximately two-thirds of the target population had been vaccinated, so even with a lower attack rate among the vaccinated (33.3% vs. 56.0% among the unvaccinated), the majority of cases will occur in the vaccinated group. The moderate protective effect observed (RR: 0.80) is consistent with the known limitations of single-dose measles vaccination at 9 months under programmatic conditions, where seroconversion rates are lower than in controlled settings, and where vaccination status was predominantly based on parental recall (card verification was possible for only 10.8% of campaign vaccinations). In any case, reported vaccination status is an unreliable predictor of seroprotection [27, 28].

Both routine and campaign coverage were approximately two-thirds of the target population, while the total proportion vaccinated by either was only 82.1%, well

below the 95% two-dose coverage necessary to interrupt transmission [29, 30]. The combination of inadequate coverage, poor targeting of the campaign towards unvaccinated children, and the high spatial overlap between routine and campaign coverage resulted in pockets of susceptible children in whom the outbreak continued to propagate following the campaign, as evidenced by the inverse spatial distribution of post-campaign attack rates and vaccination coverage.

The campaign was implemented more than 15 months after the outbreak began. Survey data suggest that approximately 698 additional cases were reported with onset between July 2018 (six months into the epidemic) and the actual campaign date, representing cases that might have been averted had the campaign been mounted earlier. During the period of MSF-supported free healthcare (Phase 2; 3 Mar – 20 Apr 2019), the 31-day CFR appeared lower (1.9%) compared with the pre-intervention period (5.0%), suggesting that access to free care may have contributed to reducing case fatality, although this comparison is subject to confounding by changes in case severity and demographics over time.

The routine surveillance system detected only an estimated 27.9% of cases and 19.9% of deaths. The low sensitivity for detecting deaths is a previously documented finding [5], reflecting poor documentation of measles deaths when death results from complications occurring days to weeks after the characteristic rash has resolved. Strengthening both routine surveillance and Early Warning, Alert and Response Systems remains essential in this context [31, 32].

Limitations

This was a retrospective household survey, and reported cases and causes of death were not clinically confirmed. To mitigate this, surveyors included images of the

maculopapular blanching rash to identify measles cases. Reported vaccination status may be subject to recall bias; although efforts were made to verify status using vaccination cards, cards were not systematically distributed during the campaign and verification was possible for only a small minority. The long recall period (approximately 18 months) may also have introduced recall bias, particularly for deaths occurring early in the outbreak. As some communities were inaccessible due to security or logistical constraints, the accuracy of these estimates is uncertain; such communities may have experienced either higher or lower attack rates and mortality, depending on the degree to which their isolation limited both exposure to the pathogen and access to care. The extrapolation to the whole HZ population further assumes that the survey sample is representative of the broader population, which cannot be confirmed in the absence of reliable demographic data for Yakusu HZ. Finally, the small number of measles-attributable deaths (n = 48) limited the statistical power of risk factor analyses, particularly for detecting an independent effect of vaccination on mortality.

Conclusion

Yakusu Health Zone experienced a severe measles epidemic characterised by high attack rates and case fatality, particularly among children under 5 years, with mortality concentrated among infants, of whom nearly one in five died within 31 days. The 31-day case fatality definition captured the majority of measles-attributable deaths, though a modest proportion of acute deaths fell just beyond this window. The reactive vaccination campaign, implemented more than one year after the outbreak began, overwhelmingly reached children already vaccinated through routine EPI while failing to reach the majority of previously unvaccinated children. Reactive campaigns in similar settings should prioritise identifying and

reaching unvaccinated populations through improved microplanning and spatial targeting, rather than maximising total doses administered.

Abbreviations

AR: attack rate; CFR: case fatality ratio; CI: confidence interval; CMR: crude mortality rate; DRC: Democratic Republic of the Congo; EPI: Expanded Programme on Immunisation; EWARS: Early Warning, Alert and Response Systems; HZ: health zone; MoH: Ministry of Public Health; MSF: Médecins Sans Frontières; MSPM: measles-specific proportional mortality; MVC: mass vaccination campaign; PD: person-days; RR: risk ratio; U5MR: under-5 mortality rate; WHO: World Health Organization.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the MSF Ethics Review Board and the Research Ethics Committee of Kisangani University, DRC (approval number UNIKIS/CER/004/2019). This study adhered to the Declaration of Helsinki and was conducted in accordance with the CIOMS guidelines for epidemiological research [33]. Verbal informed consent was obtained from all participants and from legal guardians of participants below 16 years of age. All collected data were pseudo-anonymised and stored on a password-protected remote server.

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and analysed during this study are not publicly available in accordance with the MSF data sharing policy [34], but are available on reasonable request addressed to data.sharing@msf.org.

Competing interests

The authors declare no competing interests.

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This study was funded by Médecins Sans Frontières (MSF). MSF authors were involved in study conceptualisation and design, data collection, analysis, and manuscript preparation.

Author contributions

Conceptualisation: EG, IC, FA. Formal analysis: EG, JP, MER. Investigation: FA, YK, TM, GT. Methodology: EG, JP, IC, MER. Project administration: FA, EG. Visualisation: JP, EG, MER. Writing (original draft): MER, JP, EG, IC. Writing (review and editing): all authors.

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Tables

Table 1: Description of study participants by characteristics, Yakusu Health Zone, Tshopo Province, Democratic Republic of the Congo, 1 January 2018 – 30 June 2019.

Characteristic	Number (%)
Age group	
<1 year	400 (4.5)
1–4 years	1,534 (17.1)
5–9 years	1,563 (17.4)
10–14 years	1,069 (11.9)
≥15 years	4,402 (49.1)
Sex	
Female	4,463 (49.8)
Male	4,505 (50.2)
Vaccination (EPI)	
Not vaccinated	1,238 (13.8)
Vaccinated	2,617 (29.2)
Unknown	5,113 (57.0)
Vaccination (MVC)	

Characteristic	Number (%)
Not vaccinated	641 (7.1)
Vaccinated	1,338 (14.9)
Unknown	6,989 (77.9)
Vaccination (EPI and/or MVC)	
Not vaccinated	341 (3.8)
Vaccinated	2,929 (32.7)
Unknown	5,698 (63.5)
Measles case	
Non-case	7,578 (84.5)
Case	1,390 (15.5)
Status	
Alive	8,655 (96.5)
Dead	313 (3.5)
Total	**8,968 (100)**

Table 2: Description of measles cases and decedents within 31 days, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019.

Characteristic	**Cases (%)**	**Deaths (%)**
Age group		

<1 year	77 (5.5)	15 (31.3)
1–4 years	807 (58.1)	28 (58.3)
5–9 years	416 (29.9)	4 (8.3)
10–14 years	57 (4.1)	0 (–)
≥15 years	33 (2.4)	1 (2.1)
Sex		
Female	691 (49.7)	21 (43.8)
Male	699 (50.3)	27 (56.3)
Vaccination (EPI)		
Not vaccinated	385 (27.7)	14 (29.2)
Vaccinated	824 (59.3)	19 (39.6)
Unknown	181 (13.0)	15 (31.3)
Other cases in household		
No	215 (15.5)	10 (20.8)

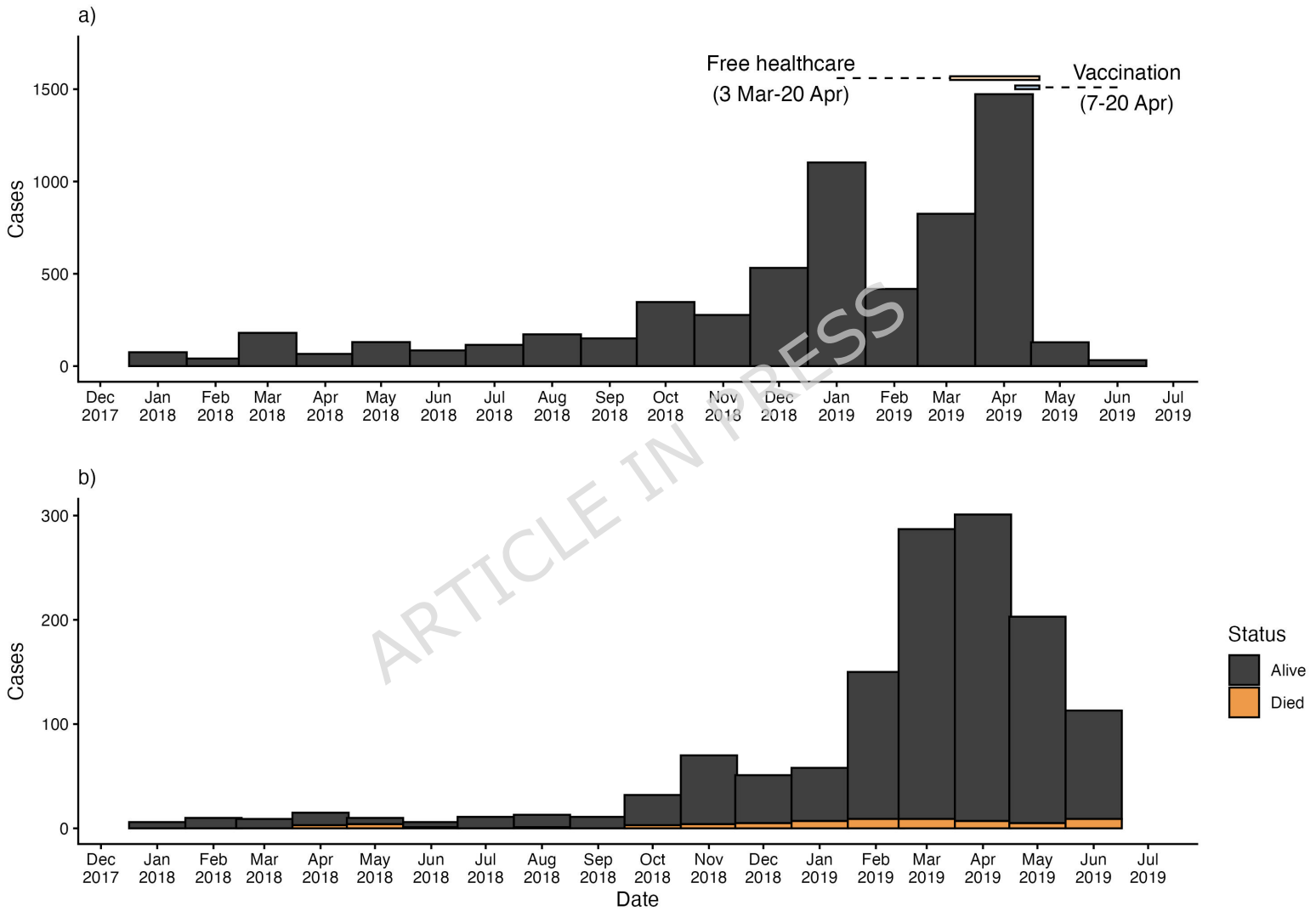
Yes	1,175 (84.5)	38 (79.2)
Sought care		
No	287 (20.6)	3 (6.3)
Yes	1,103 (79.4)	45 (93.8)
Total	**1,390 (100)**	**48 (100)**

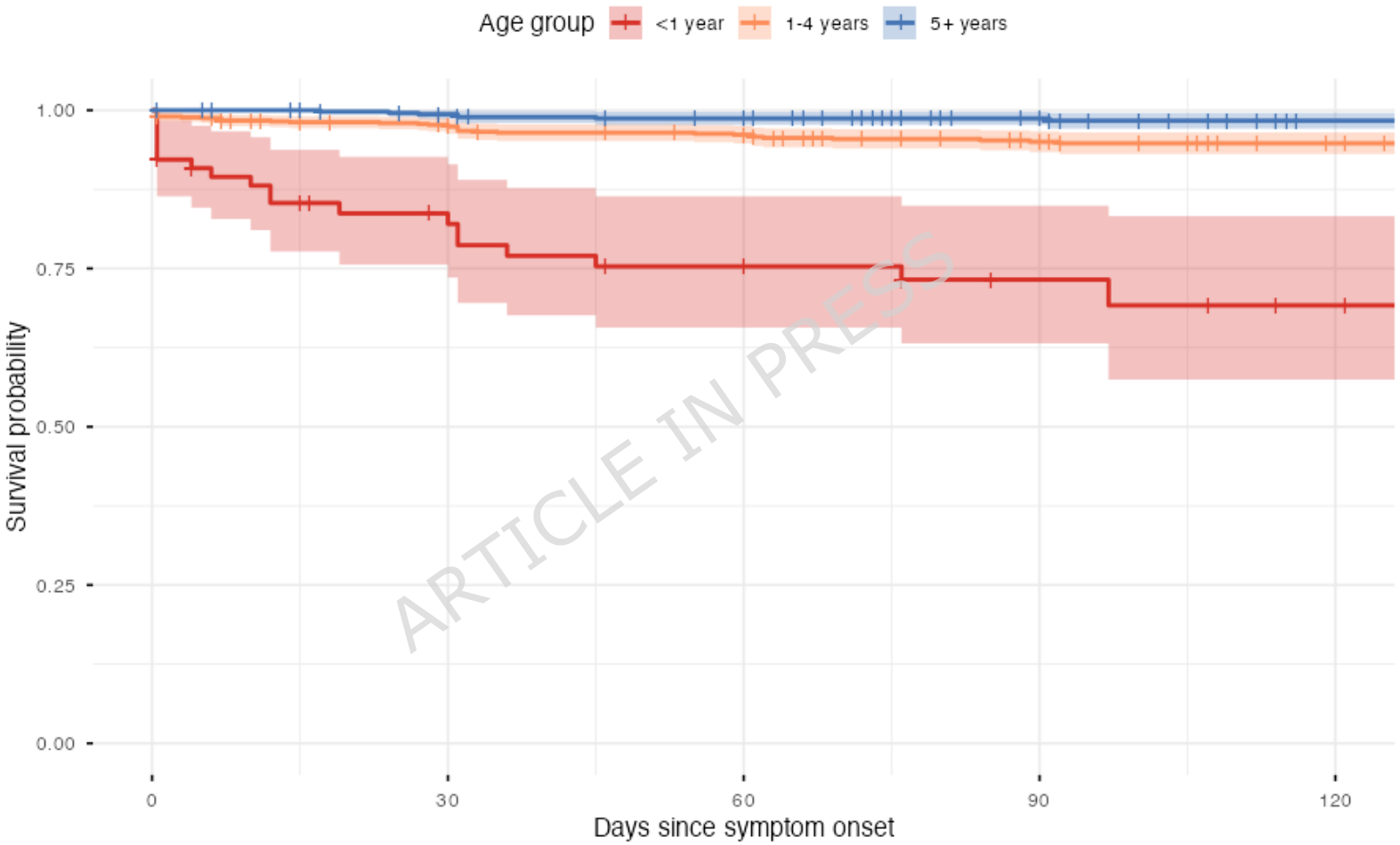
Table 3: Attack rates and case fatality ratios by age group and sex, Yakusu Health Zone, Tshopo Province, DRC, January 2018 – June 2019.

	Study sample	Cases (AR% [95% CI])	Deaths, 31-day (CFR% [95% CI])	Deaths, 90-day (CFR% [95% CI])
Age group				
<1 year	400	77 (19.3 [15.0–23.5])	15 (19.5 [12.1–26.9])	18 (23.4 [12.9–33.8])
1–4 years	1,534	807 (52.6 [45.2–60.0])	28 (3.5 [2.0–4.9])	38 (4.7 [3.3–6.2])
5–9 years	1,563	416 (26.6 [21.6–31.6])	4 (1.0 [0.0–1.9])	5 (1.2 [0.1–2.3])

	Study sample	Cases (AR% [95% CI])	Deaths, 31-day (CFR% [95% CI])	Deaths, 90-day (CFR% [95% CI])
10–14 years	1,069	57 (5.3 [3.6–7.0])	0 (–)	0 (–)
≥15 years	4,402	33 (0.7 [0.5–1.0])	1 (3.0 [0.0–8.6])	1 (3.0 [0.0–8.6])
Under 5 / 5+				
<5 years	1,934	884 (45.7 [39.6–51.9])	43 (4.9 [3.4–6.3])	56 (6.3 [4.7–7.9])
≥5 years	7,034	506 (7.2 [5.8–8.5])	5 (1.0 [0.1–1.8])	6 (1.2 [0.3–2.1])
Sex				
Female	4,463	691 (15.5 [13.2–17.8])	17 (2.5 [1.4–3.6])	24 (3.5 [2.2–4.8])
Male	4,505	699 (15.5 [12.9–18.1])	18 (2.6 [1.4–3.7])	38 (5.4 [3.6–7.2])
Total	**8,968**	**1,390 (15.5 [13.2–17.8])**	**48 (3.5 [2.4–4.5])**	**62 (4.5 [3.4–5.5])**

AR: attack rate; CFR: case fatality ratio; CI: confidence interval. Lower bounds of confidence intervals truncated at 0.





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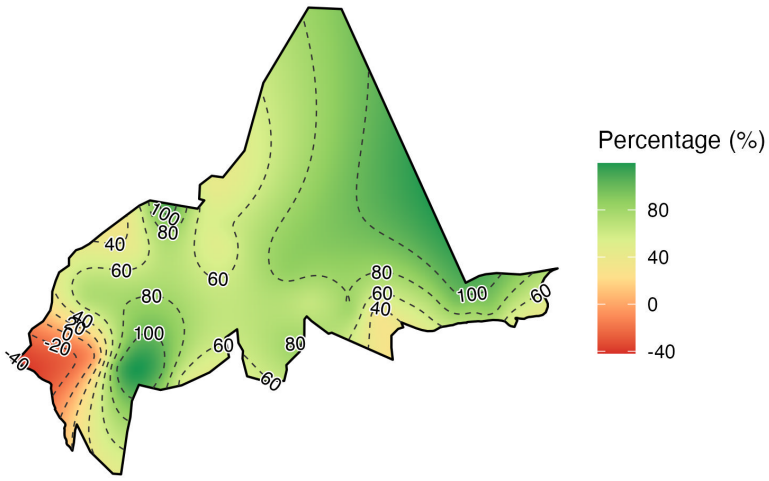

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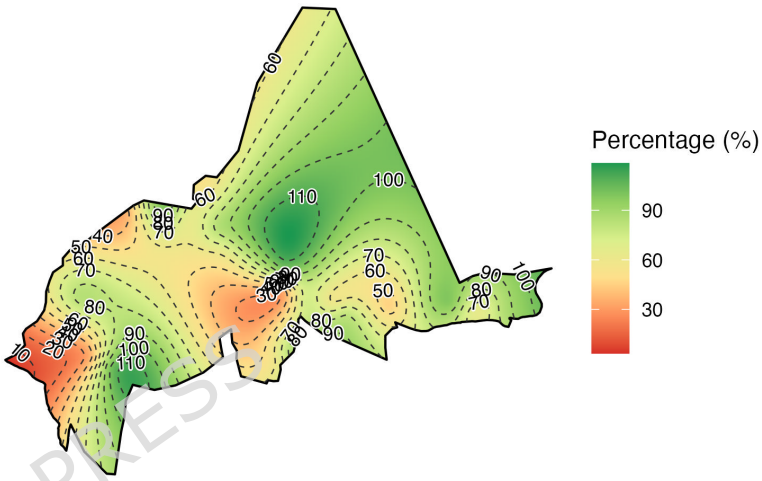

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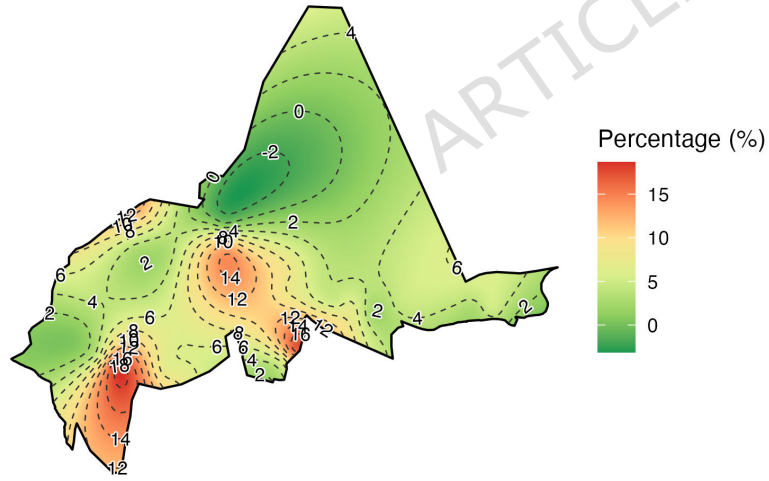

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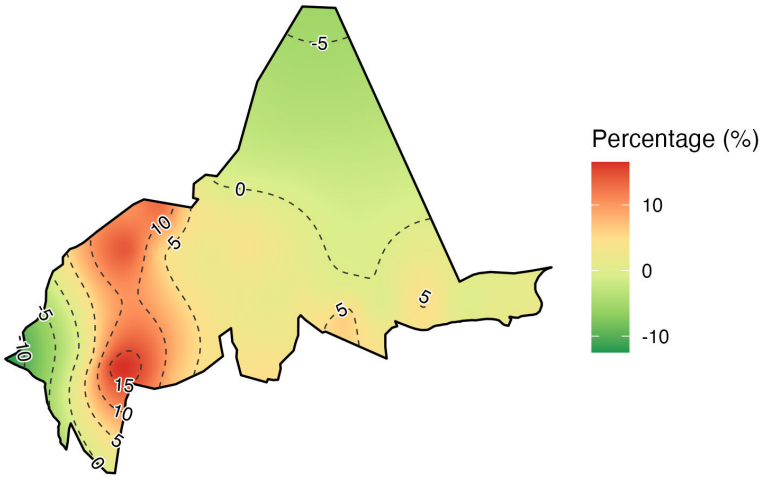

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	Study sample	Cases (AR% [95% CI])	Deaths, 31-day (CFR% [95% CI])	Deaths, 90-day (CFR% [95% CI])
Age group				
<1 year	400	77 (19.3 [15.0–23.5])	15 (19.5 [12.1–26.9])	18 (23.4 [12.9–33.8])
1–4 years	1,534	807 (52.6 [45.2–60.0])	28 (3.5 [2.0–4.9])	38 (4.7 [3.3–6.2])
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Sex				

	Study sample	Cases (AR% [95% CI])	Deaths, 31-day (CFR% [95% CI])	Deaths, 90-day (CFR% [95% CI])
Female	4,463	691 (15.5 [13.2–17.8])	17 (2.5 [1.4–3.6])	24 (3.5 [2.2–4.8])
Male	4,505	699 (15.5 [12.9–18.1])	18 (2.6 [1.4–3.7])	38 (5.4 [3.6–7.2])
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AR: attack rate; CFR: case fatality ratio; CI: confidence interval. Lower bounds of confidence intervals truncated at 0.

Table 4: Summary of mortality measures, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019.

Measure	Overall (95% CI)	Under 5 (95% CI)	Under 1 (95% CI)
All-cause mortality rate (per 10,000 PD)	0.72 (0.61–0.82)	1.51 (1.19–1.84)	5.36 (4.04–6.98)
MSPM, 31-day (%)	15.3 (10.9–19.8)	35.2 (26.0–44.5)	27.3 (19.5–35.0)
90-day mortality rate, cases (per 10,000 PD)	1.03 (0.76–1.31)	9.25 (6.98–12.0)	46.7 (27.7–73.9)
90-day mortality rate, non-cases (per 10,000 PD)	0.66 (0.56–0.76)	6.60 (5.06–8.47)	12.5 (8.77–17.3)
90-day mortality rate ratio (per 10,000 PD)	1.58 (1.12–2.22)	1.40 (0.98–2.01)	3.73 (2.12–6.58)

PD: person-days; MSPM: measles-specific proportional mortality.

Table 5: Cross-tabulation of EPI and mass vaccination campaign (MVC) status among children aged 6–59 months with known status for both, Yakusu Health Zone, Tshopo Province, DRC, January 2018 –June 2019.

	MVC vaccinated	MVC not vaccinated	Total
EPI vaccinated	56.1%	12.1%	68.2%
EPI not vaccinated	12.7%	19.2%	31.8%
Total	68.8%	31.2%	100%