Retrospective estimation of mortality in Somalia, 2014-2018: a statistical analysis

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Abstract

Background

Somalia regularly experiences drought-related crises, against the backdrop of a thirty-year old armed conflict. During 2010-2012, extreme food insecurity and famine were estimated to account for 256,000 deaths. Since 2014 Somalia has experienced recurrent below-average rainfall, with consecutive failed rains in late 2016 and 2017 leading to large-scale drought, displacement and epidemics. We wished to estimate mortality across Somalia from 2014 to 2018, and measure the excess death toll attributable to the 2017-2018 drought-triggered crisis.

Methods

We used a statistical approach akin to small-area estimation, and relying solely on existing data. We identified and re-analysed 91 household surveys done at the district level and estimating the crude (CDR) and under 5 years death rate (U5DR) over retrospective periods of 3-4 months. We captured datasets of candidate predictors of mortality with availability by district and month, as per a causal framework including climate, armed conflict intensity, forced displacement, food insecurity, nutritional status, disease burden, humanitarian and health service domains. We also reconstructed population denominators by district-month combining alternative census estimates and displacement data. We combined these data inputs into predictive models to estimate CDR and U5DR even where no ground data were available, and combined the predictions with population estimates to project death tolls. Excess mortality was estimated by constructing counterfactual no-crisis scenarios.

Results

Between 2013 and 2018, Somalia's population increased from 12.0 to 13.5 million, and internally displaced people or returnees reached 20% of the population. Using models comprising the incidence of armed conflict events, rate of nutritional therapy admissions, incidence of malaria and measles occurrence, we estimated that CDR ranged between 0.3 and 0.5 per 10,000 person-days during 2014-2018, but with an increase of about 15% during 2017-2018, translating to an excess death toll of 44,700 in the most likely counterfactual scenario, and as high as 163,800 in a pessimistic scenario. By contrast to 2010-2012, excess deaths were widespread across Somalia, including central and northern regions.

Discussion

This analysis suggests that the 2017-2018 crisis had a lower, albeit still very substantial, mortality impact than its 2010-2012 predecessor. Despite modest elevations in death rate, crisis conditions were widespread and affected a population of millions. Potential study limitations we have identified include error in population estimates and under-reporting of child deaths, which we explore in sensitivity analyses. Humanitarian response to drought-related crises in Somalia needs to be strengthened, target the most vulnerable and emphasise very early interventions.

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Disclaimer

Geographical names and boundaries presented in this report are used solely for the purpose of producing scientific estimates, and do not necessarily represent the views or official positions of the authors, the London School of Hygiene and Tropical Medicine, any of the agencies that have supplied data for this analysis, or the donor. Within this report, the denominations 'Somalia' and 'greater Somalia' are adopted for simplicity to encompass south-central Somalia, Puntland and Somaliland.

The authors are solely responsible for the analyses presented here, and acknowledgment of data sources does not imply that the agencies providing data or the donor endorse the results of the analysis.

List of tables and figures

Background

Crisis in Somalia

Somalia has experienced recurrent climate- and armed conflict-driven crises over the past 30 years. As a result, the population has limited resilience and is vulnerable to shocks brought on by such crises. In 2010-2012, largely as a result of consecutive failed rains and limited humanitarian access and assistance, a famine occurred across south-central Somalia. A study we conducted, commissioned by the United Nations, estimated 256,000 deaths attributable to exceptional food insecurity during this period, of which approximately half in children under 5 years.[1]

The two years following the famine saw modest improvements, coinciding with intensified humanitarian assistance and moderate rainfall. By end 2014, however, reduced humanitarian access due to renewed insecurity, as well as below-average rainfall, had returned pockets of Somalia to acute emergency conditions.[2] The years 2015 and 2016 saw a mixture of failed seasonal rains and exceptional flooding, complicated by the return of Somalis from Kenya refugee camps and war-stricken Yemen.[3]

In 2016, the sustained underperformance of seasonal rains in Puntland and Somaliland triggered both governments to declare states of emergency. Most regions of Somalia experienced far below-average rainfall in September-December 2016, compromising key harvests and livestock viability[4]; as shown in Figure 1, in some regions drought persisted into 2017, and large movements of internally displaced persons (IDPs) were seen, topping 2.6 million by end 2018 (see sources below). Large-scale epidemics of cholera and measles, typical of food insecurity and displacement situations, also occurred during this period.[5] Abundant rainfall was however recorded from mid-2018 (Figure 1).

Scope of this study

Protracted armed conflicts are characterised by increased population mortality, both directly (violence) and indirectly (increased risk of disease, reduced access to healthcare) attributable to the crisis.[6] Information on this "excess" mortality can inform the ongoing humanitarian response, provide evidence for resource mobilisation, and support conflict resolution.[7] In Somalia specifically, it was hypothesised that the humanitarian response in 2017-2018 had been quicker and more effective than in 2010-2012, but there was no evidence on the extent to which the latest crisis had increased population mortality. We wished to update our 2010-2012 analysis by estimating mortality across Somalia during 2014-2018, while also quantifying the excess death toll attributable to drought during 2017-2018.

Methods

Study design

An extensive paper with methodological details, as well as analysis scripts, are published separately. Source data are included here. The following is an abridged presentation of methods. Briefly, our method consists of six mostly sequential steps, summarised in Figure 2, and is broadly classifiable as a small-area estimation approach.[8] It rests on constructing a model to predict mortality based on a combination of previously collected data, and using the model, in conjunction with population denominators, to estimates death rates and tolls across the crisis-affected population and period of interest. The model is also used to predict mortality in counterfactual scenarios of no crisis, and the difference between these predictions and the estimated actual mortality is taken as the excess, crisis-attributable mortality.

Our analysis covered all of Somalia (including Somaliland and Puntland) and was stratified by district and month, spanning the period January 2014 to December 2018, with excess mortality estimated for 2017-2018, the crisis-affected period of interest. We sought to estimate all-age and under 5y mortality: corresponding indicators are the crude death rate (CDR) and the under 5 years death rate (U5DR); the latter, unlike under 5y mortality ratios (which measure the probability of survival to age 5y), expresses the incidence of death among children.

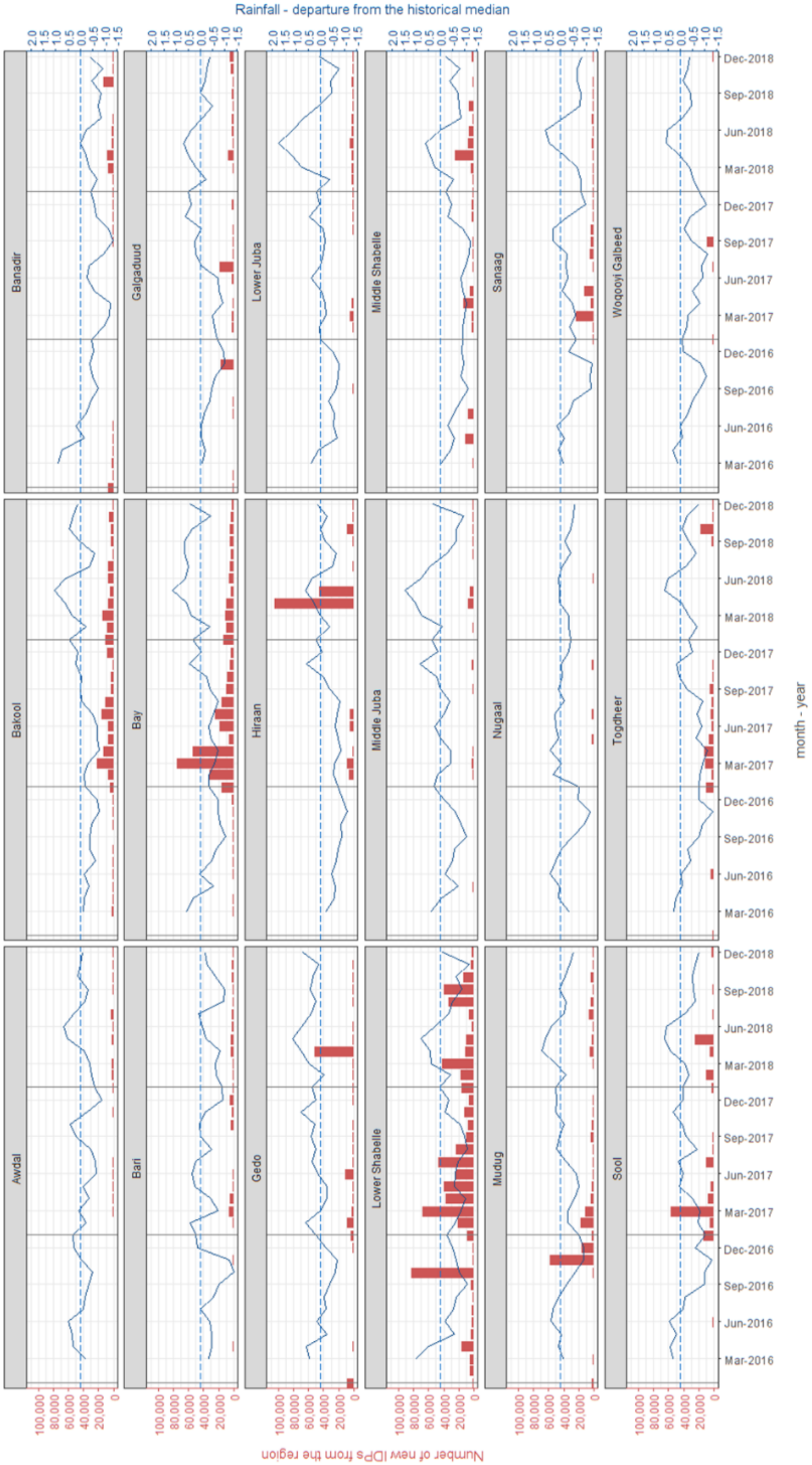

Figure 1. Rainfall levels compared to the historical average and number of people newly displaced, by region, 2016-2018.

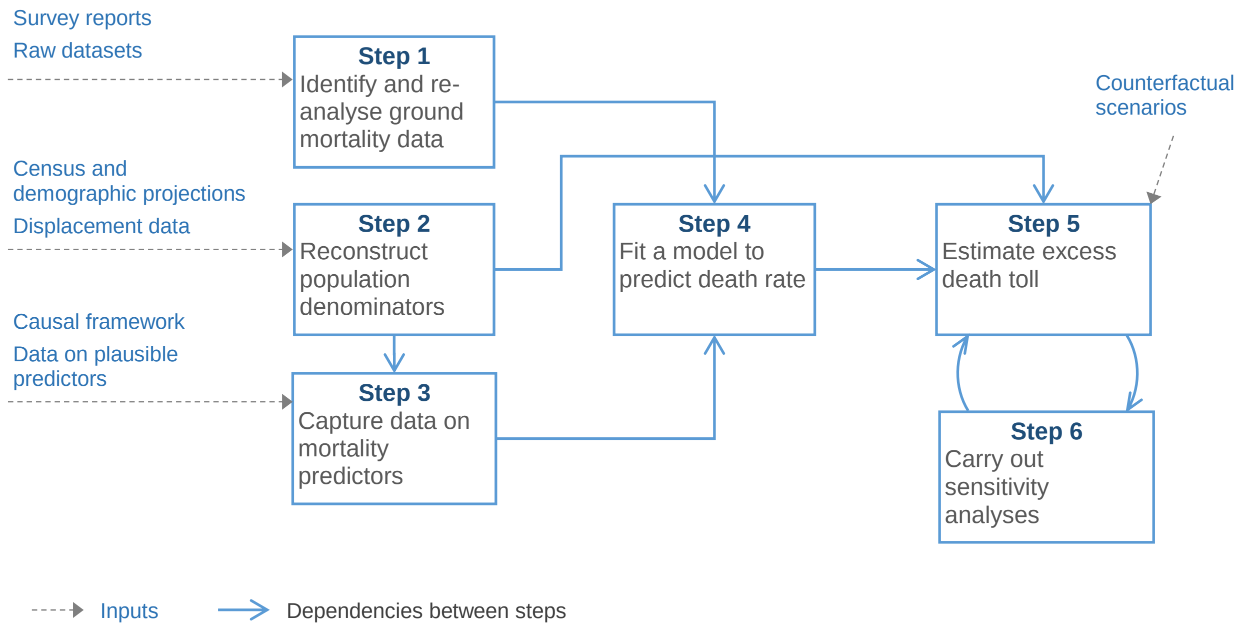

Figure 2. Schematic of estimation steps and required inputs.

Step 1: Identifying existing ground estimates of mortality covering the analysis person-time

We used retrospective household surveys conducted by different humanitarian actors using the Standardised Monitoring of Relief and Transitions (SMART) protocol[9]: while these surveys are primarily conducted to estimate the prevalence of acute malnutrition, they often include a mortality questionnaire module, which elicits information from respondents on the demographic evolution (composition, births, deaths, in- and out-migration) of their households during a 'recall' period of 3-4 months.[10,11] Prior to 2016, SMART surveys often relied on an 'aggregate' questionnaire, which elicits only numbers of household members and demographic events; since 2016, only a more detailed 'individual' questionnaire has been used, whereby each household member present during the recall period is listed. Surveys use systematic random sampling or two-stage cluster sampling with probability of cluster selection proportional to size; we used surveys whose sampling universe was an entire district, or urban or IDPs within a district. We extracted meta-data on, cleaned and re-analysed all surveys with datasets available to us, estimating CDR, U5DR and other demographic indicators using generalised linear models at the household level, assuming a Poisson distribution offset by household person-time at risk, and adjusting standard errors for intra-cluster correlation.

Step 2: Reconstructing population denominators

We reconstructed district-month populations over 2014-2018 by applying an assumed 2.1% growth rate (difference between UN-projected crude birth and death rates[12]) to four existing census estimates, while also subtracting and/or adding from/to each district IDPs and refugees known to move from/to it during each given month. Alternative census estimates consisted of (i) the March 2014 Population Estimation Survey (UNPESS), carried out by the United Nations Population Fund, and based on a stratified sample of clusters within urban, rural, IDP and nomadic communities[13]; (ii) January 2015 estimates from Afripop (https://www.worldpop.org/), which uses a validated statistical model to estimate population density by 100m^2 based on remote sensing'[14]; (iii) December 2018 data from the Polio Eradication Initiative, which in Somalia updates target vaccination population denominators through active enumeration; and (iv) January 2019 Expanded Programme on Immunization data, adjusted based on vaccination campaign performance data. Displacement data came from the United Nations High Commissioner for Refugees (UNHCR)-led Protection and Return Monitoring Network (PRMN)[15], which tracks reported displacement and returnee movements from one district to the next, with monthly data available from January 2016 to December 2018. We also reviewed situation reports on the humanitarian ReliefWeb information platform (www.reliefweb.int) and on the UNHCR web site (www.unhcr.org) to approximate refugee flows in and out of districts. We applied the median proportion of children under 5y (25.0%) as measured by the household surveys we reviewed.

Step 3: Capturing data on predictors of mortality

We used a published causal framework[16] of excess mortality in crises to identify possible predictors of death rate for which datasets with reasonable completeness ($\geq$ 70% complete for $\geq$ 70% district-months) were available. Candidate predictors for which we found data are detailed in Table 1. Where relevant, we divided predictor values by reconstructed population denominators. We used manual imputation and spline smoothing to remove missingness and minimise outliers.

Step 4: Fitting a predictive model

We evaluated the accuracy of different candidate sets of predictors to predict mortality (CDR and U5DR) by fitting quasi-Poisson models of these predictors to mortality survey data (household-level counts of deaths, offset by household person-time at risk during the recall period); average values of each predictor over the survey's recall period, and in the district surveyed, were used. After screening out predictors with poor fit, we did a brute-force search across all possible candidate models, selecting the final model out of the top 20% best-fitting alternatives: given comparable predictive accuracy, we gave preference to the most parsimonious model and predictors (e.g. epidemic occurrence) that were plausibly sensitive to crisis conditions, and thus could be used to meaningfully construct counterfactual scenarios (see below). We explored both categorical and continuous versions of variables, and lags up to 6 months where plausible. We introduced random effects (survey cluster and district) and plausible interactions, but retained neither as they worsened model fit. Lastly, we computed robust coefficient standard errors. To validate models for prediction on new data, we fit all models on an 80% random 'training' sample of surveys and observed predictive accuracy on the remaining 20% 'holdout' sample. We also did ten-fold cross-validation within the training sample.

Step 5: Estimating excess death tolls

Working with the selected models for CDR and U5DR, we predicted death rates and (after multiplying by population denominators) tolls, by district-month. We also estimated what mortality would have been in the most likely, most pessimistic and most optimistic counterfactual scenarios (Table 2): each scenario was constructed by varying both population denominators and model predictor values in accordance with assumptions on what would have happened in the absence of a crisis. We generated 10,000 bootstrap sets of actual and counterfactual predictions by sampling from model error distributions, and for each set computed excess mortality as the difference. We then computed point estimates (modes) and 95% percentile intervals from the distributions of bootstrap samples.

Step 6: Sensitivity analyses

We wished to examine the sensitivity of estimates to two key possible error sources: (i) systematic or unsystematic error in the population and displacement input data, and (ii) possible under-reporting of under 5y deaths, as noted in a previous South Sudan analysis[17], and suggested by the surprisingly low ratio of U5DR to CDR (see below). We did so by replicating the analysis for different combinations of error in district population and displacement estimates, and varying proportions of under-reporting of child deaths in the survey datasets (for the latter, we artificially augmented datasets by computing the corresponding number of under-reported deaths at survey level, and distributing these among surveyed household in a random way, with 10,000 bootstrap replicates of this procedure).

Table 1. Candidate predictors of mortality considered in the analysis.

Predictor	Variable(s)	Domain	Time span of availability	Source(s)	Notes and assumptions
Administrative level	Administrative entity within Somalia	(various)	n/a (static variable)	n/a	Somaliland, Puntland, south-central Somalia
Rainfall	Total rainfall (mm)	Climate	2013 to 2018	Climate Engine[18]	
	Mean of Standard Precipitation Index		2016 to 2018	Huntington et al. (2017)[19]	Compares current rainfall with historical averages.
Vegetation density	Normalised Difference Vegetation Index	Climate	2013 to 2018	Food Security and Nutrition Analysis Unit - Somalia (FSNAU)[20]	
Incidence of armed conflict events†	events per 100,000 population deaths per 100,000 population	Exposure to armed conflict / insecurity	2010 to 2018	Armed Conflict Location & Event Data Project (ACLED)[21]: https://www.acleddata.com/	Meta-data on individual armed conflict events based on extensive review of multi-language media sources and other public information.
Incidence of attacks against aid workers†	deaths per 100,000 population injuries per 100,000 population	Exposure to armed conflict / insecurity	2010 to 2018	Aid Worker Security Database (AWSD)[22]: https://aidworkersecurity.org/incidents	Data on various types of attacks to aid workers, capturing information from media sources, aid organisations and security actors.
Proportion of IDPs	proportion of IDPs among total district population	Forced displacement	2016 to 2018	As estimated in step 2.	
Main local livelihood type	Pastoral, agropastoral, riverine and urban	Food security and livelihoods	n/a (static variable)	FSNAU[23]	Assumed to be constant over time.
Water price	Price of 200L drum of water in Somali Shillings	Food insecurity and livelihoods	2013 to 2018	FSNAU[20]	
Terms of trade purchasing power index	Kcal equivalent of local cereals that an average local-quality goat can be exchanged for	Food insecurity and livelihoods	2013 to 2018	Calculated by the authors based on FSNAU price data[20] from 100 sentinel markets.	See Annex.
	Kcal equivalent of local cereals that can be purchased with an average daily labourer wage				
Malnutrition incidence†	cases of severe acute malnutrition admitted to treatment programmes per 100,000 population	Nutritional status	2011 to 2018	Nutrition Cluster, Somalia	Unpublished data.
	cases of global acute malnutrition admitted to treatment programmes per 100,000 population		2013 to 2018		
Cholera incidence†	cases per 100,000 population	Disease burden (epidemic)	2013 to 2018	FSNAU[20]	Suspected and confirmed cases. No cases reported before 2015.
Measles incidence†	cases per 100,000 population	Disease burden (epidemic)	2013 to 2018	FSNAU[20]	Suspected and confirmed cases. No cases reported before 2015.
Malaria incidence†	cases per 100,000 population	Disease burden (epidemic)	2013 to 2018	FSNAU[20]	Suspected and confirmed cases. No cases reported before 2015.
Humanitarian actor presence†	Ongoing humanitarian projects per 100,000 population (all sectors)	Humanitarian (public health) service functionality	2010 to 2018	United Nations Office for Coordination of Humanitarian Affairs, Somalia	Proxy of intensity of humanitarian response. Unpublished data.
	Ongoing projects per 100,000 population (health, nutrition and water, hygiene and sanitation)				
Measles vaccination	Coverage of one dose of measles-containing vaccine among children	Humanitarian (public health) service coverage	2017 to 2018	World Health Organization, Somalia	Based on programmatic data (administrative coverage). Age range unclear. Unpublished data.

Predictor	Variable(s)	Domain	Time span of availability	Source(s)	Notes and assumptions
Food security humanitarian services†	Proportion of the population that are a beneficiary of any food security service	Humanitarian (public health) service coverage	Jan 2013 to Apr 2018	Food Security Cluster, Somalia	Unpublished data.
	Proportion of the population that are a beneficiary of cash-based food security services	Humanitarian (public health) service coverage			
	Proportion of the population that are a beneficiary of food distributions	Humanitarian (public health) service coverage			
Quality of SAM treatment	Proportion of SAM admissions that exit the treatment programme cured	Humanitarian (public health) service quality	2011 to 2018	Nutrition Cluster, Somalia	Unpublished data.

† Divided by district population estimates to obtain a population rate.

Ethics

All data were previously collected for routine humanitarian response and/or health service provision purposes, and were either in the public domain or shared in fully anonymised format. The study was approved by the Ethics Committee of the London School of Hygiene & Tropical Medicine (ref. 15334) and the Research and the Ethics Review Committee of the Ministry of Health and Human Services, Somali Federal Republic (ref. MOH&HS/DGO/1944/Dec/2018).

Table 2. Most likely, worst-case and best-case counterfactual scenarios.

Variable	Most likely scenario	Worst-case scenario	Best-case scenario
Predictors			
SAM admissions rate	Month-specific median of 2014-2016 values within each stratum	Month-specific 75th percentile of 2014-2016 values within each stratum	Month-specific 25th percentile of 2014-2016 values within each stratum
Measles incidence rate	Month-specific median of 2014-2016 values within each stratum	Same as in actuality	No measles cases
Malaria incidence rate	Month-specific median of 2014-2016 values within each stratum	25% of actuality†	Same as in actuality†
Armed conflict event rate	Median of 2014-2016 values within each stratum	Same as in actuality	25% of actuality
Population			
Internal displacement flows	No displacement due to drought	Same as in actuality	No new displacement
Refugee flows	Same as in actuality	Same as in actuality	Same as in actuality

† As higher malaria incidence predicted lower mortality, we assumed a low incidence of malaria for the worst-case scenario, and vice versa. See Discussion.

Results

Mortality survey availability

We had access to 201 surveys that estimated retrospective mortality in Somalia between 2013 and 2018 inclusive (Figure 3). Most (175, 87.1%) were conducted by the FSNAU, and the remainder by four other agencies. A raw dataset was available for all surveys, but a detailed report only for 28 (13.9%). We excluded 104 (51.7%) of the surveys from analysis, 87 because they were designed to be representative of livelihood zones rather than districts: as population and predictor datasets were mostly stratified by district, analysing these surveys would have required additional assumptions (livelihood zones straddle multiple districts, and vice versa). Six further surveys done in 2013 were not used for modelling as predictor data coverage was insufficient during this year.

Of the 91 surveys entered into statistical models, most (n = 63) used an "individual" questionnaire; the remainder (n = 28) used the older "aggregate" questionnaire. Survey availability by district-month is shown in the Annex, Figure 8.

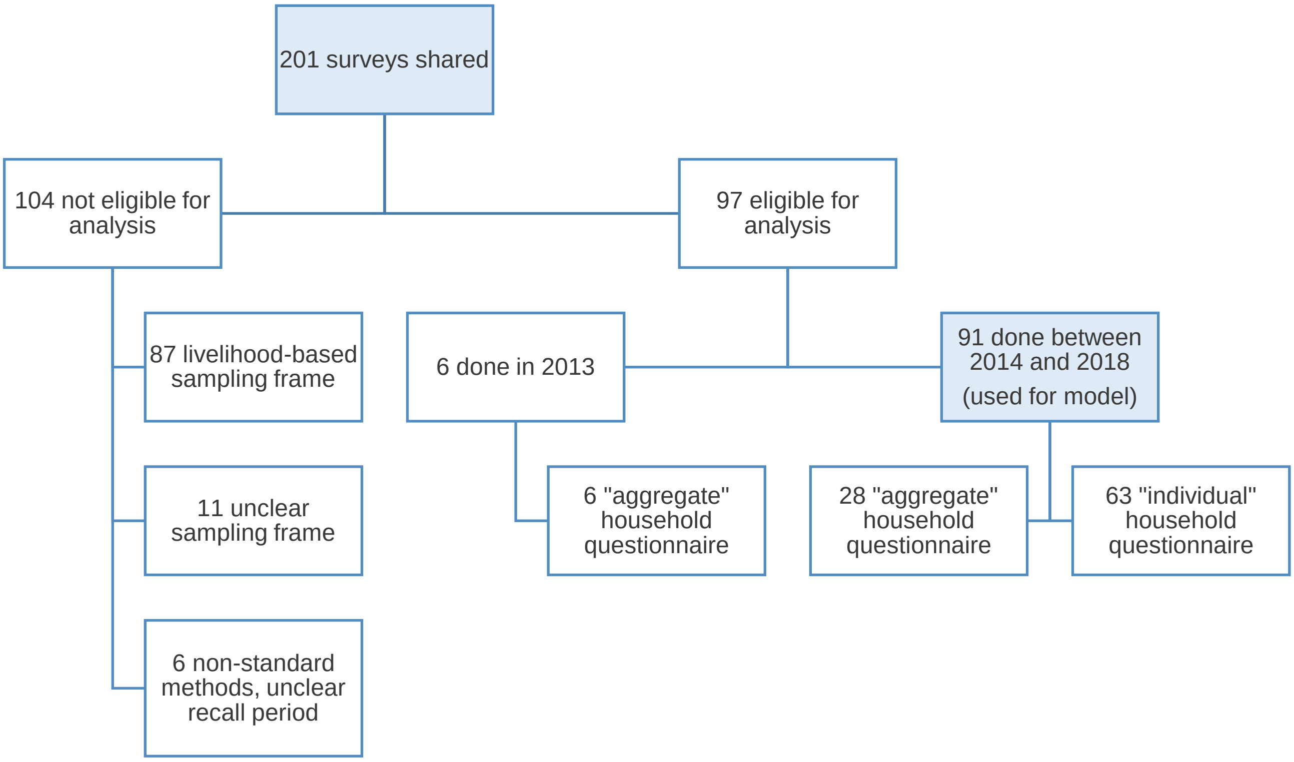

Figure 3. Schematic of mortality survey availability.

Crude survey estimates

On average, the highest death rates were estimated by surveys done in 2017 (Table 3). Eligible surveys yielded a ratio of U5DR to CDR of around 1.5, with 43% of under 5y deaths among infants; 'injury' caused some 5% of deaths on average. Net migration from households was mostly negative throughout the period, with the exception of 2017. Additional crude trends in demographic indicators over time and by region are shown in the Annex (Figure 10, Figure 11, Figure 12, Figure 13, Figure 14).

Evolution of population denominators

Between 2013 and 2018, we estimated that Somalia's population increased from 12.0 to 13.5 million (Figure 4), but with a discrepancy among sources of up to 3.5 million. Some regions (Bay, Bakool, Lower Shabelle) saw substantial declines in population, while Banadir and Lower Juba experienced a marked increase in population, reflecting internal displacement during the period (Annex, Figure 17). Overall, 2,319,000 people were reported to have become newly displaced or returned to their district of origin during 2016-2018, with reasons reported as drought (1,262,000, 54.4%), insecurity (698,000, 30.1%), flooding (291,000, 12.6%) and other (68,000, 2.9%). As a proportion of the population, this corresponds to an increase from about 8% to 20% in IDPs and returnees (Annex, Figure 18), with marked regional differences (Annex, Figure 19). We estimated that net refugee migration was 144,000 during the analysis period.

Table 3. Crude summary statistics for eligible mortality surveys, overall and by year.

Statistic†	Overall	Year					
		2013	2014	2015	2016	2017	2018
Eligible surveys (N)	97	6	9	8	24	6	44
Crude death rate (per 10,000 person-days)	0.43 (0.00 to 1.61, 97)	0.57 (0.11 to 1.61, 6)	0.46 (0.14 to 0.84, 9)	0.40 (0.14 to 0.63, 8)	0.25 (0.00 to 0.6, 24)	0.59 (0.13 to 0.68, 6)	0.51 (0.00 to 1.38, 44)
Under 5 years death rate (per 10,000 child-days)	0.66 (0.00 to 2.48, 97)	0.63 (0.37 to 1.39, 6)	0.76 (0.32 to 2.00, 9)	0.45 (0.00 to 1.32, 8)	0.37 (0.00 to 1.21, 24)	0.76 (0.33 to 1.44, 6)	0.72 (0.00 to 2.48, 44)
Proportion of under 5y deaths that were among infants <1y	0.43 (0.00 to 1.00, 59)	no data	no data	no data	0.5 (0.00 to 1.00, 10)	0.25 (0.00 to 0.33, 6)	0.5 (0.00 to 1.00, 43)
Household size	5.6 (4.1 to 6.8, 97)	5.7 (4.7 to 5.9, 6)	5.8 (5.0 to 6.1, 9)	5.9 (5.5 to 6.2, 8)	5.5 (4.7 to 6.5, 24)	4.9 (4.5 to 5.6, 6)	5.6 (4.1 to 6.8, 44)
Proportion of children aged under 5y	0.25 (0.19 to 0.42, 97)	0.24 (0.22 to 0.26, 6)	0.26 (0.21 to 0.30, 9)	0.23 (0.22 to 0.29, 8)	0.26 (0.20 to 0.34, 24)	0.29 (0.21 to 0.35, 6)	0.25 (0.19 to 0.42, 44)
Proportion of females in household	0.51 (0.48 to 0.54, 63)	no data	no data	no data	0.51 (0.49 to 0.52, 13)	0.51 (0.51 to 0.52, 6)	0.51 (0.48 to 0.54, 44)
Crude birth rate (per 1000 person-years)	36.4 (0.0 to 111.6, 97)	49.1 (26.8 to 78.4, 6)	39.2 (6.4 to 91.9, 9)	30.5 (15.0 to 60.8, 8)	28.2 (0.0 to 111.6, 24)	37.9 (18.4 to 56.5, 6)	35.8 (0.0 to 89.9, 44)
Net migration rate (per 1000 person-years)	-40.0 (-369.9 to 139.0, 97)	-25.9 (-73.3 to -18.8, 6)	-37.8 (-69.5 to 122.5, 9)	-29.2 (-62.4 to 99.7, 8)	-29.3 (-172.9 to 72.5, 24)	40.3 (9.8 to 83.1, 6)	-63.3 (-369.9 to 139.0, 44)
Injury-specific death rate (per 10,000 person-days)	0.05 (0.00 to 0.41, 54)	no data	no data	no data	0.04 (0.00 to 0.27, 12)	0.03 (0.00 to 0.07, 3)	0.07 (0.00 to 0.41, 39)

† Values in cells are median (range, number of surveys with information).

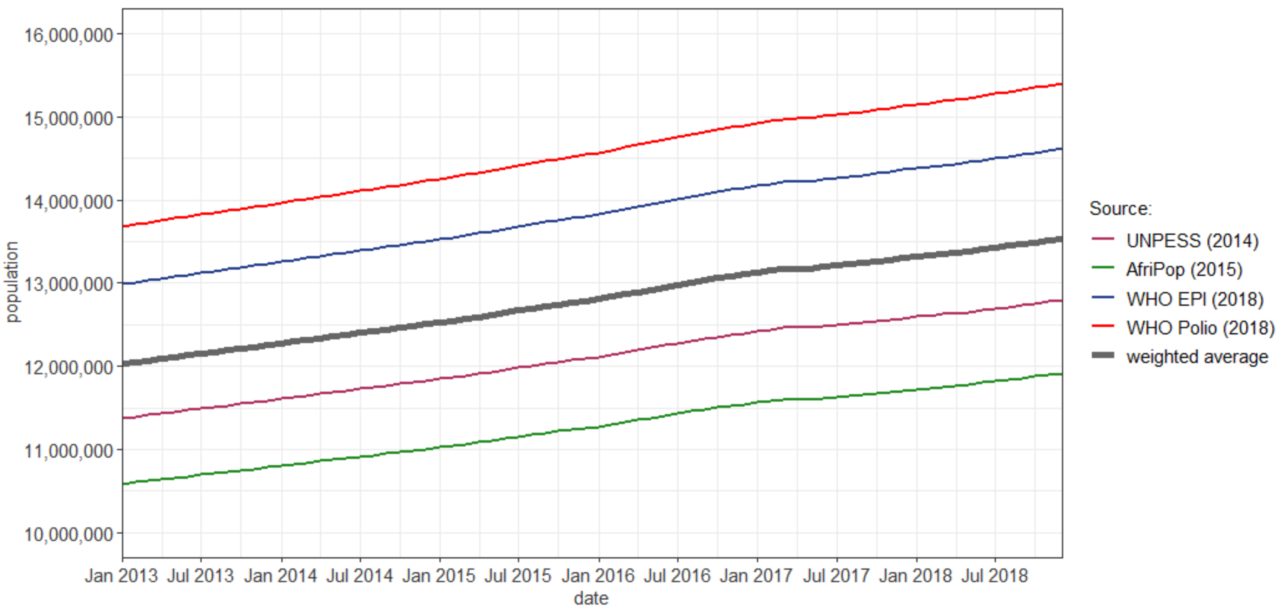

Figure 4. Evolution of total estimated population, by source.

Predictive model

Table 4 shows the selected predictive models for both CDR and U5DR (for the latter, the same model specification as for CDR was selected; while other models with strong fit were available, we considered it advantageous for interpretation that the CDR and U5DR estimates arise from the same statistical process). In both models, death rate increased with incidence of armed conflict, the rate of SAM admissions and with non-zero measles incidence, but decreased as the facility-based incidence of malaria increased (see Discussion). Both models featured comparable fit on the training dataset, on 10-fold cross-validation, and on the holdout dataset (see Annex, Figure 20 and Figure 21).

Table 4. Predictive models for crude and under 5 years death rate.

Predictor	Crude death rate			Under 5 years death rate		
	Rate ratio	95% CI†	p-value	Rate ratio	95% CI†	p-value
Administrative level						
Somaliland - Puntland	1.00 [ref.]			1.00 [ref.]		
South-Central Somalia	0.97	0.77 to 1.24	0.833	1.54	1.08 to 2.20	0.016
Incidence of armed conflict events (events per 100,000 person-months)						
< 0.25	1.00 [ref.]			1.00 [ref.]		
0.25 to 0.49	1.00	0.81 to 1.23	0.985	1.26	0.94 to 1.69	0.119
≥ 0.50	1.60	1.30 to 1.98	<0.001	1.44	1.08 to 1.92	0.013
Rate of admissions of cases of SAM into nutritional therapy (per 100,000 person-months) - lag: 2 months						
< 100	1.00 [ref.]			1.00 [ref.]		
0.25 to 0.49	1.36	1.09 to 1.69	0.007	1.10	0.79 to 1.54	0.571
≥ 0.50	1.48	1.12 to 1.97	0.007	1.24	0.83to 1.85	0.284
Health facility-based incidence rate of malaria (cases per 100,000 person-months)						
0	1.00 [ref.]			1.00 [ref.]		
1 to 49	0.78	0.59 to 1.04	0.087	0.74	0.48 to 1.13	0.165
≥ 50	0.71	0.54 to 0.94	0.017	0.55	0.37 to 0.83	0.004
Incidence rate of measles (reported cases per 100,000 person-months)						
0	1.00 [ref.]			1.00 [ref.]		
> 0	1.27	0.99 to 1.62	0.056	1.37	0.94 to 2.00	0.100

† 95% confidence intervals (based on robust standard errors adjusted for survey intra-cluster correlation).

Estimates of mortality

In the most likely counterfactual scenario, the excess death toll between Jan 2017 and Dec 2018 across Somalia was estimated at 44,700 people, out of some 454,500 total deaths in actuality (Table 5). A considerably lower excess was estimated for children under 5y, amounting to about 21% of the all-age excess death toll. However, under a pessimistic scenario the death toll rose to as many as 163,800 (and 61,400 children under 5y). The 2017 excess death toll was about double that in 2018.

Table 5. Total and crisis-attributable deaths, by year and counterfactual scenario.

Period	Total deaths (95%CI)	Excess deaths (95%CI), by counterfactual scenario		
		Most likely	Pessimistic (low counterfactual)	Optimistic (high counterfactual)
All ages				
2017	226,900 (166,500 to 313,100)	29,600 (24,500 to 35,600)	84,700 (69,400 to 101,400)	16,300 (11,900 to 22,800)
2018	227,500 (167,600 to 311,200)	15,100 (13,100 to 16,500)	79,100 (66,800 to 90,700)	3100 (1100 to 5500)
Overall	454,500 (334,100 to 624,400)	44,700 (37,600 to 52,000)	163,800 (136,300 to 192,100)	19,400 (12,900 to 28,300)
Children under 5 years				
2017	93,800 (65,300 to 136,000)	6100 (5500 to 6400)	30,800 (26,600 to 32,400)	1100 (800 to 1400)
2018	92,700 (63,800 to 136,100)	3200 (2600 to 3900)	30,600 (26,400 to 31,500)	-1400 (-1600 to -1300)
Overall	186,500 (129,000 to 272,100)	9300 (8100 to 10,300)	61,400 (53,100 to 63,900)	-400 (-400 to 100)

When aggregated by region (Table 6), the estimated death rates per 10,000 person-days in actuality varied from 0.33 in Woqooyi Galbeed to 0.60 in Gedo (CDR), and from 0.42 in Awdal to 1.02 in Hiraan (U5DR), with a markedly lower ratio of U5DR to CDR in the North-East and North-West. The highest excess death rates for all ages were observed in the North-East and in Hiraan, while among children under 5y South-Central Somalia had the highest excess mortality estimates. Estimates by district are shown in the Annex (Table 8, Figure 15, Figure 16).

Table 6. Crude death rate, excess death rate and excess death toll by region, under the most likely counterfactual scenario, for all ages and children under 5 years.

Region	All ages			Children under 5 years		
	Crude death rate† (95%CI)	Excess death rate† (95%CI)	Excess deaths (95%CI)	Under 5y death rate† (95%CI)	Excess under 5y death rate† (95%CI)	Excess deaths under 5y (95%CI)
South-Central Somalia						
Bakool	0.41 (0.26 to 0.66)	0.06 (0.05 to 0.06)	1700 (1400 to 1800)	0.87 (0.62 to 1.24)	0.08 (-0.01 to 0.11)	600 (-100 to 800)
Banadir	0.50 (0.41 to 0.61)	0.01 (-0.02 to 0.03)	1200 (-3700 to 4200)	0.80 (0.61 to 1.07)	0.02 (0.02 to 0.03)	900 (800 to 1200)
Bay	0.47 (0.36 to 0.63)	0.01 (-0.01 to 0.02)	700 (-400 to 1200)	0.82 (0.59 to 1.16)	0.00 (-0.02 to 0.01)	0 (-400 to 100)
Galgaduud	0.47 (0.34 to 0.68)	0.04 (0.03 to 0.05)	1700 (1400 to 1800)	0.80 (0.55 to 1.17)	0.03 (-0.01 to 0.05)	300 (-100 to 500)
Gedo	0.60 (0.46 to 0.79)	0.06 (0.05 to 0.06)	2600 (2300 to 2600)	0.98 (0.70 to 1.38)	0.10 (0.07 to 0.11)	1100 (700 to 1100)
Hiraan	0.49 (0.37 to 0.67)	0.11 (0.09 to 0.14)	4300 (3700 to 5300)	1.02 (0.71 to 1.49)	0.22 (0.18 to 0.26)	2200 (1700 to 2500)
Lower Juba	0.53 (0.39 to 0.72)	0.03 (0.02 to 0.03)	1600 (1000 to 1700)	0.98 (0.67 to 1.46)	0.19 (0.16 to 0.23)	2400 (2000 to 2900)
Lower Shabelle	0.36 (0.25 to 0.53)	0.03 (0.00 to 0.03)	2900 (500 to 3500)	0.85 (0.59 to 1.23)	-0.03 (-0.11 to 0.01)	-900 (-3000 to 200)
Middle Juba	0.39 (0.25 to 0.60)	0.05 (0.04 to 0.07)	1500 (1100 to 2000)	0.92 (0.60 to 1.41)	0.15 (0.10 to 0.22)	1100 (700 to 1600)
Middle Shabelle	0.37 (0.27 to 0.52)	0.04 (0.04 to 0.04)	1800 (1700 to 1800)	0.85 (0.59 to 1.23)	0.01 (-0.05 to 0.04)	200 (-600 to 500)
North-east (Puntland)						
Bari	0.45 (0.34 to 0.59)	0.11 (0.09 to 0.14)	7300 (5800 to 8900)	0.50 (0.33 to 0.75)	0.05 (0.02 to 0.05)	800 (400 to 900)
Mudug	0.42 (0.28 to 0.64)	0.12 (0.08 to 0.19)	7600 (5100 to 11,600)	0.59 (0.38 to 0.92)	0.03 (0.00 to 0.09)	400 (-100 to 1400)
Nugaal	0.50 (0.34 to 0.74)	0.08 (0.04 to 0.16)	2300 (1000 to 4200)	0.65 (0.41 to 1.03)	0.07 (0.02 to 0.19)	500 (100 to 1300)
North-west (Somaliland)						
Awdal	0.35 (0.25 to 0.50)	-0.02 (-0.03 to 0.00)	-1200 (-1800 to -200)	0.42 (0.26 to 0.68)	-0.03 (-0.04 to 0.00)	-500 (-600 to 0)
Sanaag	0.47 (0.33 to 0.66)	0.07 (0.04 to 0.13)	2800 (1500 to 5000)	0.56 (0.36 to 0.88)	0.05 (0.01 to 0.12)	400 (100 to 1200)
Sool	0.49 (0.36 to 0.68)	0.06 (0.03 to 0.10)	1600 (800 to 2800)	0.60 (0.40 to 0.89)	-0.01 (-0.01 to 0.00)	-100 (-100 to 0)
Togdheer	0.45 (0.35 to 0.59)	0.05 (0.03 to 0.08)	2500 (1500 to 4100)	0.53 (0.35 to 0.80)	0.00 (-0.02 to 0.03)	0 (-200 to 400)
Woqooyi Galbeed	0.33 (0.24 to 0.45)	0.02 (0.01 to 0.04)	1900 (900 to 3800)	0.46 (0.30 to 0.71)	0.00 (-0.01 to 0.03)	0 (-300 to 800)
Overall	0.43 (0.32 to 0.60)	0.04 (0.04 to 0.05)	44,700 (37,600 to 52,000)	0.72 (0.50 to 1.05)	0.04 (0.03 to 0.04)	9300 (8100 to 10,300)

† per 10,000 person-days for CDR, and children under 5y-days for U5DR.

During 2014-2018, CDR across Somalia remained within a limited range, but an appreciable elevation (up to 0.09 per 10,000 person-days higher than the most likely counterfactual) was estimated from early 2017 to mid-2018, coinciding with the food security crisis period (Figure 5). The pattern was similar for U5DR, but with a less marked elevation in 2017-2018 (Figure 6).

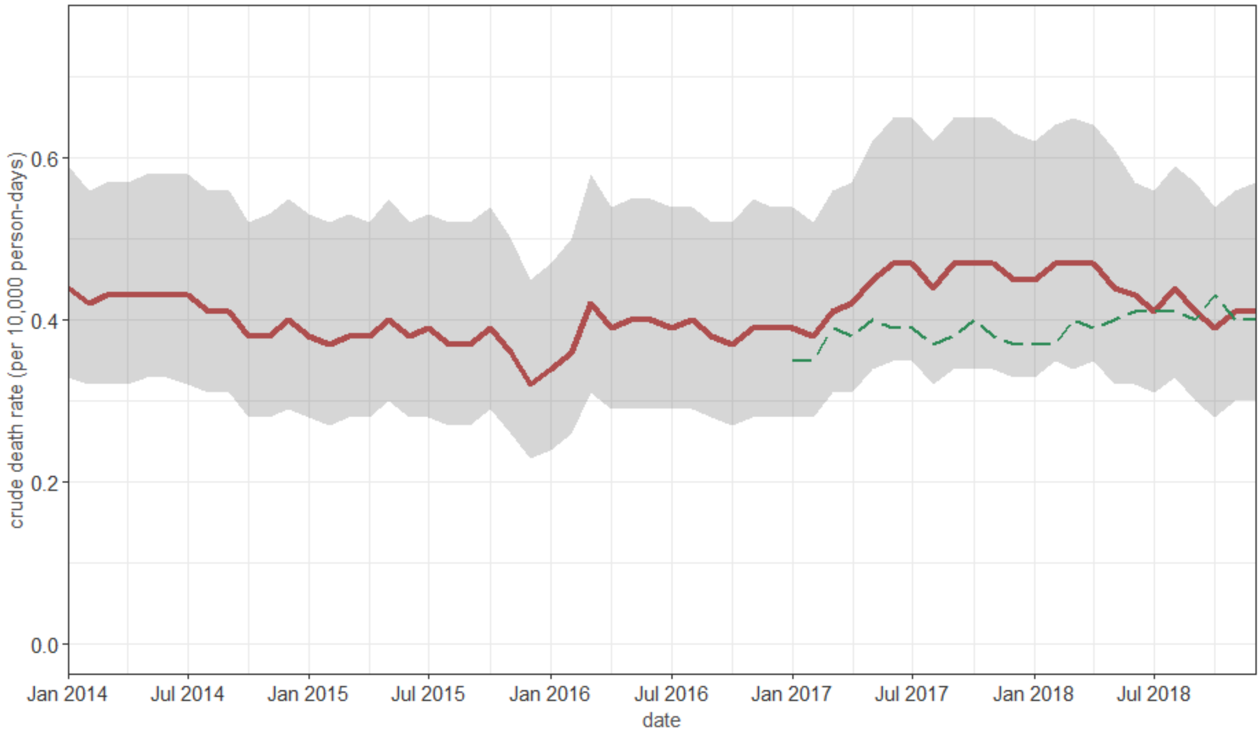

Figure 5. Trends in the estimated actual (point estimate: red line, 95%CI: grey range) and counterfactual (dashed green line) crude death rate.

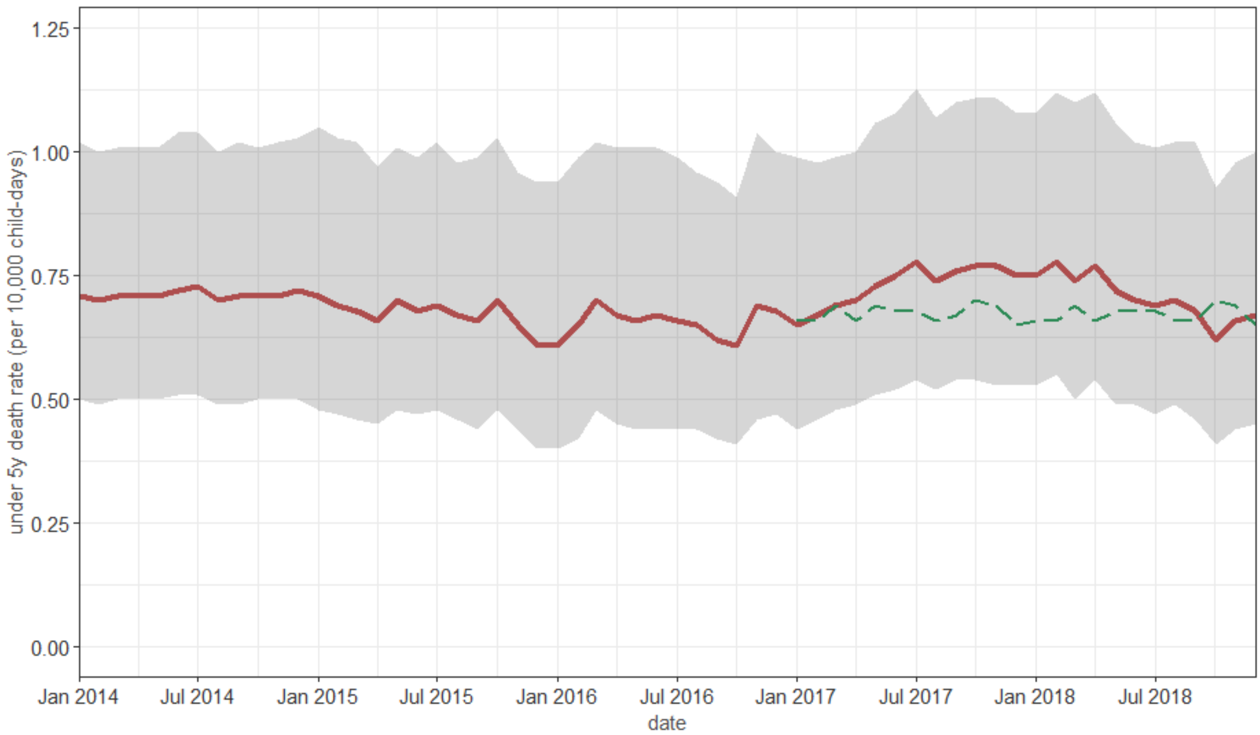

Figure 6. Trends in the estimated actual (point estimate: red line, 95%CI: grey range) and counterfactual (dashed green line) under 5 years death rate.

Discussion

Findings in context

To our knowledge this is the first comprehensive analysis of mortality patterns in Somalia since 2014 and in particular death tolls attributable to the food security crisis of 2017-2018. It follows on from a similar study[1] covering the period October 2010 to April 2012, when a very severe crisis, featuring large pockets of famine, swept through the country.[24] Despite some methodological and data source differences with the 2010-2012 study, the present analysis suggests that the 2017-2018 crisis had a lower mortality impact (about 45,000 excess deaths, compared to 258,000 in 2010-2012, when CDR across South-Central Somalia peaked at some three times the baseline).

Nevertheless, excess mortality estimates for 2017-2018 remain staggering, indicating considerable unmet needs in the response to this latest crisis. This large death toll, occurring despite an increase in CDR of 'only' about 15%, reflects a much larger population at risk than in 2010, due to demographic growth and more geographically widespread drought conditions: in 2010-2012, mortality was concentrated in Bay, Lower and Middle Shabelle and Banadir regions, but in 2017-2018 Central and North-East Somalia (Puntland) also seemed heavily affected.

By contrast to 2010-2012, we found no consistent association of terms of trade (purchasing power) with mortality (data not shown). The 2010-2012 study suggested that mortality increased steeply below the 10,000 Kcal cereal per daily wage threshold. As shown in the Annex (Figure 22), this threshold was crossed in most regions both in 2008 and in 2010-2011, while in 2017 terms of trade varied little or remained above 20,000 Kcal cereal per daily wage. Despite this, the unusual levels of rainfall, displacement and nutritional therapy admissions in 2017-2018, along with country-wide measles and cholera epidemics, suggest that a substantial crisis did occur in Somalia during this period. Broadly, our regional estimates of the excess death rate do correlate reasonably with the forecast severity of the crisis as of early 2017, as summarised by the proportion of people projected to be in phases 3 (crisis) or 4 (emergency) of the Integrated Phase Classification system (Figure 7). We plan further analyses to explore reasons for displacement and the causal relationships among drought, food insecurity and outcomes upstream of mortality, including prevalence of acute malnutrition and epidemic incidence, so as to better understand the dynamics of this latest crisis, and the role of food security versus other drivers. Notably, large-scale displacement in this recent drought has been linked to a 'pull' factor from urban centres offering humanitarian assistance, and the widespread sale of land by impoverished farmers in south-central Somalia.[25]

Study validity

Key study limitations are discussed below and their overall effect summarised in Table 7. The validity of the predictive model is central to the estimates' robustness. Cross-validation and the accuracy of prediction on holdout samples support external validity, with little evidence of systematic bias. Internal validity is suggested by the plausible associations in the final models, namely evidence (albeit with weak significance) of higher mortality as a function of armed conflict intensity, admissions for malnutrition and occurrence of measles. Less interpretably, mortality was associated with increasing malaria incidence in health facilities: this may reflect either levels of drought (lower rainfall could have led to decreased mosquito breeding and thus malaria transmission) or better access to health services if malaria caseload was a proxy for outpatient service utilisation.

A possible source of bias (albeit with unclear directionality) is inaccuracy in the source demographic estimates. We attempted to mitigate this by averaging the four available estimates based on their assumed robustness. However, the observed discrepancy among estimates suggests considerable uncertainty, particularly when considering estimates at the regional and district scale. Moreover, our redistribution of population among districts based on internal displacement movements rests on the accuracy of PRMN reports, which are not based on statistically representative estimation methods, but rather ground informants. Though the PRMN project captures both departures and returns, it is plausible that the latter flows would be less systematically reported.

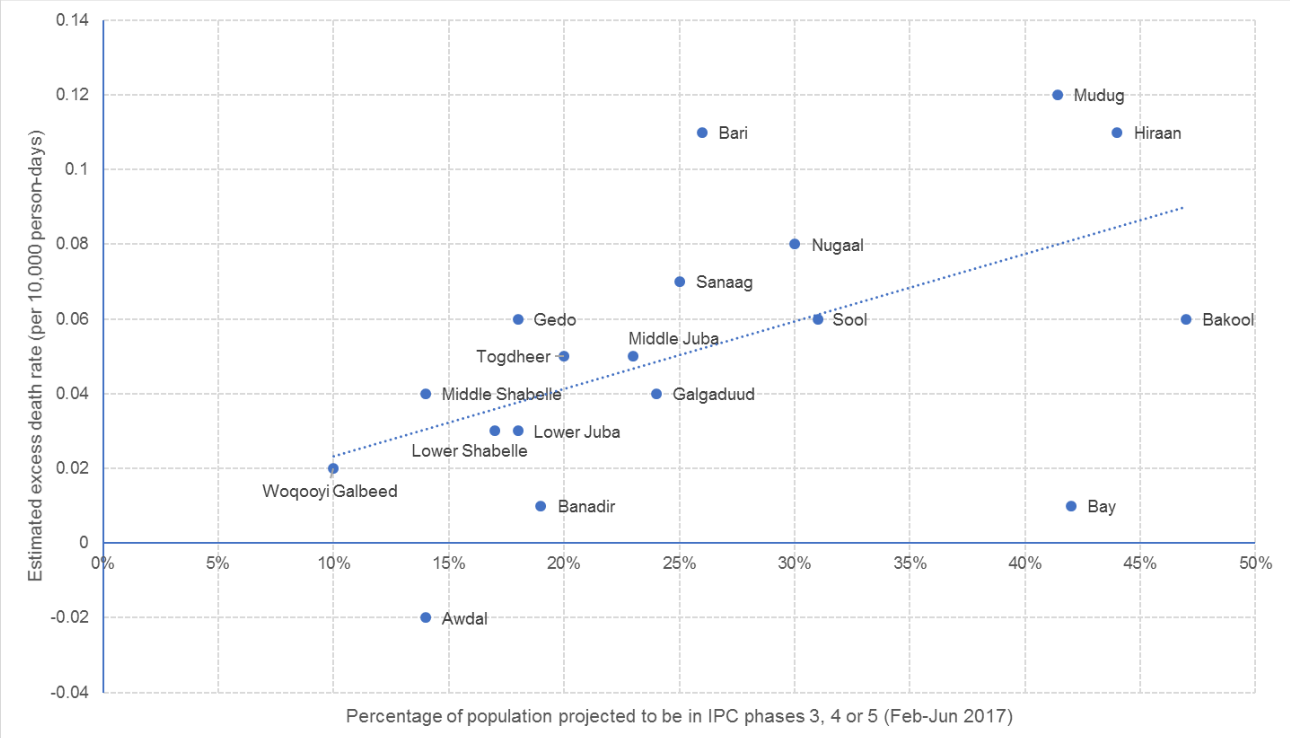

Figure 7. Correlation between Integrated Phase Classification projections (early 2017) and estimated excess death rate (2017-2018), by region.

We estimated a relatively low excess mortality among children under 5y, compared to among all ages: by comparison, about half of excess deaths in 2010-2012 were in this age group, and meta-analyses of SMART surveys have generally found the U5DR to CDR ratio to be around two, rather than 1.5 in this study.[26,27] A similar analysis in South Sudan[17] suggested that deaths among infants had been substantially underestimated by SMART surveys, possibly due to stigma associated with child deaths or faulty administration of the mortality questionnaire. It is possible that surveys included in this analysis were also subject to some underestimation in neonatal and infant events, as suggested by a lower crude birth rate (36 versus 43 per 1000 person-years) and proportion of infants among under 5y deaths (43% versus 60%) than estimated by demographic models for Somalia.[12]

Table 7. Assessment of strength of evidence of the estimates.

Direction of bias	Details
Known or suspected reasons for underestimation	Under-reporting of child deaths, particularly among neonates and infants Selection bias due to exclusion of insecure or inaccessible areas of a district from the survey's sampling frame (information on this was very scant, as survey reports were mostly not available to us) Exclusion of refugees in Somalia and Somali refugees abroad from the analysis
Known or suspected reasons for overestimation	[none]
Other possible biases with unclear directionality	Inaccuracy in demographic estimates Reduction in birth rate and increase in mortality during the crisis period, leading to lower rate of population growth and thus overestimation of population Inaccuracy in reported internal displacement figures, particularly for returnees to districts of origin Faulty assumptions about the counterfactual baseline
Likely overall extent and direction of bias	Mild-moderate underestimation in the actual and counterfactual mortality estimates; see Sensitivity analysis below for overall effect on excess mortality estimates

To explore sensitivity of our estimates to key potential sources of error, we (i) assumed different levels of bias in source demographic estimates and reported displacement movements, and (ii) varying proportions of under-reporting among deaths under 5y (see methods paper for detail). Generally, excess mortality estimates appeared relatively insensitive to bias in displacement figures, but decreased substantially as bias in demographic estimates (either over- or underestimation) increased (Annex, Figure 23). As assumed under-estimation in U5DR rose from 0% to 50%, a doubling in the excess death toll under 5y was projected, but all-age death tolls increased only moderately (Annex, Figure 24).

Conclusions

This study finds evidence of elevated mortality during a drought-triggered crisis in Somalia over 2017-2018, despite a lesser effect on food security than in previous similar events, and a more proactive and far-reaching humanitarian response.[28] Our findings indicate that even at moderate levels of population stress (for example, IPC phase 3), excess mortality accrues. Therefore, even if the sole aim of humanitarian actors is to support survival, a response needs to be implemented to scale very early in the curve of deterioration in food security and other upstream crisis indicators. While our analysis does not have granularity below district level, we speculate that mortality risk is likely to be clustered within particularly vulnerable communities and households: more specific targeting of limited resources to support these communities and individuals would probably increase the cost-effectiveness and efficiency of humanitarian responses.

Somalia and other fragile regions of the world appear to face an increased threat of drought. Understanding the mortality impact of these events can support rational resource allocation and benchmark the adequacy of humanitarian responses. As such, mortality analyses such as ours should arguably become a systematic component of monitoring and evaluation in drought-triggered crises. It is also critical that the narrative of Somalia's crisis not lose sight of human security as a key driver of mortality, as shown in our model. Armed conflict and the securitisation of much of Somalia exacerbate the severity of drought and underlie the chronic vulnerability of Somali people to unfavourable climate: the restoration of peace and governance to all of Somalia holds perhaps the greatest potential for attenuating the impact of droughts and other natural disasters on its population.

References

1. Food and Agriculture Organisation, Famine Early Warning Systems Network. Mortality among populations of southern and central Somalia affected by severe food insecurity and famine during 2010-2012. Rome and Washington, DC: FAO and FEWS NET, 2013. http://www.fsnau.org/downloads/Somalia_Mortality_Estimates_Final_Report_8May2013_upload.pdf, accessed 28 May 2018
2. Food Security and Nutrition Analysis Unit - Somalia, Famine Early Warning Systems Network. Technical release: Over one million people in Somalia face acute food insecurity as food crisis worsens. Nairobi: FSNAU, 2014.http://www.fsnau.org/downloads/FSNAU-FEWSNET-Technical-Release-August-2014.pdf (accessed 25 January 2020).
3. Food Security and Nutrition Analysis Unit - Somalia. Somalia Food Security & Nutrition Analysis Post Deyr 2015/16 Technical Series Report No VII. 64. Nairobi: FSNAU, 2016.http://www.fsnau.org/downloads/FSNAU-Post-Deyr-2015-16-Food-Security-and-Nutrition-Analysis-Technical-Report.pdf (accessed 25 January 2020).
4. United Nations Office for the Coordination of Humanitarian Affairs. Somalia: Humanitarian Response Plan Revision - May 2017. Mogadishu: UN OCHA, 2017.https://www.humanitarianresponse.info/en/operations/somalia/document/somalia-humanitarian-response-plan-revision-may-2017 (accessed 25 January 2020).
5. Seal A, Checchi F, Balfour N, Nur AH, Jelle M. A weak health response is increasing the risk of excess mortality as food crisis worsens in Somalia. *Confl Health* 2017; **11**: 12.
6. Salama P, Spiegel P, Talley L, Waldman R. Lessons learned from complex emergencies over past decade. *Lancet* 2004; **364**(9447): 1801-13.
7. Checchi F, Roberts L. Documenting mortality in crises: what keeps us from doing better. *PLoS Med* 2008; **5**(7): e146.
8. Rao JNK, Molina I. Small area estimation. 2nd ed. Hoboken, NJ: John Wiley & Sons, Inc.; 2015.

9. Standardised Monitoring and Assessment of Relief and Transitions (SMART). Measuring Mortality, Nutritional Status, and Food Security in Crisis Situations: SMART Methodology. SMART Manual Version 2, 2017.https://smartmethodology.org/survey-planning-tools/smart-methodology/ (accessed 4 May 2019).
10. Cairns KL, Woodruff BA, Myatt M, Bartlett L, Goldberg H, Roberts L. Cross-sectional survey methods to assess retrospectively mortality in humanitarian emergencies. *Disasters* 2009; **33**(4): 503-21.
11. Checchi F. Estimation of population mortality in crisis-affected populations: Guidance for humanitarian coordination mechanisms. Geneva: World Health Organization, 2018.https://www.who.int/health-cluster/resources/publications/LSHTM-Mortality-Estimation-Options-oct2018.pdf (accessed 19 February 2019).
12. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. World Population Prospects: The 2019 Revision. New York: UN; 2019.https://population.un.org/wpp/DataQuery/
13. United Nations Population Fund. Composition and Demographic Characteristics of the Somali People. Nairobi: UNFPA, 2016.http://www.dns.org.so/docs/Analytical_Report_Volume_2.pdf (accessed 20 Jan 2020).
14. Linard C, Alegana VA, Noor AM, Snow RW, Tatem AJ. A high resolution spatial population database of Somalia for disease risk mapping. *Int J Health Geogr* 2010; **9**: 45.
15. United Nations High Commissioner for Refugees. UNHCR Somalia Protection & Return Monitoring Network (PRMN): Notes on methodology. Nairobi: UNHCR, 2017.https://reliefweb.int/sites/reliefweb.int/files/resources/PRMN-MethodologyNotesv1.0.pdf (accessed 20 Jan 2020).
16. Checchi F, Warsame A, Treacy-Wong V, Polonsky J, van Ommeren M, Prudhon C. Public health information in crisis-affected populations: a review of methods and their use for advocacy and action. *Lancet* 2017; **390**(10109): 2297-313.
17. Checchi F, Testa A, Warsame A, Quach L, Burns R. Estimates of crisis-attributable mortality in South Sudan, December 2013-April 2018: A statistical analysis. London: London School of Hygiene and Tropical Medicine,, 2018.https://crises.lshtm.ac.uk/2018/09/25/south-sudan/ (accessed 22 October 2018).
18. Desert Research Institute and University of Idaho. Climate Engine. 2019.http://climateengine.org
19. Huntington JL, Hegewisch KC, Daudert B, et al. Climate Engine: Cloud Computing and Visualization of Climate and Remote Sensing Data for Advanced Natural Resource Monitoring and Process Understanding. *Bulletin of the American Meteorological Society* 2017; **98**(11): 2397-410.
20. Food Security and Nutrition Analysis Unit - Somalia. Early Warning - Early Action Dashboard. Nairobi; 2019.https://dashboard.fsnau.org/
21. Raleigh C, Linke A, Hegre H, Karlsen J. Introducing ACLED-Armed Conflict Location and Event Data. *Journal of Peace Research* 2010; **47**(5): 1-10.
22. Humanitarian Outcomes. Aid Worker Security Database. 2019.https://aidworkersecurity.org/
23. Food Security and Nutrition Analysis Unit - Somalia. Somalia: Livelihood Zones. Nairobi: FSNAU; 2015.
24. Maxwell D, Fitzpatrick M. The 2011 Somalia famine: Context, causes, and complications. *Global Food Security* 2012; **1**(1): 5-12.
25. Jaspars S, Adan GM, Majid N. Food and power in Somalia: business as usual? A scoping study on the political economy of food following shifts in food assistance and in governance. London: London School of Economics and Political Science Conflict Research Programme, 2020.http://eprints.lse.ac.uk/103138/4/Food_and_Power_in_Somalia_business_as_usual_FINAL21Jan2020.pdf (accessed 25 January 2020).
26. Guha-Sapir D, Panhuis WG. Conflict-related mortality: an analysis of 37 datasets. *Disasters* 2004; **28**(4): 418-28.
27. Guha-Sapir D, van Panhuis WG, Degomme O, Teran V. Civil conflicts in four african countries: a five-year review of trends in nutrition and mortality. *Epidemiol Rev* 2005; **27**: 67-77.
28. DuBois M, Harvey P, Taylor G. Rapid Real-Time Review: DFID Somalia Drought Response. London: Humanitarian Outcomes, 2018.https://assets.publishing.service.gov.uk/media/5a8566e4e5274a2e87dc3e43/DFID_Somalia_2017_IRF_Real_Time_Review_FINAL.pdf (accessed 25 January 2020).

Annex

Computation of terms of trade indicators

FSNAU field researchers collect monthly data from 50 rural and 50 urban markets located throughout Somalia. We extracted price data for the following items: 1 Kg white sorghum; 1 Kg red sorghum; 1 Kg yellow maize; 1 Kg white maize; 1 Kg imported red rice; 1 Kg wheat flour; 1 goat of local quality (i.e. not for export); daily wage in the local currency. Sorghum and maize are locally produced while wheat and rice are mostly imported.

We combined the above variables to compute two terms of trade food security indicators for each district-month: (i) the Kcal equivalent of staple cereal that can be purchased by a typical daily wage, and (ii) the Kcal staple cereal equivalent of the selling price of a local quality goat. For any given market, only price items with ≥ 75% data completeness over the period 2013 to 2018 were retained in the analysis.

The equation for the terms of trade (ToT) of a typical daily wage, for a given district-month, is as follows:

$$ToT_{W,k,t} = \frac{\sum_m^{M_k} \frac{\sum_c^{C_m} \left(\frac{W_{m,t}}{I_{c,m,t}} r_c E_c\right)^2}{\sum_c^{C_m} \frac{W_{m,t}}{I_{c,m,t}} r_c E_c} U_m}{\sum_m^{M_k} U_m}$$

where k is a district, t a month, m one of the M_k markets within the district, c one of the C_m cereals with sufficient data completeness in market m, I_c is the price of 1 Kg of cereal c, $W_{m,t}$ is the average daily labour wage in market m and month t, r_c is the proportion of cereal c that is recovered after milling, E_c is the Kcal value of 1 Kg of milled cereal c and U_m is a weight equal to 3 for urban markets and 1 for rural markets.

We first computed the monthly terms of trade for each cereal-market time series by working out the Kcal equivalent of the amount of that cereal that a daily wage could purchase, based the price of 1 Kg of the cereal, the proportion lost after milling and an assumed Kcal per Kg.

Whenever more than one cereal-market time series was sufficiently complete for analysis (e.g. white sorghum, red rice), we took a weighted mean of these. In the absence of data on relative purchase quantities of different cereals, we assumed based on simple elasticity principles that, in the context of a poor harvest and high poverty levels, people would have had a strong preference for purchasing the cheapest cereal, and would have shifted their preference according to cereal prices, with a greater tendency to shift to cheaper staples, the lower the daily wage. We represented this assumed elasticity by using the ToT for each cereal itself as a weight when averaging all cereals (mathematically this is equivalent to averaging the squares of each cereal's ToT).

Lastly, if more than one market was located within the district, we calculated a weighted mean of ToT from each market, weighting urban markets three times more than rural ones.

We replicated the above calculation for the ToT of a local-quality goat, by substituting $W_{m,t}$ with $G_{m,t}$, the price of a local-quality goat.

Additional tables and figures

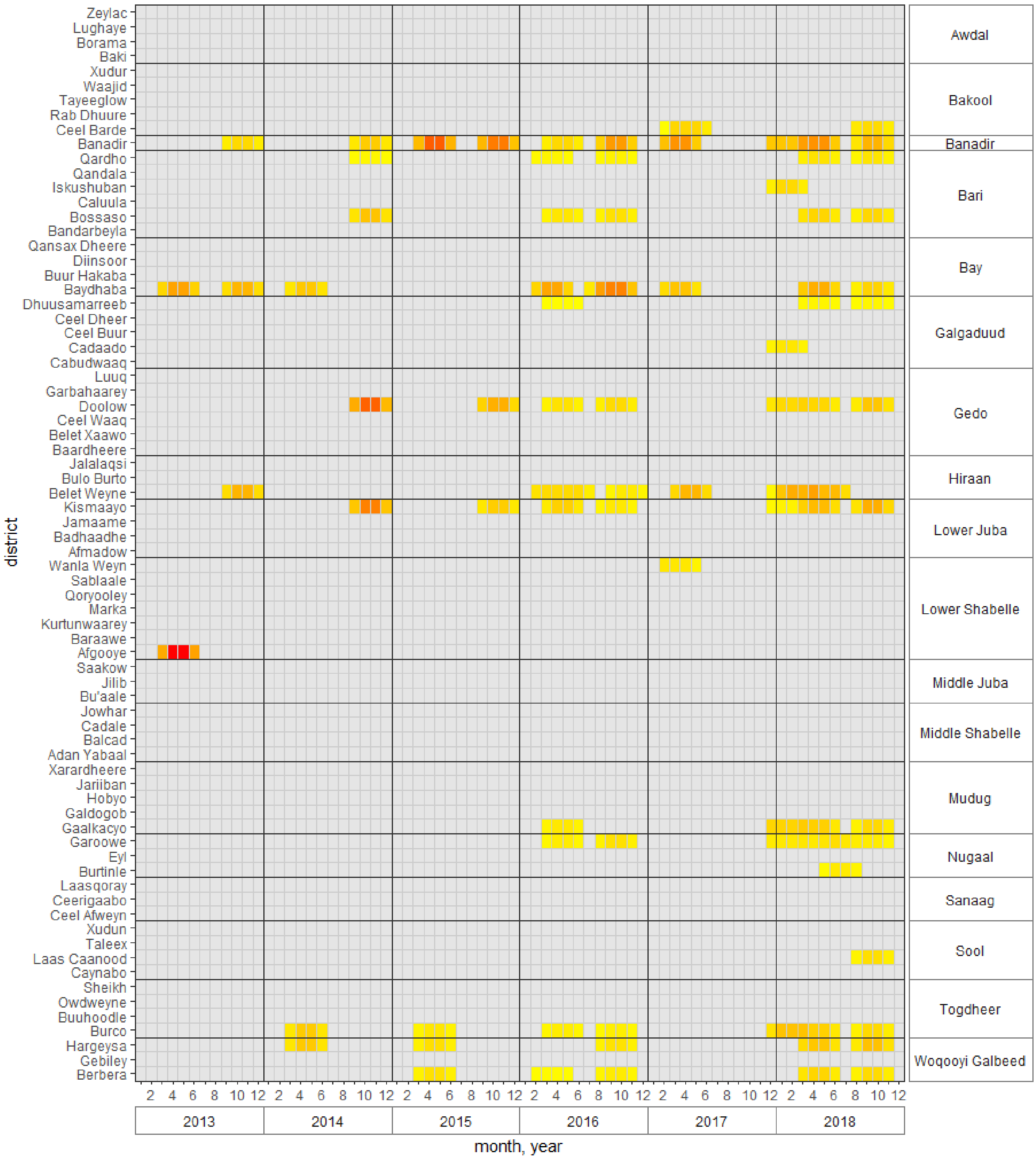

Figure 8. Schematic of survey district-month coverage.

Grey indicates that the district-month is not included in any of the surveys' sampling frame. The intensity of heat colours is proportional to a data availability index for each stratum-month, calculated as follows: (i) first, we multiplied the total person-time sampled by the survey, the survey's quality score and the proportion of the month included in the survey's recall period; (ii) if more than one survey covered the same district-month, we summed the data availability indices of all surveys concerned; (iii) lastly, we rescaled the index to $[0, 1]$ by dividing all values by their maximum.

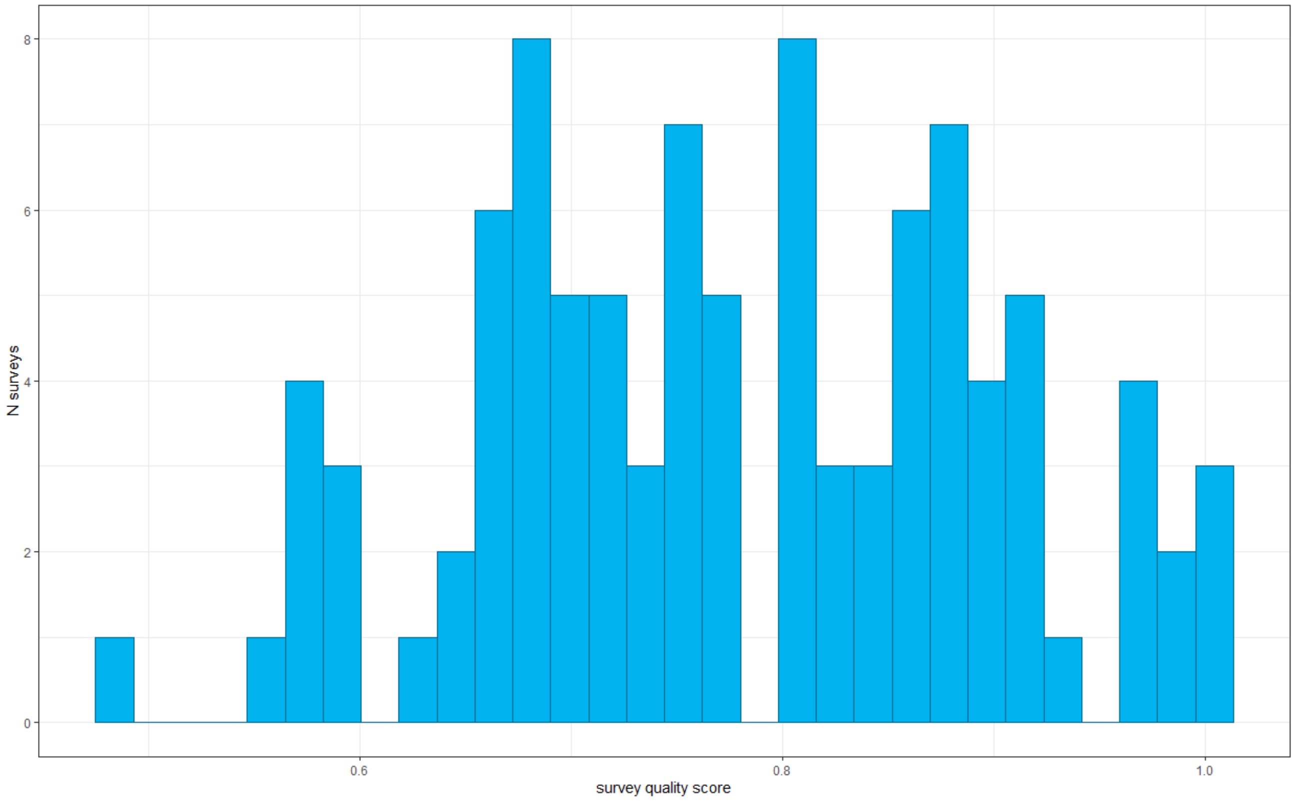

Figure 9. Frequency distribution of survey quality score.

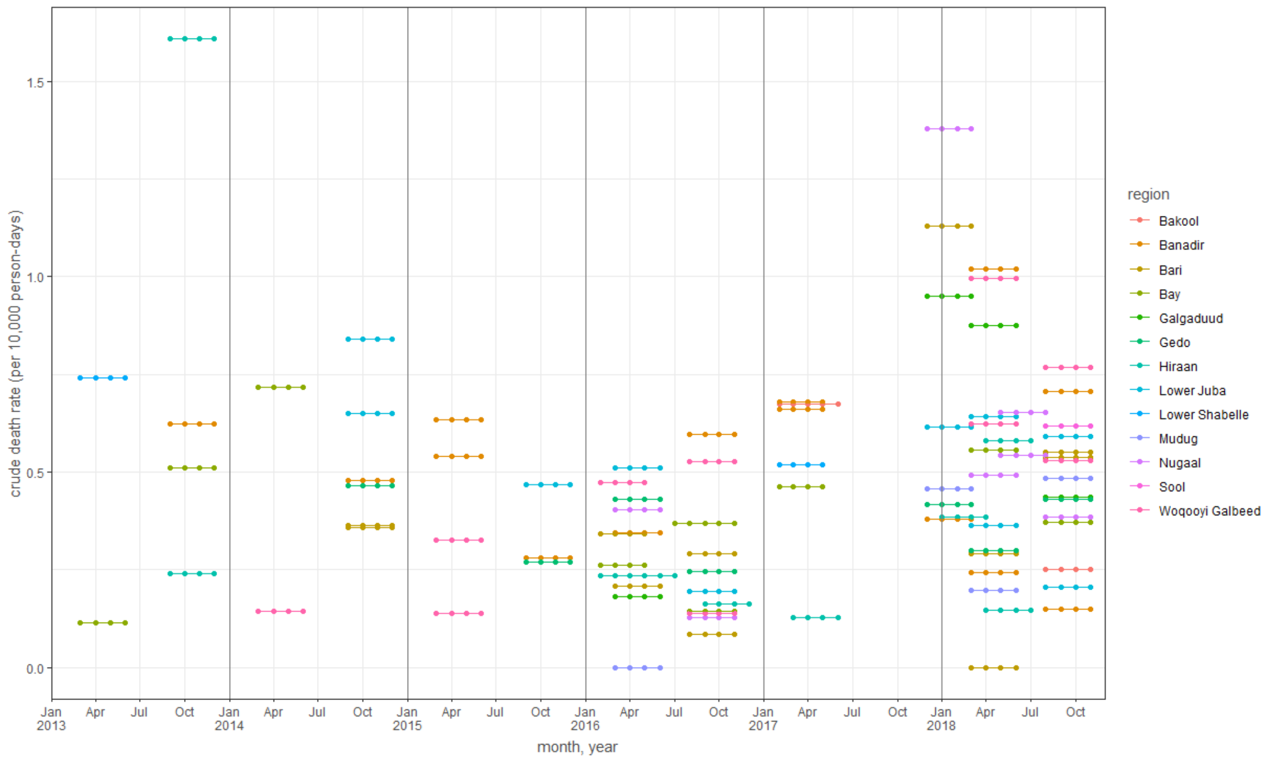

Figure 10. Crude trends in the crude death rate over the survey's recall period.

Each dotted segment represents the point estimate of a survey, with dots being the months falling within the survey's recall period.

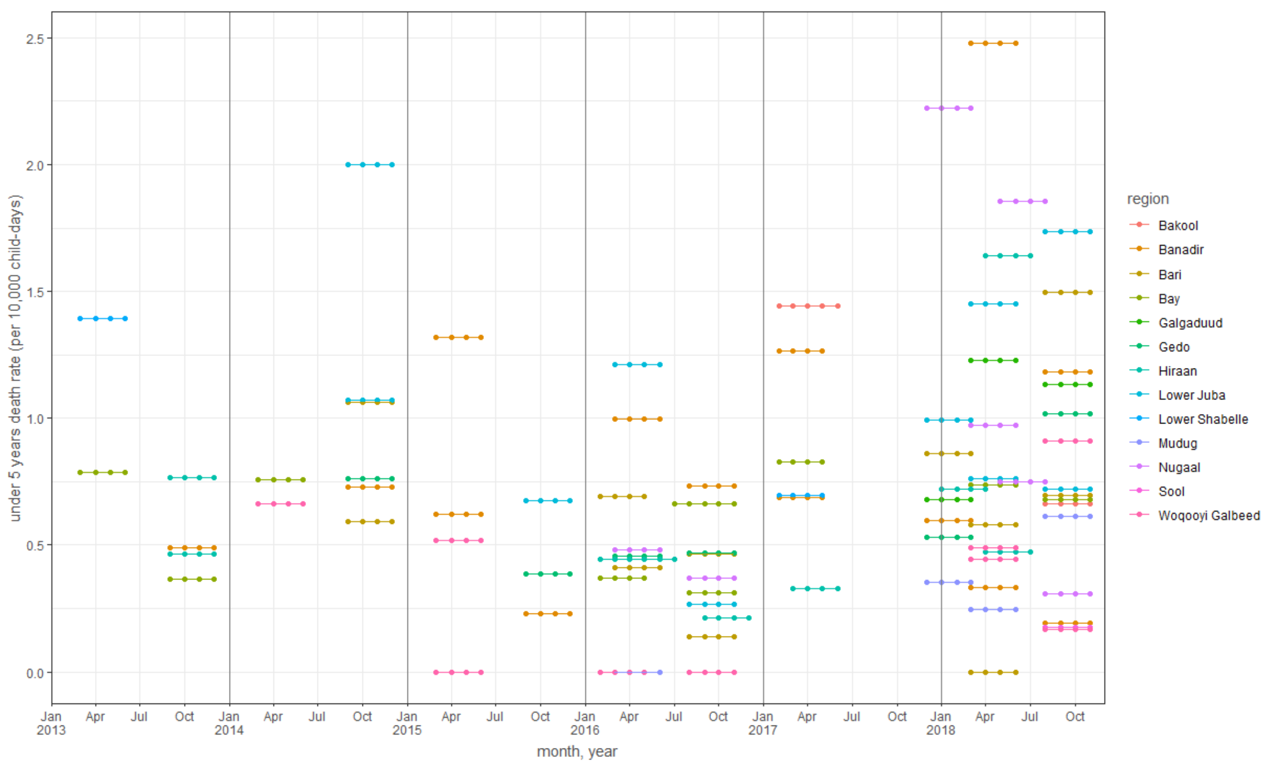

Figure 11. Crude trends in the under 5 years death rate over the survey's recall period.

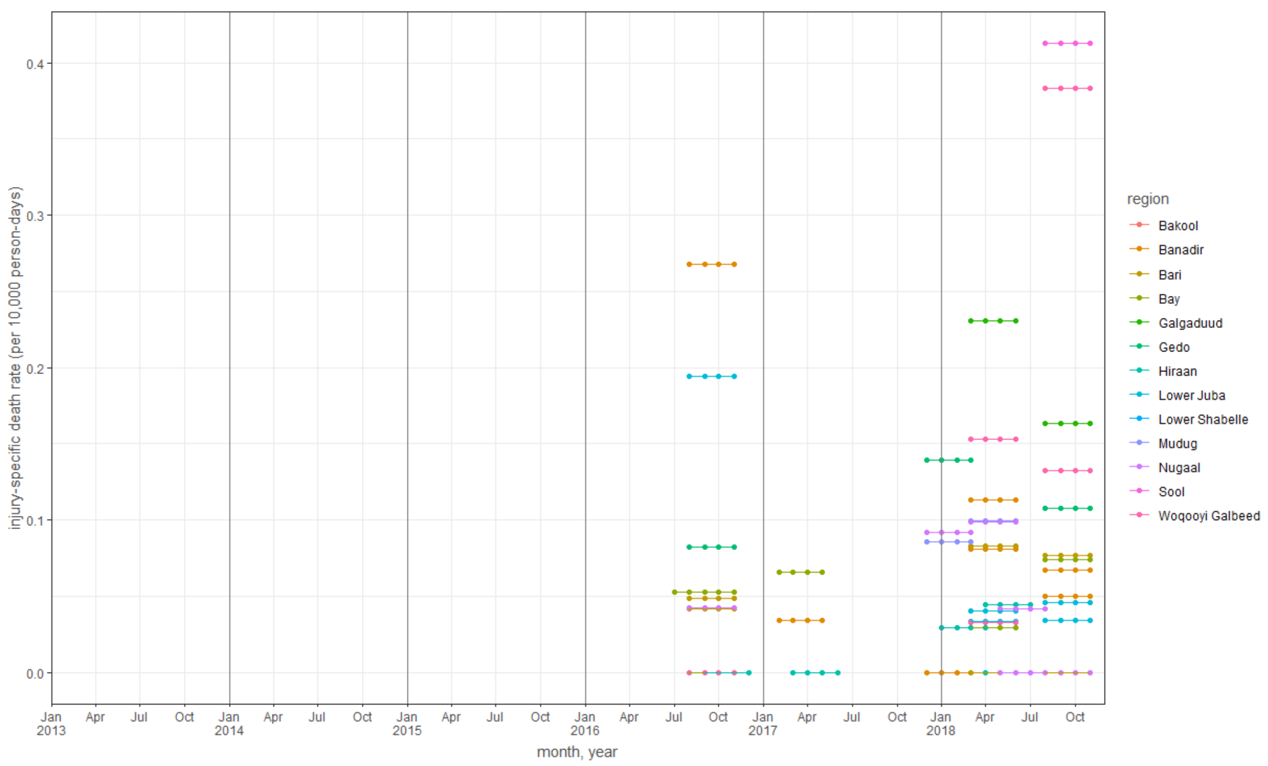

Figure 12. Crude trends in the injury-specific death rate over the survey's recall period.

Note that surveys prior to 2016 relied on an "aggregate" questionnaire that did not collect cause of death.

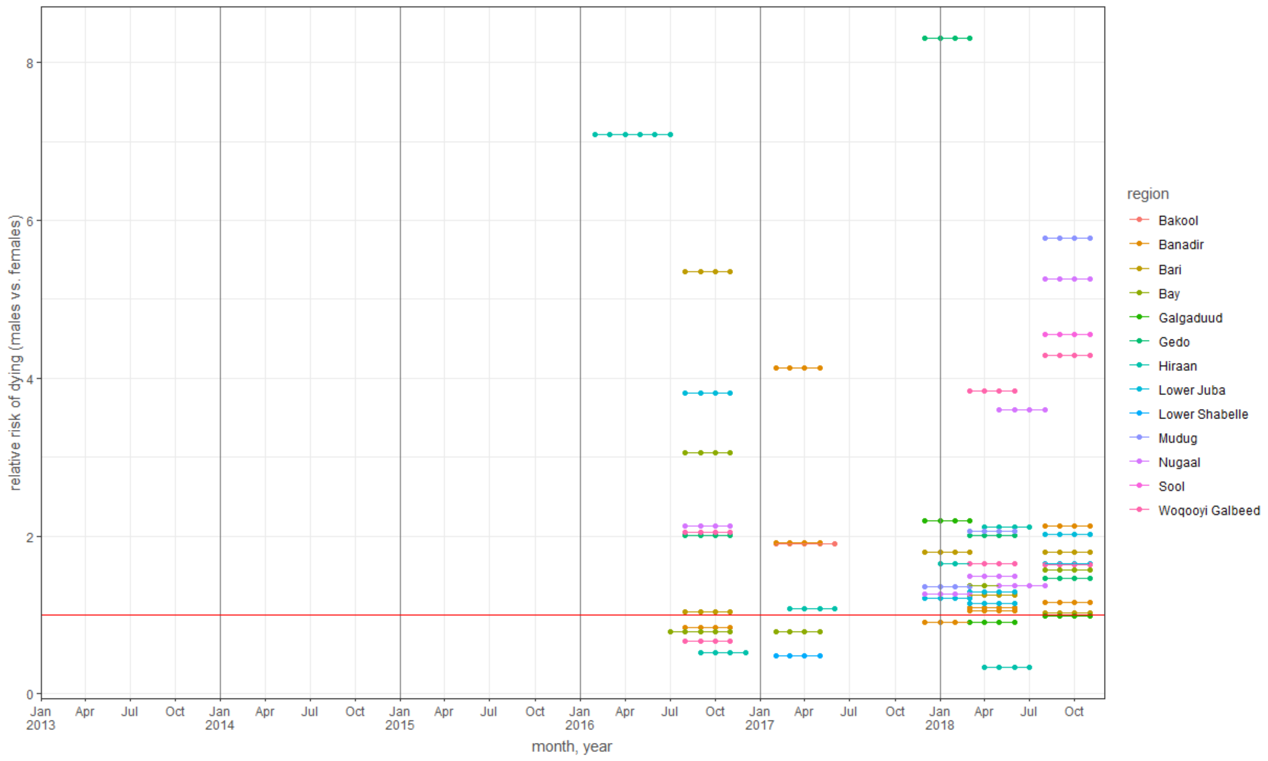

Figure 13. Crude trends in the relative risk of dying (males versus females) over the survey's recall period. The red horizontal line indicates a relative risk of 1.

Note that surveys prior to 2016 relied on an "aggregate" questionnaire that did not collect gender of household members.

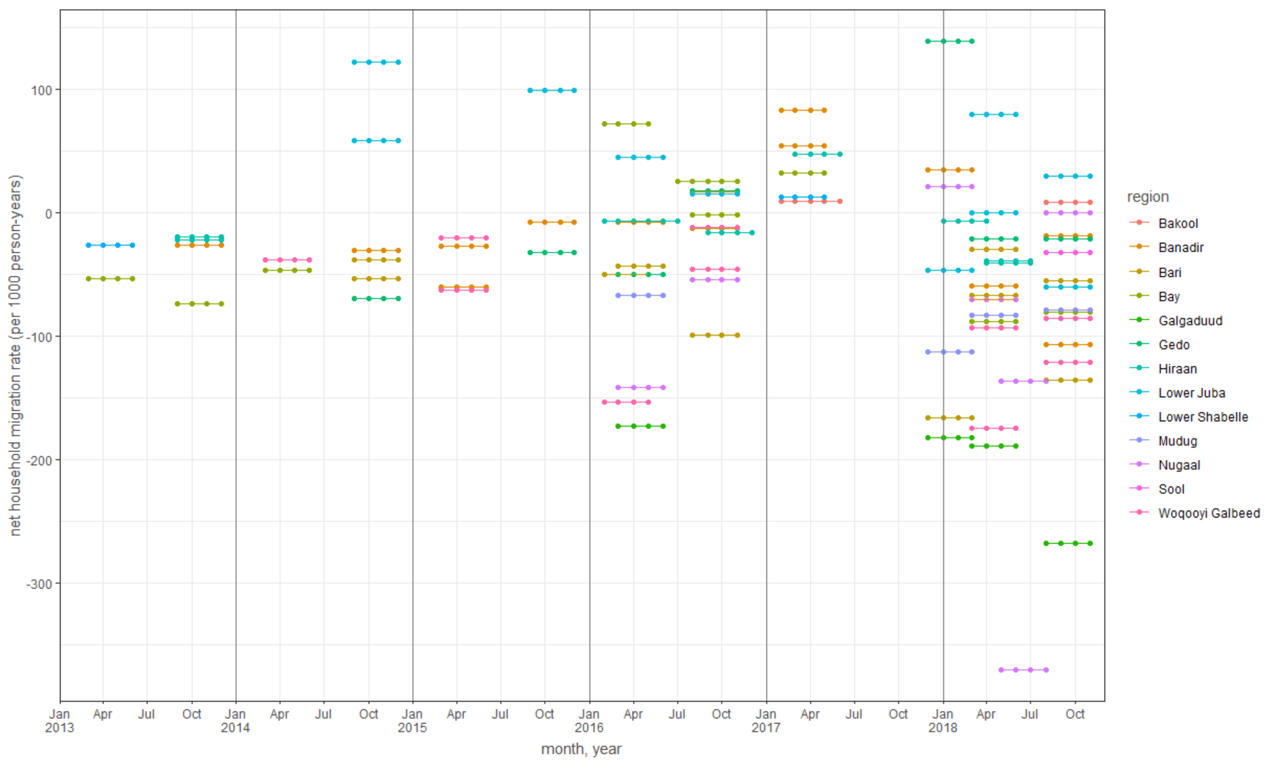

Figure 14. Crude trends in the net migration rate among household members over the survey's recall period.

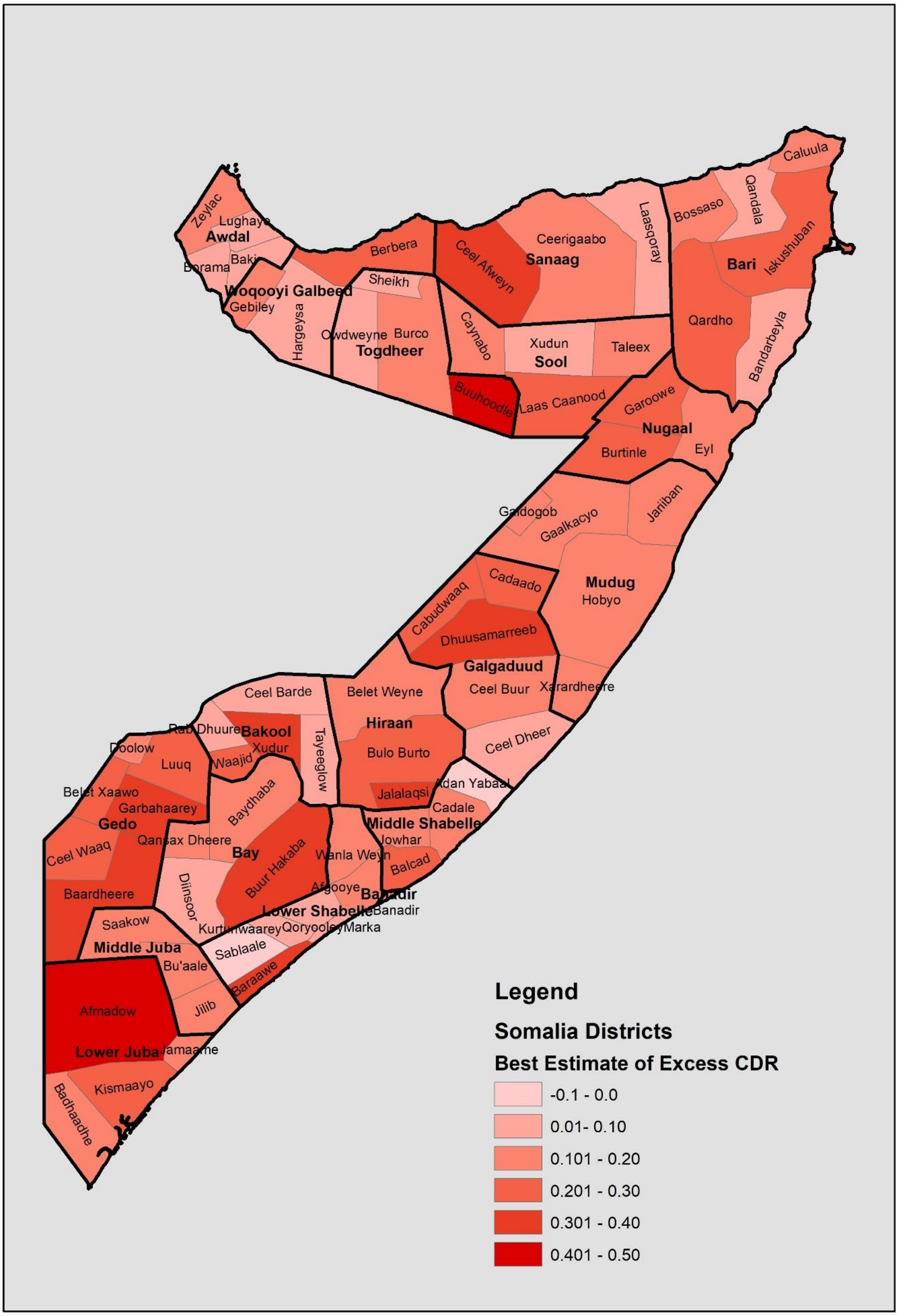

Figure 15. Best estimate of excess crude death rate (CDR), by district.

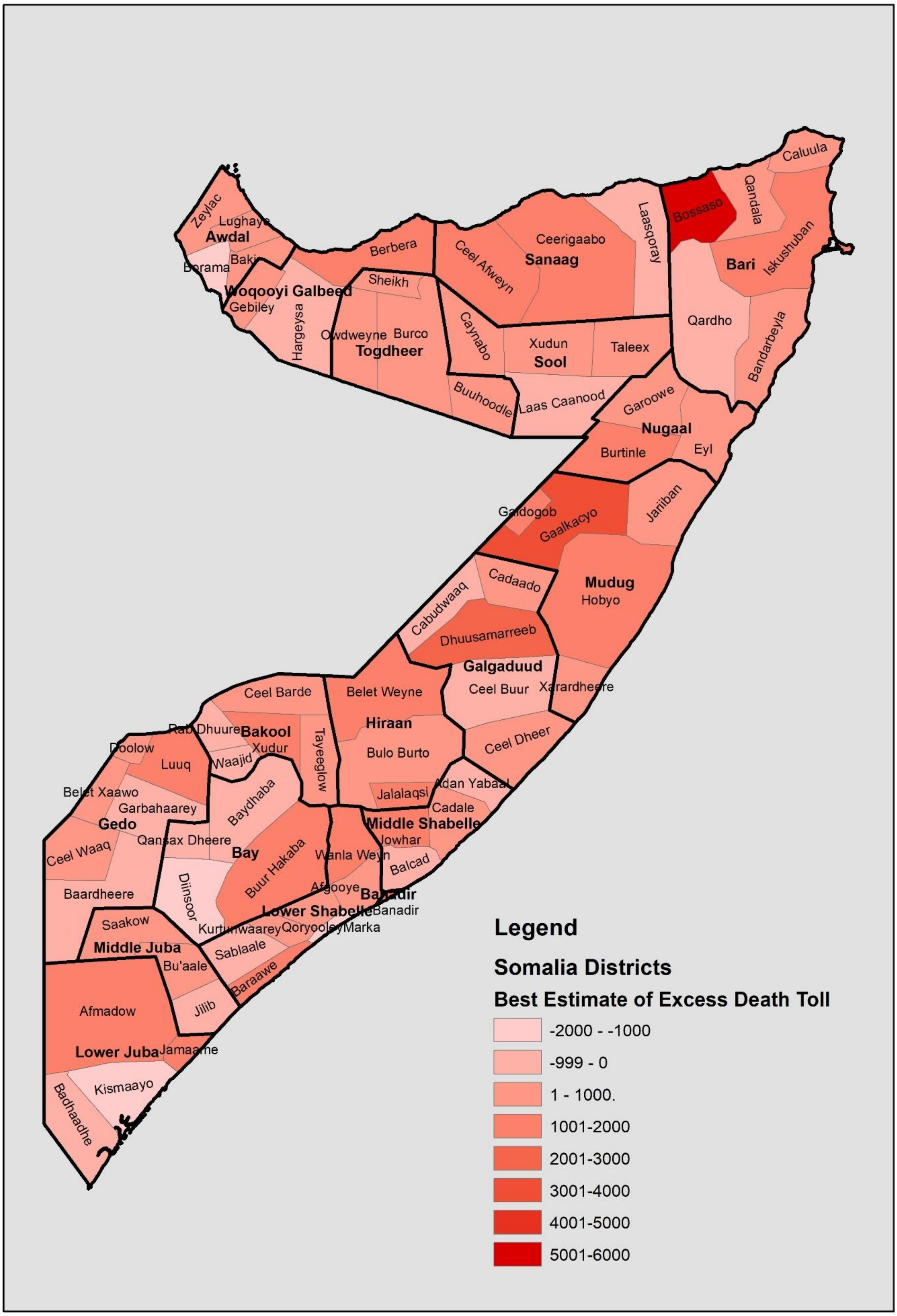

Figure 16. Best estimate of excess death toll, by district.

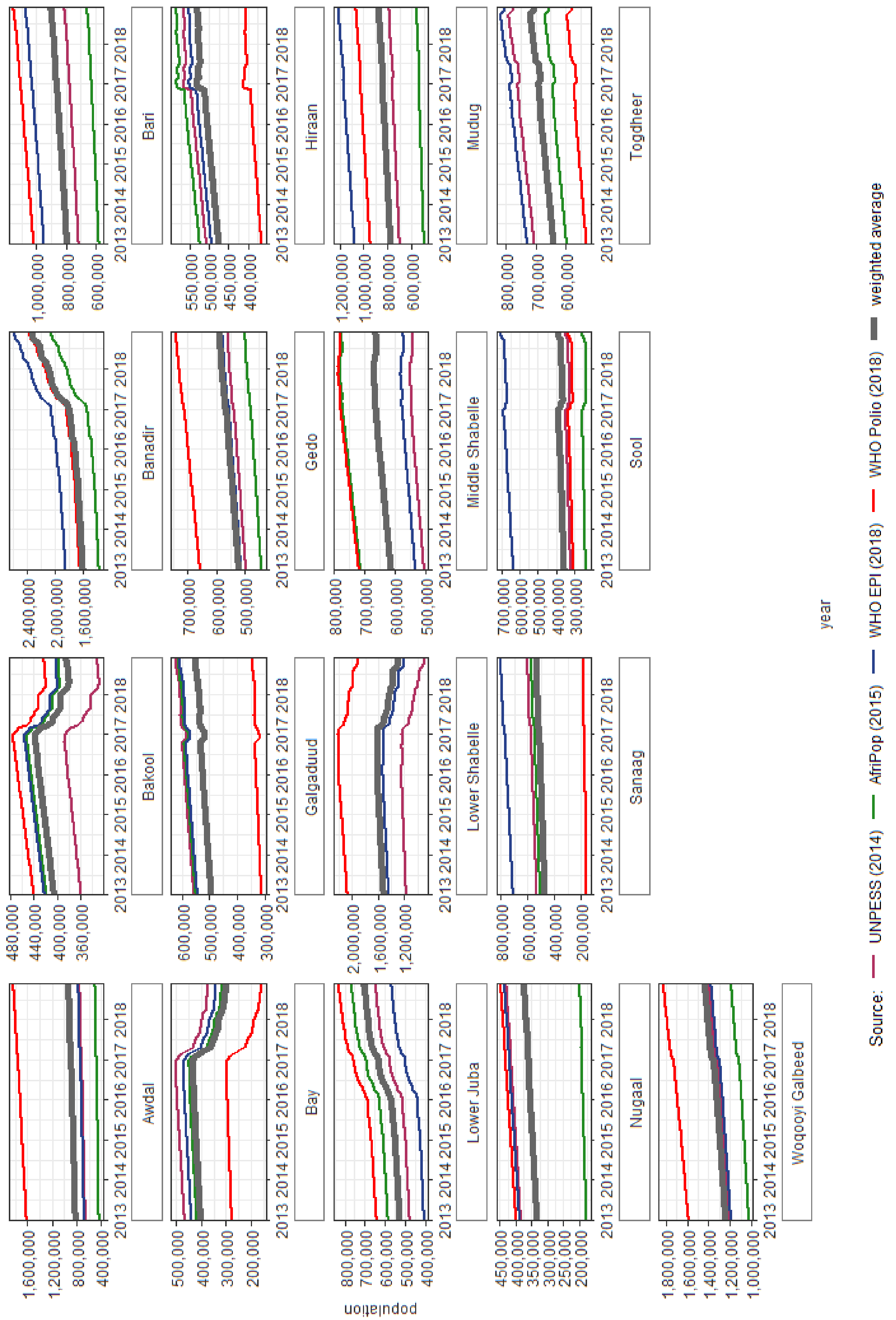

Figure 17. Evolution of population denominators, by region and source.

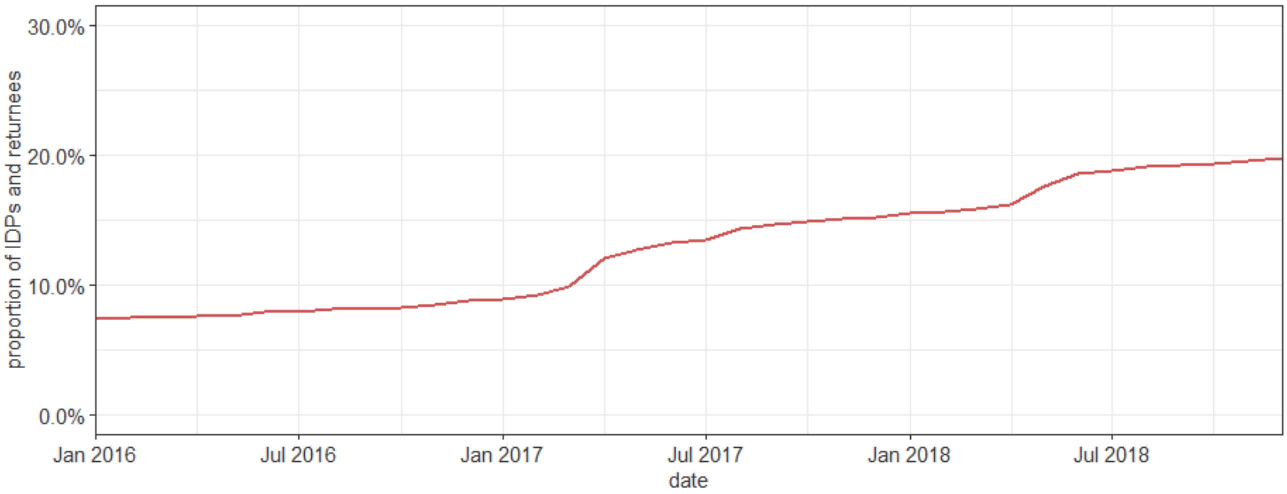

Figure 18. Evolution of the proportion of IDPs and returnees across Somalia.

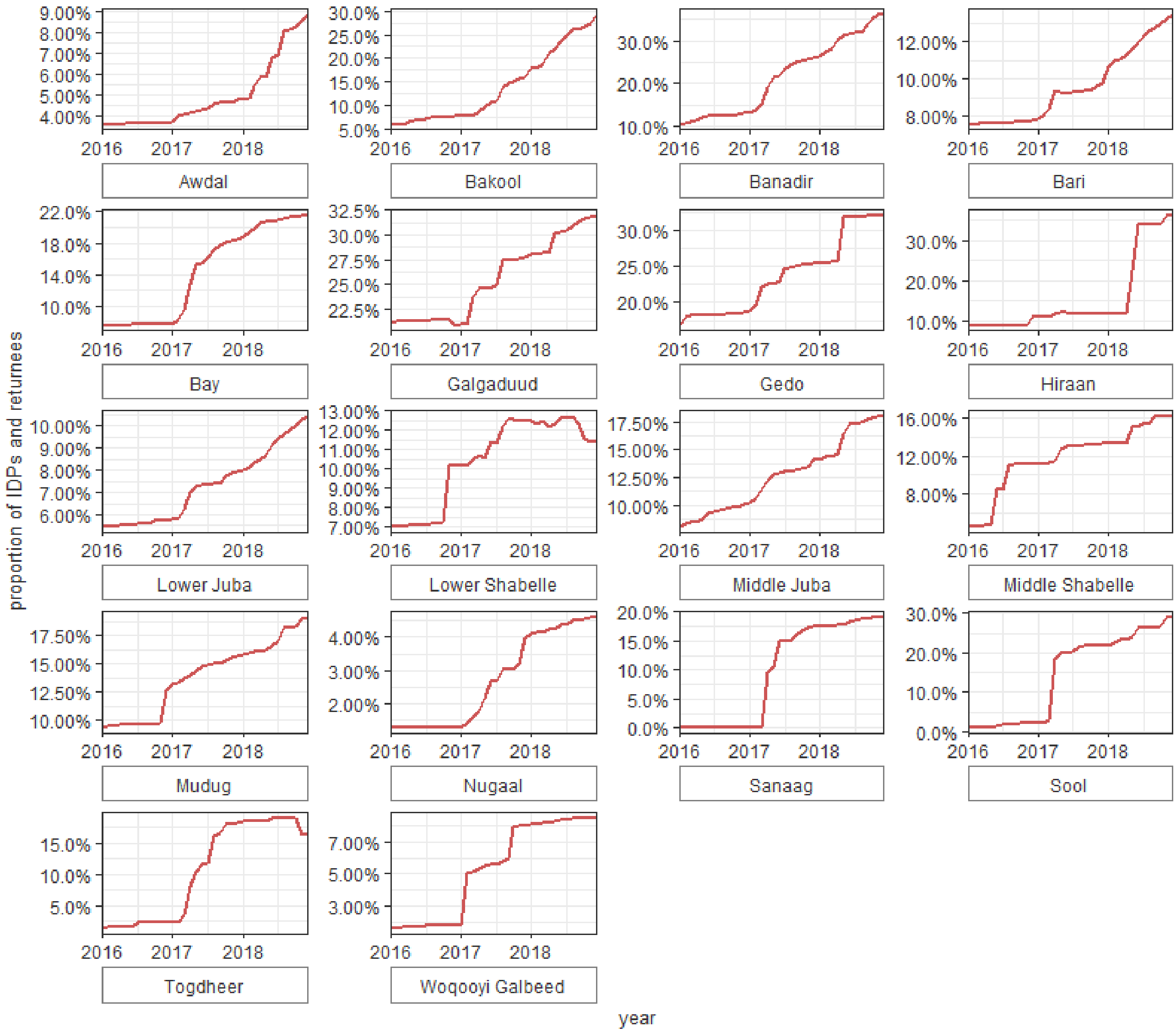

Figure 19. Evolution of the proportion of IDPs and returnees, by region.

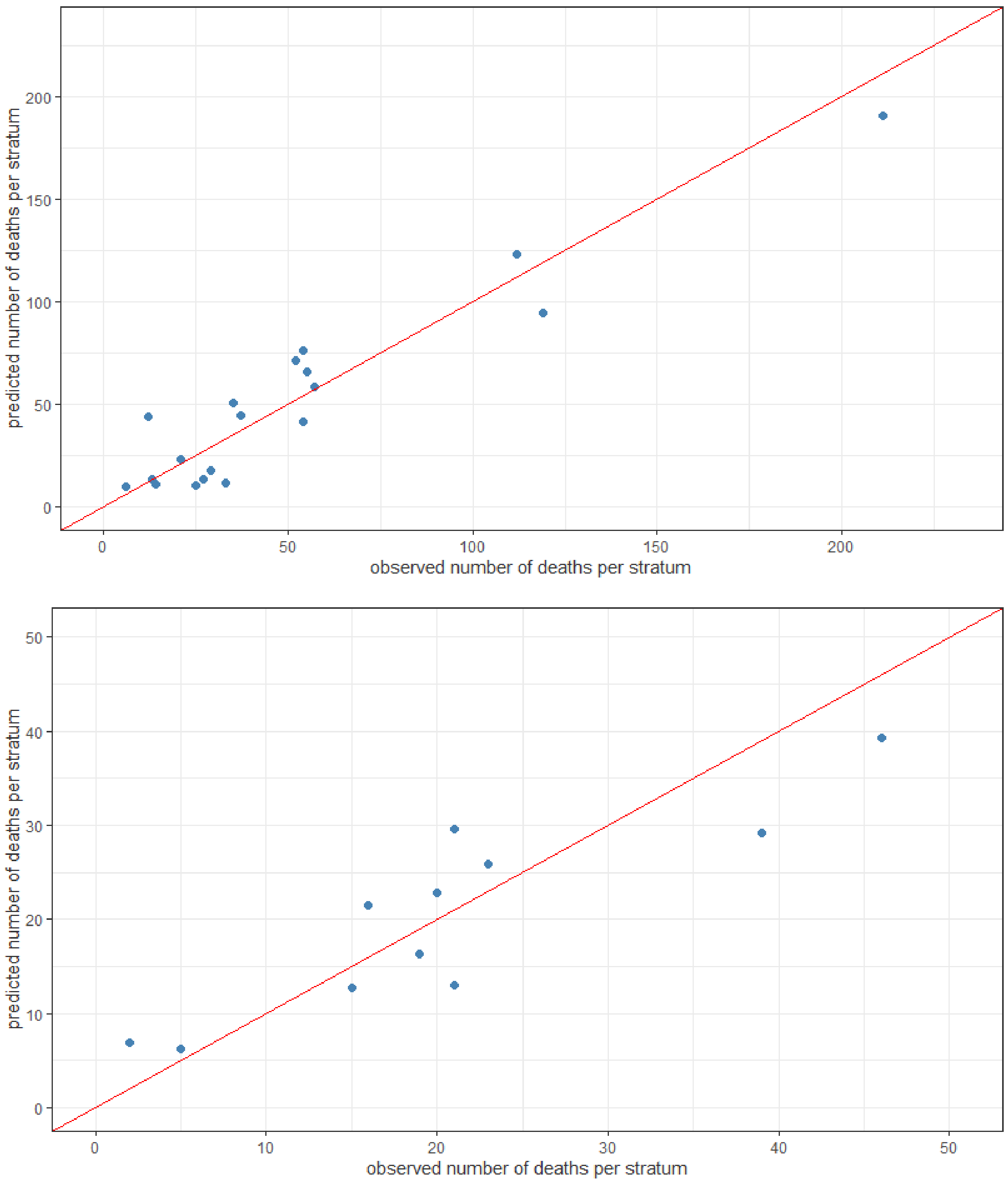

Figure 20. Observed versus predicted number of all-age deaths, by stratum (district), after 10-fold cross-validation (top panel) and prediction on the holdout sample (bottom panel). The red line indicates perfect fit.

On 10-fold cross-validation, the model predicted 970 deaths on average, compared to 966 observed across all surveys in the training sample. Corresponding totals for the holdout sample were 227 and 223.

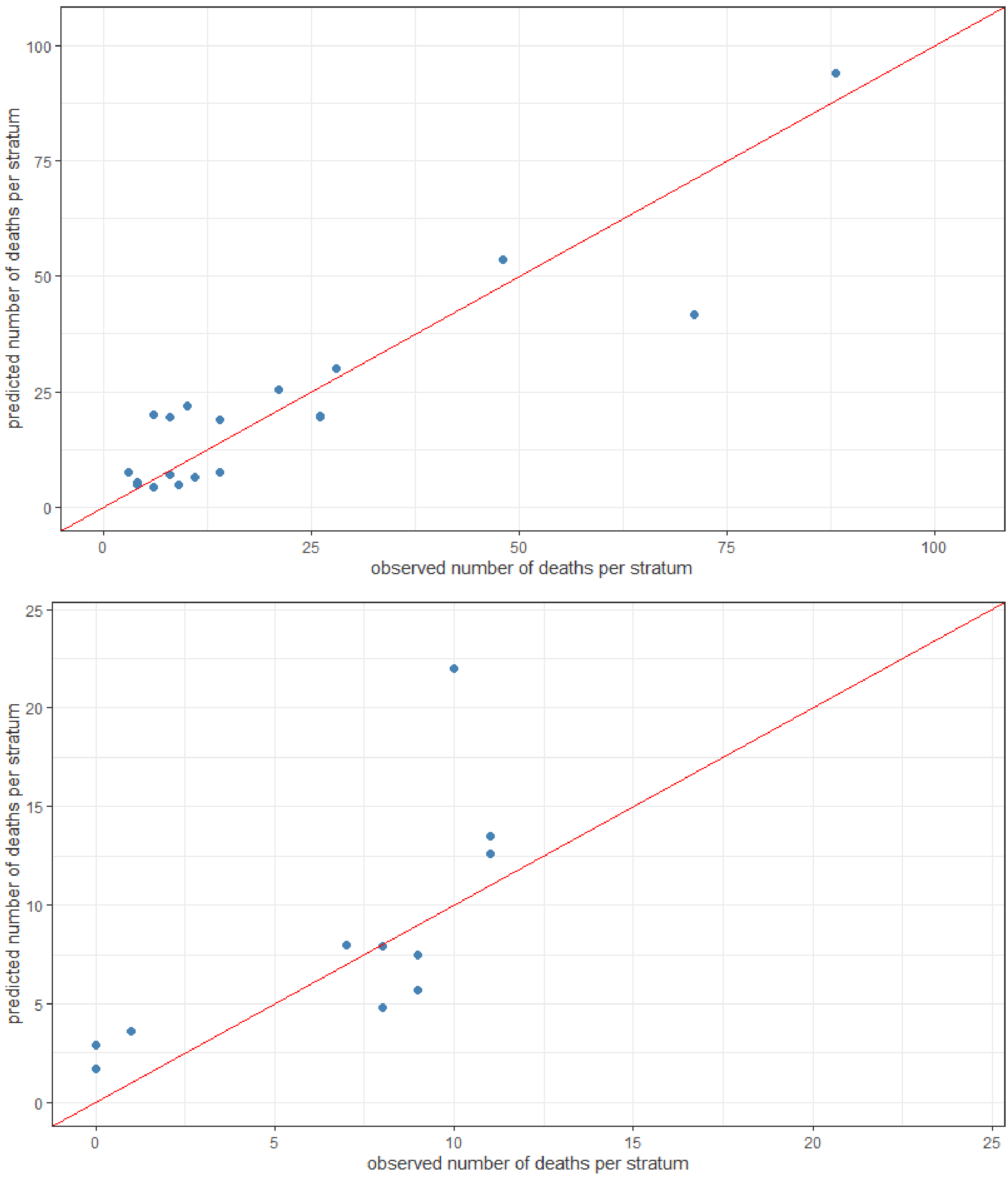

Figure 21. Observed versus predicted number of under 5y deaths, by stratum (district), after 10-fold cross-validation (top panel) and prediction on the holdout sample (bottom panel). The red line indicates perfect fit.

On 10-fold cross-validation, the model predicted 412 deaths on average, compared to 405 observed across all surveys in the training sample. Corresponding totals for the holdout sample were 90 and 74.

Table 8. Point estimates of crude death rate, excess death rate and excess death toll, under the most likely counterfactual scenario, by district, for all ages and for children under 5y.

District	Crude death rate	Excess death rate	Excess death toll	Under 5 years death rate	Excess death rate, children under 5y	Excess death toll, children under 5y
Adan Yabaal	0.23	-0.01	0 (-100 to 0)	0.67	-0.02	0 (0 to 0)
Afgooye	0.41	0.03	800 (-500 to 1300)	0.88	-0.03	-300 (-1200 to 200)
Afmadow	0.71	0.15	1800 (1400 to 2400)	1.15	0.33	1000 (700 to 1600)
Baardheere	0.68	-0.01	-100 (-400 to 100)	1.04	0.02	100 (-100 to 200)
Badhaadhe	0.47	0.01	0 (0 to 100)	0.91	-0.03	0 (-100 to 0)
Baki	0.34	0.04	200 (100 to 300)	0.44	0.02	0 (0 to 100)
Balcad	0.46	-0.02	-200 (-600 to 0)	0.90	0.00	0 (-300 to 200)
Banadir	0.50	0.01	1200 (-3700 to 4200)	0.80	0.02	900 (800 to 1200)
Bandarbeyla	0.42	0.06	100 (100 to 200)	0.48	0.01	0 (0 to 0)
Baraawe	0.58	0.17	1100 (900 to 1400)	1.13	0.16	300 (200 to 300)
Baydhaba	0.42	0.00	-100 (-1000 to 400)	0.73	-0.01	-100 (-100 to 0)
Belet Weyne	0.44	0.09	1900 (1700 to 1900)	0.99	0.23	1200 (800 to 1200)
Belet Xaawo	0.52	0.09	600 (300 to 700)	0.94	0.16	300 (0 to 300)
Berbera	0.48	0.14	1600 (1200 to 2400)	0.65	-0.02	-100 (-100 to 0)
Borama	0.35	-0.04	-2000 (-2100 to -1500)	0.41	-0.05	-600 (-700 to -200)
Bossaso	0.39	0.17	5200 (4400 to 5800)	0.45	0.10	700 (200 to 800)
Bu'aale	0.40	0.08	600 (400 to 900)	0.97	0.21	400 (200 to 700)
Bulo Burto	0.54	0.05	600 (300 to 1100)	1.08	0.13	400 (100 to 900)
Burco	0.42	0.02	800 (500 to 1200)	0.51	-0.03	-200 (-300 to -200)
Burtinle	0.53	0.21	1300 (800 to 2000)	0.61	0.13	200 (100 to 400)
Buuhoodle	0.71	0.16	900 (400 to 1700)	0.72	0.09	100 (0 to 300)
Buur Hakaba	0.69	0.16	1800 (1500 to 2100)	1.01	0.07	200 (0 to 200)
Cabudwaaq	0.42	-0.10	-600 (-1300 to -300)	0.81	-0.22	-400 (-600 to -200)
Cadaado	0.49	0.04	300 (200 to 300)	0.70	-0.06	-100 (-200 to -100)
Cadale	0.42	0.18	1000 (700 to 1400)	0.83	0.18	200 (200 to 400)
Caluula	0.43	0.12	400 (300 to 700)	0.49	0.06	100 (0 to 100)
Caynabo	0.51	0.17	800 (500 to 1200)	0.56	0.11	100 (100 to 200)
Ceel Afweyn	0.75	0.16	1100 (600 to 2000)	0.73	0.10	200 (0 to 400)
Ceel Barde	0.41	0.07	300 (200 to 400)	0.93	0.13	100 (100 to 200)
Ceel Buur	0.49	-0.07	-600 (-800 to -400)	0.82	-0.16	-300 (-500 to -200)
Ceel Dheer	0.33	0.05	400 (300 to 500)	0.59	0.11	200 (200 to 300)
Ceel Waaq	0.55	0.24	900 (600 to 1300)	1.14	0.45	400 (300 to 600)
Ceerigaabo	0.46	0.11	1900 (1200 to 2900)	0.62	0.08	300 (200 to 700)
Dhuusamarreeb	0.59	0.21	2300 (1800 to 2600)	0.99	0.32	800 (800 to 900)
Diinsoor	0.45	-0.13	-1000 (-1400 to -700)	0.94	-0.09	-200 (-200 to -100)
Doolow	0.56	0.14	600 (500 to 800)	0.86	0.18	200 (200 to 300)
Eyl	0.41	0.13	800 (500 to 1200)	0.53	0.08	100 (100 to 200)
Gaalkacyo	0.45	0.11	3500 (2500 to 5100)	0.56	-0.09	-700 (-800 to -700)
Galdogob	0.37	0.11	1300 (900 to 2200)	0.63	0.14	400 (200 to 800)
Garbahaarey	0.68	-0.11	-900 (-1200 to -800)	0.96	-0.22	-500 (-700 to -300)
Garoowe	0.52	0.01	200 (-300 to 1000)	0.71	0.05	200 (-100 to 700)
Gebiley	0.40	0.05	600 (300 to 1100)	0.45	0.05	100 (100 to 200)
Hargeysa	0.29	0.00	-300 (-600 to 400)	0.43	0.00	0 (-300 to 700)
Hobyo	0.46	0.15	1100 (700 to 1700)	0.65	0.17	300 (200 to 600)
Iskushuban	0.57	0.23	1300 (900 to 1900)	0.58	0.15	200 (100 to 300)
Jalalaqsi	0.58	0.30	1900 (1500 to 2500)	1.02	0.39	600 (400 to 900)
Jamaame	0.40	0.11	1200 (800 to 1600)	0.82	0.16	500 (400 to 600)
Jariiban	0.38	0.14	1000 (600 to 1600)	0.61	0.16	300 (200 to 500)
Jilib	0.39	-0.01	-100 (-400 to 0)	0.87	0.02	0 (-200 to 100)
Jowhar	0.34	0.05	1100 (1100 to 1100)	0.87	-0.01	-100 (-600 to 200)
Kismaayo	0.50	-0.07	-1500 (-3000 to -600)	0.99	0.19	1000 (900 to 1000)
Kurtunwaarey	0.34	0.01	100 (-100 to 100)	0.74	-0.06	-200 (-400 to 0)
Laas Caanood	0.52	-0.01	-200 (-300 to 0)	0.66	-0.11	-300 (-500 to -200)
Laasqoray	0.35	-0.01	-200 (-300 to 200)	0.43	-0.01	0 (-100 to 100)

District	Crude death rate	Excess death rate	Excess death toll	Under 5 years death rate	Excess death rate, children under 5y	Excess death toll, children under 5y
Lughaye	0.36	0.07	400 (200 to 700)	0.47	0.05	100 (0 to 100)
Luuq	0.51	0.21	1500 (1200 to 1800)	0.92	0.33	600 (500 to 600)
Marka	0.28	-0.06	-1200 (-2300 to -600)	0.84	-0.27	-1400 (-1800 to -1000)
Owdweyne	0.44	0.10	600 (400 to 1000)	0.49	0.05	100 (0 to 100)
Qandala	0.46	0.08	800 (600 to 1100)	0.54	0.04	100 (100 to 100)
Qansax Dheere	0.41	0.00	0 (-100 to 0)	0.90	0.01	0 (-100 to 100)
Qardho	0.51	-0.04	-500 (-700 to -400)	0.54	-0.09	-300 (-400 to -200)
Qoryooley	0.26	0.01	200 (200 to 200)	0.77	0.00	0 (-100 to 200)
Rab Dhuure	0.39	-0.07	-200 (-600 to -100)	0.87	-0.17	-100 (-300 to 0)
Saakow	0.38	0.11	1000 (700 to 1500)	0.96	0.28	600 (400 to 1100)
Sablaale	0.29	-0.03	-100 (-200 to -100)	0.68	-0.07	-100 (-100 to 0)
Sheikh	0.38	0.03	200 (100 to 300)	0.49	0.03	0 (0 to 100)
Taleex	0.48	0.15	800 (500 to 1200)	0.55	0.10	100 (100 to 200)
Tayeeglow	0.27	0.06	400 (300 to 500)	0.67	0.09	100 (0 to 200)
Waajid	0.43	-0.01	-100 (-400 to 100)	0.88	-0.05	-100 (-200 to 0)
Wanla Weyn	0.44	0.12	1900 (1800 to 1900)	0.89	0.17	700 (200 to 800)
Xarardheere	0.38	0.13	700 (500 to 1100)	0.56	0.09	100 (100 to 200)
Xudun	0.41	0.04	200 (100 to 300)	0.52	0.01	0 (0 to 0)
Xudur	0.51	0.16	1400 (1200 to 1500)	1.00	0.23	500 (200 to 600)
Zeylac	0.44	0.02	100 (0 to 300)	0.46	0.01	0 (0 to 100)

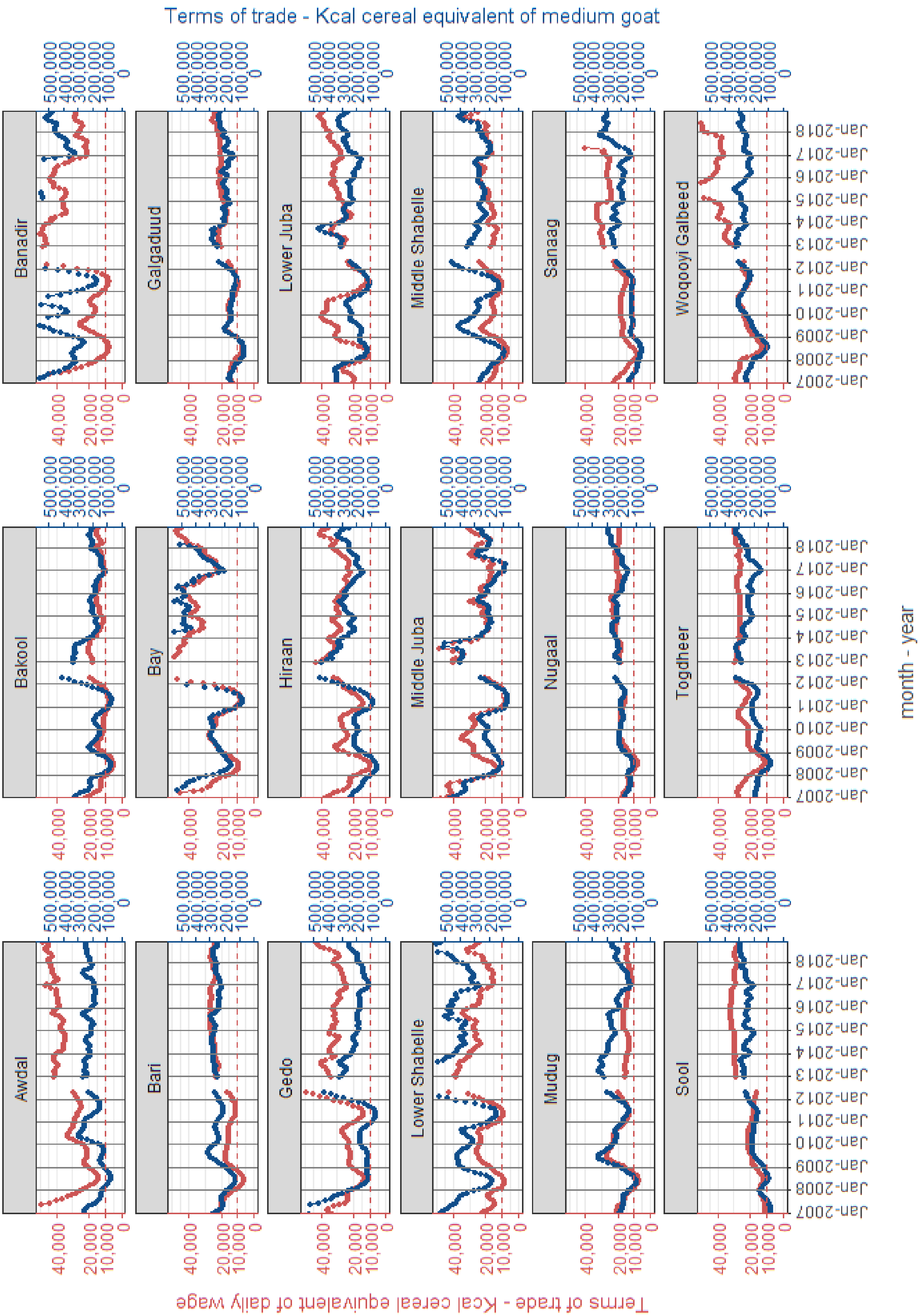

Figure 22. Trends in terms of trade (daily wage vs. cereal, medium-quality goat vs. cereal), by region.

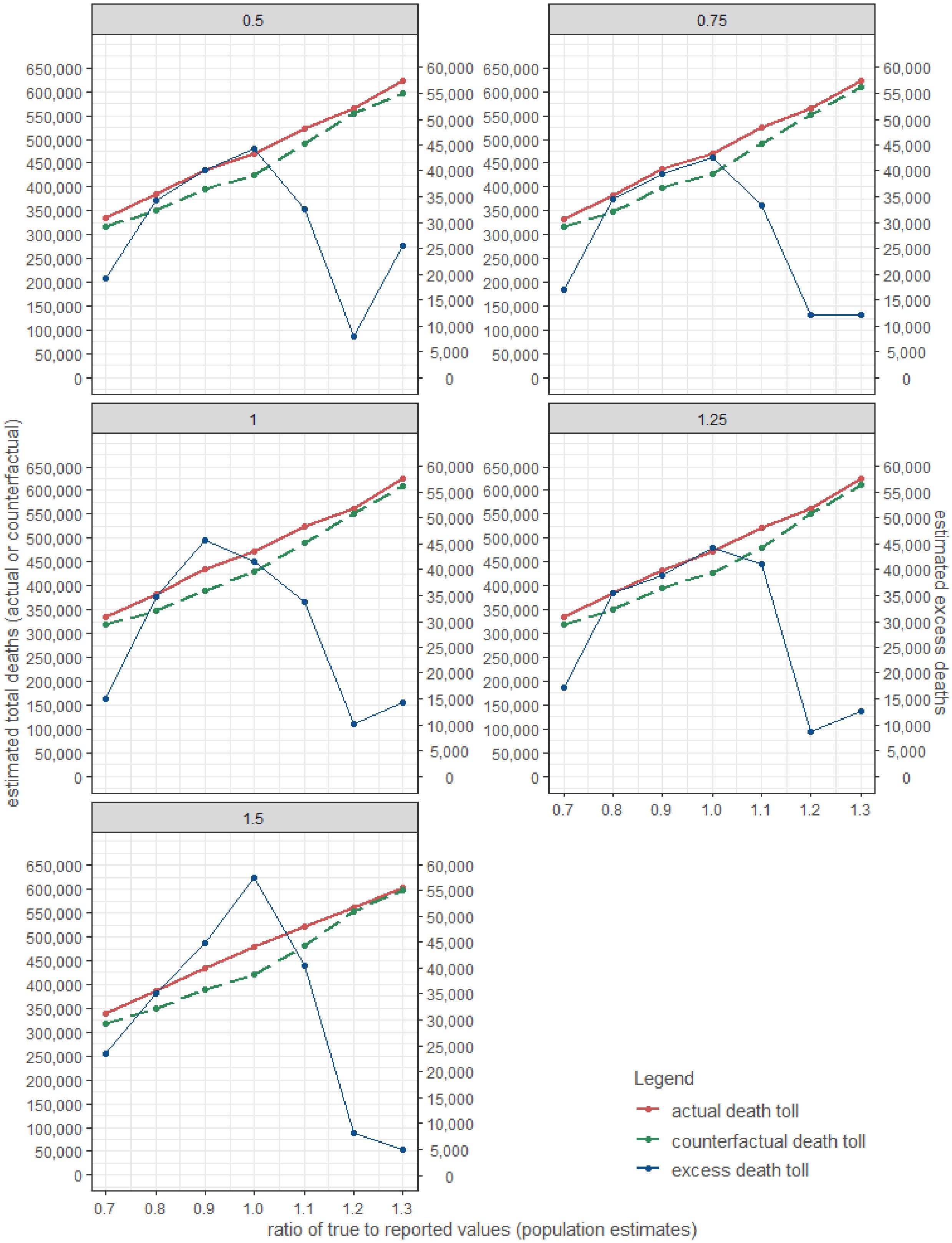

Figure 23. Estimated actual, counterfactual and excess death toll for all age groups, by sensitivity value of the ratio of true to reported population estimates. Each panel presents results for different sensitivity values of the true number of internal displacements (as a ratio to the observed/reported value). Only the most likely counterfactual scenario is presented.

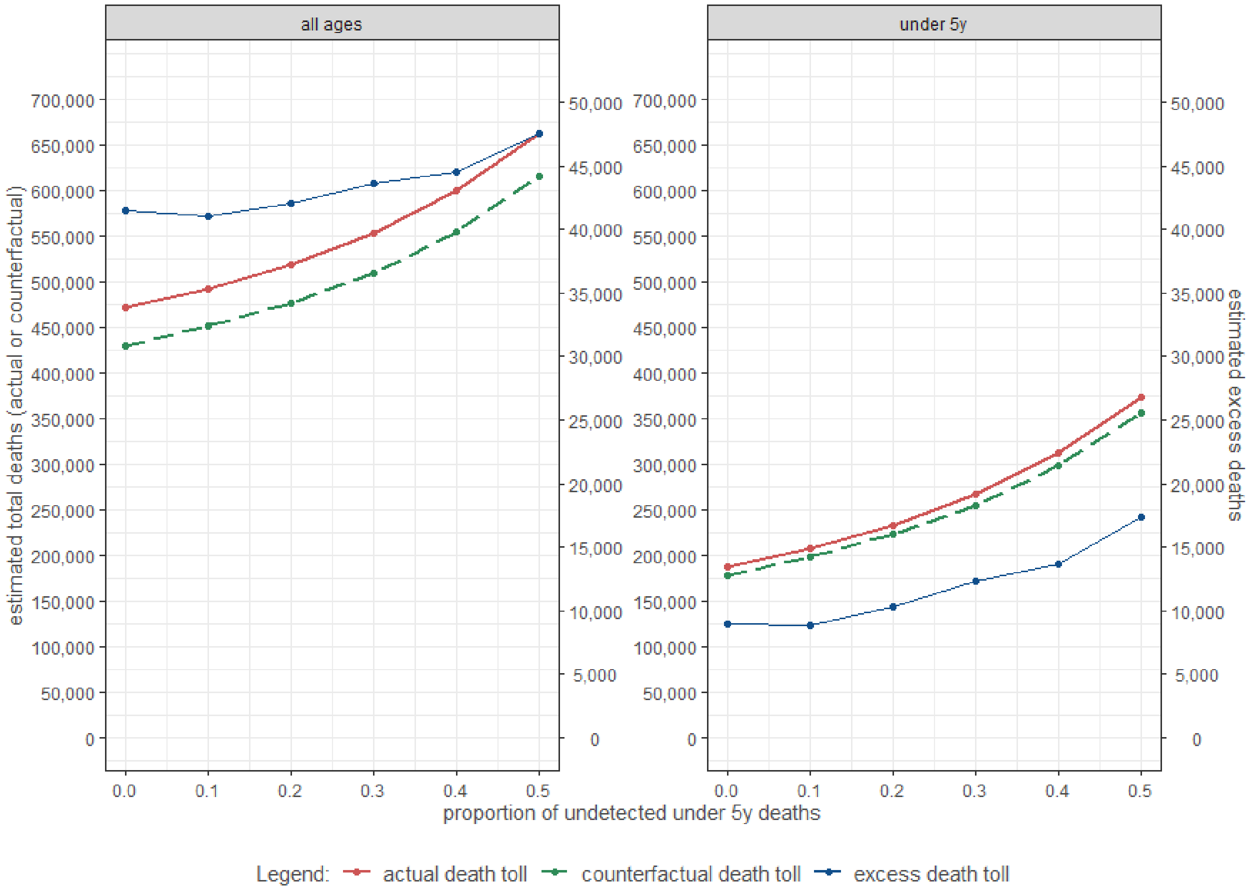

Figure 24. Estimated actual, counterfactual and excess death toll for all age groups and children under 5y, by sensitivity value of the ratio of true to reported U5DR. Only the most likely counterfactual scenario is presented.