Estimation of population mortality in crisis-affected populations

Guidance for humanitarian coordination mechanisms

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List of abbreviations

CDR	Crude death rate
CFR	Case-fatality ratio
ENA	Emergency Nutrition Assessment software
IDP	Internally displaced person
IMR	Infant mortality ratio
MMR	Maternal mortality ratio
NMR	Neonatal mortality ratio
SMART	Standardised Monitoring and Assessment of Relief and Transitions
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs
USD	United States Dollar
U5DR	Under 5 years death rate
U5MR	Under 5 years mortality ratio
WHO	World Health Organization

1 Background

1.1 Mortality in crisis-affected populations

Crises resulting from armed conflict or natural disasters have wide-ranging effects on human health, including worsened mental health and long-term disability. Strictly in terms of physical survival, the public health impact of any crisis can be ultimately quantified by how many deaths it causes, either directly (i.e. through trauma injuries due to violence or the mechanical force of nature) or indirectly (i.e. through disruption of health systems and increased exposure to risk factors such as overcrowding, poor nutrition, inadequate water and sanitation etc.).[1] **Population mortality is therefore an essential public health metric of a crisis' impact**, and, by implication, of the need for humanitarian public health services.[2]

Mortality estimates collected over the past decades across multiple crises support some cautious generalisations:

- Substantial elevations in mortality (two- to ten-fold the baseline) are very common, particularly during the acute emergency phase and in low- and middle-income settings; in the protracted crisis phase, elevations are less pronounced, but nonetheless sustained over long periods;[3,4]
- Internally displaced persons (IDPs) experience higher mortality than non-displaced crisis-affected populations, while refugees living in accessible camps have lower death rates;[5]
- Most crisis-attributable mortality appears to be indirect[6], with the exception of high-intensity armed conflicts (e.g. recent wars in Syria and Iraq[7-9]);
- Beyond the initial spike in trauma deaths, natural disasters tend to cause considerably lower mortality than armed conflicts and food-insecurity crises;
- In low and middle-income settings, children experience higher mortality both at baseline and during a crisis, though the relative increase among children may often be larger[10], reflecting their greater vulnerability; deaths among the elderly have largely gone unmeasured in past crises, but are likely to also contribute disproportionately to excess mortality.[11]

Any given crisis, however, may not fit the above pattern depending on how its specific threats to health (e.g. the extent of food insecurity) act upon pre-crisis vulnerabilities (e.g. the resilience of the health system) and the underlying epidemiological profile of the population.

1.2 Scope of this paper

This paper focusses on **population mortality estimation at the scale of the entire crisis-affected area**, i.e. in support of crisis-wide humanitarian coordination, or other efforts to influence assistance to and protection of the affected population as a whole. It is aimed primarily at technical staff, e.g. cluster coordination teams, who need to decide whether and how to allocate resources for mortality estimation, and who must subsequently interpret and act upon any mortality estimates. As such, it does not provide detailed methods or data collection and analysis instruments: where relevant, key references to existing resources are provided. An abridged version of this guidance is provided in the Global Health Cluster's Standards for Public Health Information Services.[12]

1.3 Indicators of population mortality

A variety of indicators may be used to quantify population mortality: these are summarised in Table 1. All of these indicators refer to a given period and population over which they are measured: in development settings, this is typically 3-5y, while in humanitarian settings even week-by-week changes may be important to measure (see Chapter 2). The denominator of CDR and U5DR is, as for any epidemiological incidence rate, person-time (i.e. the cumulative time contributed by all individuals in the population being measured: note that some individuals contribute less to total person-time than the full period of analysis, as they are born, die or migrate in and out of the population during the period itself). As person-time is in practice difficult to accurately measure, simplifying assumptions are often made during analysis (e.g. all deaths, births and migration events are assumed to occur at the mid-point of the period).[13,14]

In most crisis scenarios, only some of these indicators are feasibly measurable (Chapter 3). Furthermore, **the use of crude (CDR) and under 5y death rates (U5DR) for humanitarian response has been criticised by demographers**. Objections include:

- The poor comparability of CDR across different populations, due to varying age structures (proportionately older populations, e.g. Swedes, will experience a relatively high CDR compared to younger populations, e.g. Tanzanians, despite enjoying better overall health status); **age standardisation** is a technique that addresses this limitation;
- Reliance on short units and periods of measurement (e.g. per day, per week), which does not reflect random fluctuation of mortality over such time intervals, particularly in numerically small populations;
- Nomenclature confusion between the “humanitarian” U5DR expression (incidence rate of under 5y deaths, where the denominator is person-time) and the U5MR prominent in development settings (i.e. probability of dying before age 5y, where the denominator is live births): while these indicators are mathematically related (given U5DR and the crude birth rate, one may roughly approximate the U5MR), in practice the latter is measured over far longer periods and relies on assumptions of stable age-gender structure and birth rate that may not hold in crisis settings.

Table 1. Indicators of population mortality.

Indicator	Also known as	Description	Unit of measurement	Notes
Indicators measured prominently in humanitarian settings				
Crude death rate (CDR)	Crude mortality rate (CMR)	Number of all-age, all-cause deaths that occur in a given population per unit of time, as measured over a specified period.	Typically, per 10,000 person-days (or people per day) Also per 1000 person-months or per 1000 person-years	Incidence rate of death. Accordingly, the denominator is person-time (all ages).
Under 5 years death rate (U5DR)	Under 5 years mortality rate (U5MR) 0-4 years death rate	Number of all-cause deaths among children under 5y old that occur in a given population of children under 5y old per unit of time, as measured over as specified period.	Typically, per 10,000 under 5y child-days (or children under 5y per day) Also per 1000 child-months or per 1000 child-years	Example of age-specific death rate. The denominator is person-time contributed by children under 5y old only.
Excess death rate	Crisis-attributable death rate	Death rate that occurs in a given population and period, above and beyond the baseline death rate that would have occurred in the absence of a crisis.	As for CDR	Observed CDR minus (counterfactual) baseline death rate: see Section 3.3. The ratio of CDR to baseline death rate is a kind of standardised mortality ratio.
Excess death toll	Crisis-attributable death toll	Total number of deaths experienced by a population over a specified period, above and beyond deaths that would have occurred in the absence of a crisis.	Number	Equal to excess death rate times the population and period (i.e. person-time) that it refers to
Death rate due to trauma injury	Violent death rate (in armed conflicts)	Number deaths due to (intentional) trauma injury that occur in a given population per unit of time, as measured over a specified period.	As for CDR	Example of cause-specific death rate.

Indicator	Also known as	Description	Unit of measurement	Notes
Indicators measured mainly in development settings				
Age-standardised death rate	Age-standardised mortality rate	CDR that is mathematically adjusted so that it reflects the age structure of a reference population, thereby allowing two or more death rates to be compared while taking into account the different age structures of the populations they are measured in.	As for CDR	Accounts for the fact that, for example, an older population experiences a higher CDR than a younger one, even if the latter has higher age-specific death rates. Useful mainly for comparison of different crises or different periods.
Under 5y mortality ratio (U5MR)	Child mortality ratio Under 5y mortality rate	Probability of dying before age 5y, i.e. number of children born who die before their fifth birthday, out of all children born alive.	Deaths per 1000 live births (i.e. excluding stillbirths)	Note that the denominator here is not person-time, but live births: this is a risk, not a rate.
Infant mortality ratio (IMR)	Infant mortality rate	Probability of dying before age 1y, i.e. number of children born who die before their first birthday, out of all children born alive.	Deaths per 1000 live births	Fraction of the U5MR
Neonatal mortality ratio (NMR)	Neonatal mortality rate	Probability of dying before age 28d, i.e. number of children born who die during the first 28d of life, out of all children born alive.	Deaths per 1000 live births	Fraction of the IMR and U5MR
Maternal mortality ratio (MMR)		Probability of dying during pregnancy or within 42d of termination of pregnancy, out of all children born alive.	Deaths per 100,000 live births	Where possible, a more specific definition of maternal death is applied, i.e. from any cause related to or aggravated by the pregnancy or its management.
Other indicators				
Proportional mortality		Fraction of deaths that is due to a given cause, out of all deaths.	Percent	
Case-fatality ratio (CFR)	Case-fatality rate, lethality	Proportion of cases who die of their illness; should be measured among a group of cases only once their outcomes (i.e. cured or dead) have been fully ascertained; however, for simplicity it is sometimes taken as the number of deaths divided by the number of cases over the same time period.	Percent	May refer to cases of any illness admitted to a specific health facility, or cases of a specific disease, in either a healthcare setting or the community. Known as a ratio or rate but is actually a proportion or risk.

1.4 Uses of mortality estimates in crisis settings

Population mortality information has multiple potential uses, listed in Table 2 along a spectrum from immediately informing humanitarian responses to historical documentation and, more rarely, forensic applications. These applications are not mutually exclusive, but they may involve stakeholders with contrasting agendas, and the mortality indicators and analysis periods most appropriate to support them may require implementation of separate, incompatible methods.

Table 2. Uses of population mortality estimates from crisis-affected populations.

Broad use	Specific applications	Most appropriate indicators	Population and period of interest
Inform the humanitarian response	Benchmark the public health gravity of the crisis as part of needs analysis	CDR U5DR Excess death rate	Entire crisis-affected population or specific project areas of interest to a given actor Very recent period (≤ 3mo)
	Monitor physical health status during an ongoing response		
	Increase the crisis' visibility as an aide for resource mobilisation, whether or not public health needs are already clear	CDR U5DR Excess death toll	Entire crisis-affected population Recent period (≤ 6-9mo)
	Gauge the appropriateness of the health services package, and adapt as needed	Proportional mortality (by cause; by age group: proportion of neonates and infants among all under 5y deaths)	Entire population or specific project areas of interest to a given actor Very recent period (≤ 3mo)
	Undertake humanitarian advocacy for protection of civilians	Death rate due to (intentional) trauma injury Death toll due to (intentional) trauma	Entire population or specific "case study" sub-populations / sites where crimes are alleged to have been committed Period of sufficient duration to establish patterns of violence and/or intent to harm
Support human rights and international law advocacy, documentation and prosecution	Undertake diplomatic and civil society advocacy to promote human rights and respect of international law		
	Document the effect of the crisis on human health and/or the extent of intentional violence	Death toll due to (intentional) trauma Excess death toll	Entire crisis-affected population Entire duration of the crisis
	Prosecute alleged crimes against humanity or other violations of international law	Death rate due to (intentional) trauma injury Death toll due to (intentional) trauma Excess death toll	Entire population or specific "case study" sub-populations / sites where crimes are alleged to have been committed Period of sufficient duration to establish patterns of violence and/or intent to harm

2 Deciding which mortality data to collect and when

2.1 Specifying the intended uses of data collection

When considering whether and which mortality data should be collected, **it is imperative to explicitly agree on the expected applications of mortality estimates**, i.e. the "what for?" (Table 2). These applications (e.g. increased resource mobilisation; improved civilian protection) should not merely be aspirational: rather, a realistic **"pathway to action"** should be established, e.g. by consulting important stakeholders about how useful estimates might be to them or identifying upcoming opportunities to disseminate the findings at decision-making fora (e.g. a mid-year revision of the Humanitarian Response Plan, or a high-level diplomatic meeting).

While one may wish to collect data that enable certain uses, in practice there may be situations in which none of the appropriate methods (Chapter 3) may be feasible, because of insecurity, lack of access to the population, unavailability of funding or expertise, and/or methodological reasons. The process of specifying the intended uses of mortality data – and deciding whether to carry out mortality estimation at all – should therefore be iterative and involve method experts.

On the other hand, multiple uses may be served by estimating the same indicators over the same population (for example, a survey among Rohingya refugees forcibly displaced to a Bangladeshi camp could measure CDR since the start of attacks against civilians in order to document pre-displacement mortality[15], but could simultaneously compute estimates over the previous 3mo so as to help benchmark the public health situation in the camp): this will make data collection more efficient. However, it is important to verify whether involving a new set of stakeholders will not negate the original main uses of the estimate (e.g. data collection might be planned to monitor the humanitarian response; simultaneously collecting data for war crimes prosecution might result in warring parties denying authorisations for the study or refusing to engage with the findings).

2.2 Is a mortality estimate actually useful?

Before undertaking mortality estimation, it is worth reviewing carefully whether a mortality estimate will in fact be useful.[16] If any of the following criteria apply, plans for mortality estimation should be re-considered:

- Data of robustness sufficient for action (see Section **Error! Reference source not found.**) are already available, e.g. from previous estimation efforts, or are being / will be collected by other groups;
- By the time data are collected and analysed, they will be too late to support their intended applications (e.g. a specific funding decision moment will have been missed);
- There is no realistic pathway to action, either in the short or long term, and no clear plan for study dissemination;
- **The picture of public health needs is already sufficiently clear**, or, otherwise put, fresh mortality information would realistically not alter needs analysis and resource allocation. This last point is particularly important: a well-conducted **public health situation analysis[17]**, informed by secondary data or rapid ground assessments, should, in most instances, enable confident, albeit broad projections of the expected excess mortality, and inform decisions about which humanitarian services to offer where, and with what intensity. Mortality estimates for the purpose of informing the humanitarian response would thus only be useful (i) when there is genuine doubt about the extent of excess deaths or the contribution of different causes of death, or (ii) when, despite the picture being clear, humanitarian actors fail to pay sufficient attention to the crisis (i.e. mortality estimation is conducted to provide a basis for more objective resource mobilisation).

2.3 Selecting the appropriate mortality indicators

The choice of indicators to estimate should follow on from the intended uses of mortality information (Table 2). Additional considerations, however, are warranted:

- In practice all available methods (Chapter 3) allow for both the CDR and the U5DR to be estimated simultaneously. The U5DR is of particular interest because of the high importance assigned across cultures to preserving the life of children, and because it is plausibly more sensitive than CDR to changes in risk factors for mortality (e.g. food insecurity and nutritional status; overcrowding; insufficient health services), i.e. it provides an earlier, more sensitive signal of deteriorating conditions.
- Estimation of the excess death rate is generally doable within a range (see Section 3.3), provided that CDR (or U5DR for excess child deaths) is known. Estimating excess mortality is more useful for interpretation than presenting CDR alone (Chapter 4).
- Computing the excess death toll requires an estimate of the excess death rate, but also critically depends on the robustness of data on the population denominator, and should therefore only be quantified if population figures are available or can be estimated (Chapter 3).
- The **IMR, NMR and MMR**, while potentially useful, are formidably difficult to measure robustly in crisis settings (see Section 3.3).
- On the other hand, measuring mortality among specific age groups, e.g. **the elderly** (usually defined as ≥ 60y old), is theoretically no more challenging than for U5DR, and may be particularly relevant in institutional settings (e.g. care homes, psychiatric institutions) or in crises where these are particularly vulnerable age groups (e.g. eastern Ukraine). A ≥60y death rate, however, should

be stratified into smaller age groups (e.g. 5y increments), and age standardised rates should be presented to enable meaningful interpretation (e.g. taking the Japanese population as reference).

2.4 Specifying the appropriate period and timing of estimation

Generally, **for human rights advocacy or documentation** uses one should attempt to capture the entire period over which armed conflict or violent attacks against civilians are known to have taken place, as exemplified by a recent estimate of Yazidi deaths in Iraq.[18] By contrast, **for humanitarian uses** the period of measurement should be as close to real-time as possible, the only justifiable limitation being methodological (e.g. surveys with very short retrospective periods have unfeasibly high sample size requirements[13]: see Section 3.1). A period longer than 3mo is unlikely to meaningfully represent the current situation.

In the acute phase of crises, mortality can increase suddenly due to epidemics or worsening nutritional status: a high frequency of mortality measurement (at least once per month) is thus warranted, and the first estimate should be available within the first month of the emergency. **In the protracted phase**, quarterly estimates are probably sufficient. If prospective community surveillance is undertaken (see Section 3.1), it may be possible in theory to generate weekly estimates (or even daily in the case of a major epidemic): while these are useful to closely monitor trends, in small population units (e.g. < 50,000 people), chance fluctuation over increments of a day or week will usually make it very difficult to pick up a signal of deterioration out of the random noise, and month-by-month analysis will be more interpretable.[19]

Of note, **excess mortality attributable to the crisis does not stop when the crisis ends**. Rather, long-term health system disruptions, delayed onset of disease contracted due to crisis conditions (e.g. tuberculosis cases resulting from life in overcrowded camps), and the physical effects of mental health problems may manifest over decades and across generations.[20,21] Efforts to document such long-term excess mortality have been scant, but require well-designed cohort studies that are beyond the scope of this paper.

2.5 Ethical considerations

Whether mortality estimation requires **ethics committee review** depends largely on the method to be employed and the intended uses of data. Generally, if mortality estimates are to be used for routine humanitarian response applications, such as analysing needs or monitoring an ongoing response, they are considered exempt from ethics committee review: accordingly, local SMART-like surveys and prospective surveillance systems are rarely subjected to such review. In practice, it is understood that such data collection satisfies the essential public health surveillance function of the (humanitarian) health system. Other or additional uses of data, however, e.g. advocacy or war crime investigation, do warrant ethics committee review and approval.

Irrespective of the intended uses of data, ethics review is also strongly recommended when new methods are being tested, or when the risk-benefit balance of conducting estimation is not straightforward (see below). Generally, ethics committee review is always advisable, and most committees not based in the country of data collection expect that local committees are also consulted. Scientific journals also uniformly demand evidence of ethics approval to publish mortality studies. However, unless the committee(s) can offer expedited review, ethics approval delays may negate the benefits of data collection, which in itself may be ethically dubious. To address this, the Médecins Sans Frontières Ethics Committee has pre-approved generic protocols for retrospective mortality surveys, thereby greatly expediting approval of its studies based on these protocols[22]: such arrangements should be put in place by all actors planning to conduct mortality estimation in various settings.

Of note, authorisations for data collection by country or local authorities are not a replacement for ethics committee approval, and, vice versa, denied or unsought authorisation does not necessarily mean data collection is unethical (see Section 4.2).

While ethics committee review can enhance the ethical conduct of estimation studies, it is imperative to proactively conduct, and document, a **risk-benefit assessment** of any proposed data collection, if necessary involving appropriate stakeholders (e.g. decision-makers who will ultimate use the estimates, or context experts who can advise on the possible adverse consequences of the study for humanitarian access). At a minimum, the following risks need to be assessed:

- Death, injury or psychological harm of people from whom data are collected, e.g. by way of retribution for sharing information or through recall of traumatic events;
- Death, injury or psychological harm of staff involved in data collection and analysis, either during fieldwork or by way of retribution;
- Reduction in humanitarian access or imposition of other restrictions on the work of humanitarian actors, as a result of their support for the study;
- Opportunity costs of conducting estimation, such as reduction in funding for other health information services or diversion of staff attention from life-saving activities.

Identifying substantial risks does not automatically mean estimation should be abandoned, particularly if the potential benefits are considerable: instead, alternative methods and mitigation measures should first be considered.

Irrespective of whether ethics review is sought, **important ethics principles** must be adhered to when planning and implementing data collection.[23] In particular:

- All reasonable measures should be taken to minimise risk for data providers (e.g. households) and collectors. In particular, data confidentiality should be ensured and data providers should not be identifiable (this may include arrangements to administer questionnaires in safe locations);
- Data providers should be offered informed consent, verbal or preferably written. Forms of community consent may be appropriate for prospective surveillance systems.[24]

3 Methodological options and requirements

3.1 Brief description of the main available methods

Retrospective household survey. In this approach[13,14,25], a representative sample of households is selected from the population: sampling methods include simple random sampling, systematic random sampling, spatial sampling and, more commonly, various forms of cluster sampling, a default option adopted when, as is often the case, a sampling frame of individual households is not available or cannot readily be constructed. Sampling designs may be made relatively complex to enable independent estimates for sub-populations (e.g. by district, or camp of residence) to be computed with sufficient precision (this is known as stratification).

Teams of data collectors visit each sampled household and, if consent is provided, interview senior members of the household using a standardised structured questionnaire that, at a minimum, attempts to capture the composition of the household and demographic events (births, deaths, in- and out-migration) over a recall period of interest. Various questionnaires have been used, though the SMART initiative[26] has developed a widely adopted standard protocol for anthropometric and mortality surveys, complemented by sampling design, data management and automated analysis software (ENA). Of note, these questionnaires have never been rigorously validated, and response biases (e.g. under-reporting of infant deaths; inflation of the household size; misallocation of an event within or outside the recall period) are believed by experts to be the main limitation of these surveys.[13] A few key measures (rigorous training and field piloting; registering and asking about individual household members as opposed to aggregate totals; use of a local calendar of salient events to help with date recall) are recommended to mitigate these potential biases.

Retrospective surveys enable estimation of death rates with associated confidence intervals. They are thus subject to imprecision as well as the sum effect of any sampling and response biases, which may result in over- or under-estimation even when the estimate appears very statistically precise (i.e. narrow confidence interval).

Example sample sizes for a retrospective survey are provided in Table 3, assuming a simple scenario without any stratification of estimates for sub-populations: this shows how difficult it is, in sample size terms, to come up with very recent death rate estimates. An inherent limitation of mortality surveys is thus that they reflect past mortality: the assumption that the situation has remained the same is rarely appropriate, particularly in dynamic acute emergency scenarios. This considerably hinders the usefulness of such surveys for informing the humanitarian response.

Large surveys to estimate mortality at the crisis-wide scale have been conducted in the Democratic Republic of Congo[27], Darfur[28], northern Uganda[29], Iraq[7,30] and other settings, including more recently for documenting pre-displacement mortality among Rohingya refugees in Bangladesh.[15] These surveys are generally high-profile and have been subjected to intense methodological criticism or political controversy.[31-33] On the other hand, they appear to have played a pivotal role in scaling up resource mobilisation for certain crises (Democratic Republic of Congo, Darfur and northern Uganda).

Table 3. Example sample sizes (number of households) for a mortality survey, assuming a desired relative precision of ± 25%.†

Death rate (per 10,000 person-days)	Recall period			
	1 month	3 months	6 months	12 months
Crude death rate				
0.5	16,728	5576	2788	1394
1.0	8364	2788	1394	697
2.0	4182	1394	697	349
Under 5y death rate				
1.0	41,820	13,940	6970	3485
2.0	20,910	6970	3485	1743
4.0	10,455	3485	1743	871

† Additional assumptions: cluster sampling with design effect of 1.5; infinite population size; mean household size of 5; proportion of the population aged under 5y of 20%; and a proportion of non-response of 20%.

Prospective community surveillance. This approach, also known in stable settings as vital events registration, is methodologically far simpler than surveys, but costlier: it entails at a minimum collecting information on deaths on an ongoing basis, and, if population estimates are not available, carrying out (and regularly updating) a population count. Because in nearly all crises many or most deaths occur outside health facilities, data collection must be community-based, and is generally done by home visitors (usually around one per 1000 population) appointed to specific localities (or camp sectors). In rare circumstances it may also be possible to count deaths by tallying burial shrouds distributed or freshly dug graves.

Mortality surveillance is easiest and cheapest to organise and monitor in urban or camp settings, where data collection should be exhaustive (i.e. cover all households), but the method has also been validated in rural scenarios with a more complex sentinel site approach.[19] The main advantage of prospective surveillance is that its real-time estimates are immediately applicable to the humanitarian response. Home visitors can also be tasked with other measurement activities (e.g. screening children for malnutrition; registering new pregnancies). However, such systems are known to deteriorate with time (leading to artificial decreases in the measured death rate) unless home visitors are incentivised and supervised closely, and communities see the continued benefit of providing information.[34,35]

Key informant interviews. A few studies have tested key informants in the community as sources of information on deaths. The so-called informant method[36] relies on focus group discussions to rapidly identify three sets of informants (e.g. community midwives; religious leaders; health workers), who are asked to lead data collectors to households with recent deaths. Total mortality is estimated after removing any multiple reports of the same deaths occurring in different lists. The method was trialled in four crisis settings, but achieved a moderate sensitivity (50-70% deaths detected).[36] Aside from incomplete detection, the method's main limitation is that it only generates the numerator of death rate, with the denominator (population) needing to be estimated if not already available. On the other hand, the method is highly efficient[37] at identifying deaths, and can provide a precise estimate over very recent period (1-2mo), i.e. of relevance for humanitarian applications.

Verbal autopsy. Deaths in the community are rarely subject to medical ascertainment of cause of death, and information provided by next-of-kin is known to be medically unreliable. As an alternative, different verbal autopsy questionnaires have been tested, that classify cause of death on the basis of structured information on demographics, signs and symptoms and medical history as related by next-of-kin respondents. The WHO verbal autopsy questionnaire is most well-established and is now complemented by InterVal software for automatically attributing cause of death, thereby improving its feasibility by removing the need for expert clinician analysts.[38] However, there is increasing evidence that verbal autopsy methods, already known to be only partly accurate, may in fact be even less robust when tested against objective clinical autopsies.[39] The method is thus likely to be accurate mainly for broad groupings of causes of death. Moreover, the questionnaire is long (about 40-60 minutes per death). Verbal autopsies however can complement survey, surveillance or key informant methods to provide more accurate proportional mortality information. As an alternative or complement, social autopsies are a method to explore circumstances leading to death.[40]

Systematic "body count". This approach consists of capturing information from a variety of media and other publicly available sources on armed conflict incidents and deaths or injuries reported from these. Painstaking data management and removal of multiple reports referring to the same deaths results in an overall number of reported (trauma) deaths: an example of this approach is the Iraq Body Count project set up in the aftermath of the 2003 US-led coalition invasion.[41] Databases of people killed collected by civil society groups also provide sources for this kind of analysis, as exemplified by UN-commissioned estimates of people killed in Syria.[42] This method is restricted to documentation of intentional trauma deaths, requires databases that contain sufficient detail to distinguish multiple reports of the same death or conflict event, and, critically, only provides a minimum number of deaths: depending on the setting, a varying and potentially large number of deaths may not be reported by any sources.[43]

Capture-recapture analysis. Also known as multiple systems estimation, this approach consists of establishing separate, independent lists of deaths (usually between two and four), composed from databases (hospital records, civil society human rights groups) or key informants. Statistical methods are then used to analyse the overlap among lists, and estimate the number of deaths not occurring on any list, which are then summed to those reported by at least one list to give total mortality. The approach has been used prominently to estimate numbers of people killed and abducted in various armed conflicts, providing key evidence for war crimes prosecutions (e.g. former Yugoslavia[44]) and truth and reconciliation proceedings (e.g. Guatemala[45]).

This approach also requires a population denominator to be constructed separately, if not already available, so as to compute death rates. It is, however, an obvious extension of community surveillance, key informant interviews and "body count" methods, as all of these generate lists that are potentially amenable to capture-recapture analysis.

Statistical regression. This approach relies on identifying a set of risk factor variables (e.g. food insecurity, displacement, conflict intensity, public health service availability, epidemic occurrence, etc.) that, taken together, predict mortality with acceptable accuracy. A statistical model is essentially a mathematical formula that outputs an estimated value for the death rate, provided the values of these risk factor variables are known. The approach was used in Darfur[46], and, more comprehensively, in Somalia[47] and South Sudan[48], alongside demographic analysis of available population and displacement data, to estimate the death toll of a food security and famine crisis (2010-2012) and civil war (2013-2018), respectively. The approach draws from the general methods of small area estimation[49].

This option has the key advantage of providing an estimate even where no ground data collection (e.g. surveys) can be done because of insecurity. It enables efficient estimation for small geographical areas and periods, and quantifies associations between specific risk factors and mortality, helping to better characterise the crisis and lending internal validity to the findings. However, it requires extensive data management and very strong statistical expertise. Moreover, a critical ingredient is the availability of data points on mortality that can be used to fit and validate the model. In Somalia, these data points were 186 small-area SMART surveys conducted across the affected region before and during the crisis.

Statistical modelling of mortality is being explored in other current crises, with improved statistical methods and an emphasis not just on retrospective estimation, but also on predicting future mortality over a reasonably short time horizon (e.g. 3-6mo). Results however are not yet available at the time of writing. The approach is, however, likely to only work where a sufficient number (indicatively, >60-80) of small-area surveys or other mortality data points is available to fit a locally valid model – and, moreover, where data on risk factors are plentiful and continuously collected across the crisis area, even where mortality surveys are not being done.

3.2 Choosing the appropriate method

The **inter-dependency of available methods** is shown in Figure 1. Verbal autopsies are a complement to surveys, surveillance or key informant interviews. Surveillance, key informant interviews and systematic "body counts" may all be used to generate lists for capture-recapture analysis. Survey and surveillance estimates can feed into statistical modelling.

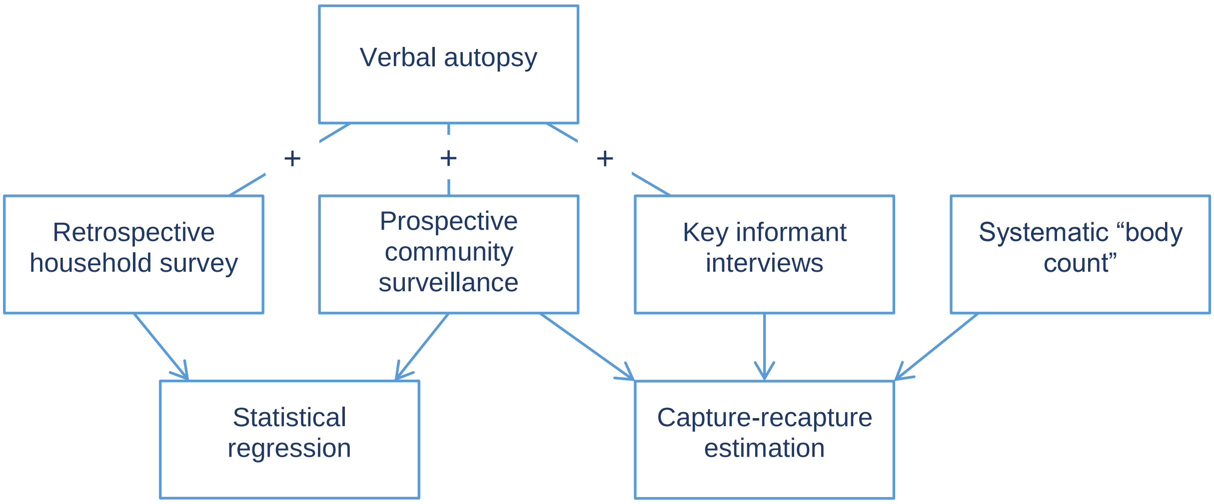

Figure 1. Inter-dependency of mortality estimation methods.

Strengths, limitations, approximate resource requirements and appropriate applications of the different methods are summarised in Table 4.

Table 4. Comparison of the main mortality estimation methods.

Method	Main strengths	Main limitations	Approximate resource requirements†	Applicability (indicators)
Retrospective household survey	Applicable wherever there is access Can rapidly generate an estimate Can reconstruct mortality over a given period in the past Can simultaneously estimate prevalence of acute malnutrition and other public health indicators	Reflects mortality in the past rather than the present High potential for sampling and response biases if poorly designed and implemented	100,000-300,000 USD (one-off)	CDR, U5DR, Excess death rate, Death rate due to trauma injury, Excess death toll (requires population estimate)

Method	Main strengths	Main limitations	Approximate resource requirements†	Applicability (indicators)
Prospective community surveillance	Allows for real-time monitoring and reaction to deteriorations Home visitors can also perform other screening / measurement tasks	Deteriorates with time without ongoing supervision and incentives for reporting Less feasible in rural, dispersed settings or where supervision is remote	50,000-100,000 USD core costs + 0.5-2 USD per capita population (one year)	CDR, U5DR, Excess death rate, Death rate due to trauma injury, Excess death toll
Key informant interviews	Can generate an estimate that is almost real-time (previous 1-2mo) Rapid	Probably subject to under-estimation Limited experience with field use	100,000-300,000 USD (one-off)	CDR, U5DR, Excess death rate, Death rate due to trauma injury, Excess death toll (requires population estimate)
Verbal autopsy	Can establish main causes of death where no medical diagnosis is available (i.e. at community level)	Lengthy questionnaire Limited accuracy	10,000-30,000 USD (as add-on to other studies)	Proportional mortality
Systematic "body count"	Based on public sources; can be done remotely Can also explore typology of trauma deaths and injuries (e.g. weaponry used)	Subject to under-estimation: only provides a minimum number of deaths	50,000-200,000 USD (one year)	Death toll due to trauma injury
Capture-recapture analysis	Lists required for analysis may already be available Theoretically superior to methods that rely only on one source of data	Lists need to contain enough identifier information Statistical requirements may make the method inapplicable in some contexts	30,000-100,000 USD (as add-on to other studies)	More feasible: Death toll due to trauma injury Less feasible: CDR, U5DR, Excess death rate, Excess death toll (requires population estimate)
Statistical regression	Generates an efficient estimate that can be stratified by area and period Good option where many areas are inaccessible, i.e. surveys or surveillance are unfeasible	Statistically complex May only work if sufficient small-survey and mortality risk factor data are available to fit a model	50,000-100,000 USD (one-off)	CDR, U5DR, Excess death rate, Excess death toll (requires population estimate) Death rate and toll due to trauma injury (if trauma deaths are systematically reported in data points used to build the model)

† Assuming estimation is conducted at the scale of the entire crisis.

Ultimately, **the choice of which method (or combination of methods) to adopt** should be taken in consultation with method experts. The following decision process is suggested:

1. Decide on the intended uses of mortality estimation;
2. Select indicators, population of interest and a timing and frequency of estimation that enable these uses;
3. Establish whether a new mortality estimate is truly warranted;
4. Identify methods that can estimate the indicators of interest;

5. Consider the feasibility of the alternative methods, given security, logistics and resource constraints;
6. If relevant, consider the opportunity provided by a given method of simultaneously estimating other public health indicators, e.g. prevalence of acute malnutrition.

To some extent, opportunistic considerations may drive the choice of method:

- In camps or urban settings where the affected population is easily reachable, it is strongly advisable irrespective of mortality information needs to set up a network of home visitors to undertake various measurement and case finding / screening tasks: including prospective mortality surveillance among these tasks is usually sensible and efficient, though not without a commitment to ongoing supervision;
- In many crises, nutritional surveillance relies on conducting regular, small-site anthropometric surveys (using the SMART method) across the affected population[1,50]: adding or enhancing the mortality component of these surveys can provide useful information on crisis-wide patterns, and data points for the statistical modelling approach.

One must also be prepared for a scenario in which no single method can feasibly be implemented with sufficient quality to generate a robust and thus useful estimate.

3.3 Key methodological challenges

Estimating baseline mortality. The excess death rate can only be computed if an estimate of the baseline, i.e. the death rate that the population would have experienced in the absence of a crisis, is subtracted from the total CDR. This baseline is a counter-factual quantity that cannot be measured directly. Instead:

- In natural disasters or relatively recent armed conflicts, a simple but reasonable approach is to consider the pre-war death rate as the baseline[5], as long as one or more robust estimates are available, e.g. from a census or crisis-wide demographic and health survey; where multiple estimates are available, these can be triangulated to compose a plausible high-low range; it is critical however that baseline estimates refer to the same crisis-affected population (e.g. district), rather than a different region or population group;
- In very protracted crises (e.g. Afghanistan, eastern Democratic Republic of Congo), relying on the pre-war death rate as the baseline (i.e. referring to decades ago) clearly would not take into account the secular reductions in mortality that would plausibly have occurred in the absence of a crisis: some projection of realistic death rates in the absence of an armed conflict should thus be made;
- When a new emergency is superimposed onto a pre-existing crisis, one may wish to zero in on excess mortality attributable to this new emergency: for example, in a study of excess deaths due to the food insecurity emergency in Somalia during 2010-2012[47], mortality attributable to pre-existing armed conflict was considered part of the baseline;
- Whatever the method of estimating the baseline, it is strongly recommended to refrain from presenting a single figure for the excess death toll, and instead provide a range that takes into account imprecision in the CDR and high-low scenarios for the baseline death rate.

Fragmented populations. When populations migrate, individual households or entire communities may split (e.g. some household members, or entire households or villages may stay behind or migrate to other sites): if this phenomenon is suspected to be prevalent, studies seeking to document the mortality experience of such populations before or during displacement[51,52] need to adapt questionnaires so as to capture data not just on people who have arrived (e.g. Rohingya refugees in Bangladeshi camps), but also on those who are elsewhere: at a minimum, this will provide some information on the extent of mortality that may have been missed by the study.

Survival bias. In situations where deaths are very clustered in space (e.g. resulting from airstrikes[9] or an earthquake[53]), entire households can disappear or disintegrate, leaving no survivors who are able to report these deaths, e.g. during a survey. This leads to under-estimation of mortality. Sensitivity analysis (whereby assumptions are made on the frequency of all-household mortality), statistical techniques to model the extent of survival bias, and adapted questionnaires that solicit information on neighbour households, are options to mitigate this under-estimation.

Estimating maternal, neonatal and infant mortality. In a crisis, measuring mortality among these groups may be useful to illuminate gaps in maternal, neonatal and child health services, and to track progress towards development goals. However, standard methods for measuring the maternal, neonatal and infant mortality ratios require large, well-planned surveys, cannot provide estimates for recent periods, and key assumptions for these methods (e.g. a stable demographic structure of the population) are likely to be violated in a crisis due to displacement and fluctuations in death rate. Such methods should thus only be implemented if the situation is reasonably stable (i.e. there is good access to the entire population) and method experts confirm their feasibility. Some information on neonatal and infant mortality may be obtained by comparing the ratio of these deaths among all under 5y deaths, as observed in a retrospective survey or other estimation method, with the expected ratio in demographically similar, but not crisis-affected settings.

3.4 Areas for further methodological research

Despite the widespread collection of mortality data in crises to date, outstanding questions remain on the validity of available methods[54], and novel approaches also deserve rigorous testing. The following is a shortlist of methodological research questions that deserve further exploration:

- The retrospective mortality questionnaire used in SMART and similar surveys has not been formally validated in terms of its ability to correctly detect recent deaths and elicit reliable information on dates and ages; moreover, it is unclear to what extent respondents in different settings are able to provide reliable information on recall periods of varying duration;
- The extent to which prospective mortality surveillance systems require supervision and/or incentives to provide acceptably accurate estimates also remains unclear, particularly over long periods (e.g. years);
- Validation of shortened, simplified verbal autopsy questionnaires designed to broadly classify cause of death would enable better data to be collected on proportional mortality, with obvious benefits for prioritisation of public health interventions;
- Statistical prediction of past and/or future death rates using regression techniques should be explored further, as an aide to exploring what-if scenarios as well as monitoring the evolution of health status in real-time. Machine learning and other advanced statistical techniques could be adapted to tackle this prediction problem, and Bayesian approaches could be leveraged to transfer evidence on mortality predictor variables from previous crises into estimation in new scenarios.

4 Quality assurance and interpretation of mortality estimates

4.1 Increasing the robustness of estimates

Mortality estimation at the crisis-wide scale is a considerable undertaking, and findings may strongly influence humanitarian responses, with downstream effects on human life. It is therefore both ethical and efficient to take proactive steps to increase the robustness of estimates. Key steps include:

- Relying on centres of methodological excellence to advise on methods and undertake or closely supervise estimation;
- Arranging for review of the study protocol and the draft analysis and report by a panel of independent experts;
- Carefully recruiting local data collection staff, ideally looking for literate staff with prior clerical or survey experience;
- Carrying out extensive training on and field piloting of the questionnaire and method, and undertaking spot check audits of data collection;

- Budgeting accurately to capture all costs and contingencies: doing mortality estimation on a shoe-string will usually result in a disappointing product.

4.2 Ensuring acceptance of mortality estimates

Criticism of and failure to accept findings may reflect political considerations (e.g. some warring parties may wish to obfuscate objective information on the effects of their actions) or the agendas of humanitarian and human rights advocacy actors, some of whom may mistrust the findings based simply on who is sponsoring the study or may be disappointed that the findings do not support their advocacy narrative.

Measures to enhance acceptance of mortality findings include:

- Anticipating likely sensitivities, and engaging different stakeholders openly and early in the process;
- Making a clear and early commitment to releasing findings, agreeing specifically on which analyses will be presented, and working in coordination (e.g. if a cluster mechanism is sponsoring the estimate, key cluster led agencies, UN OCHA and other important humanitarian actors should be fully aligned on supporting study dissemination);
- Holding dissemination events in country, with ample time to explain methods;
- Publishing methods, statistical code and (if possible) curated, anonymised data to a level of detail sufficient to enable independent replication of the study;
- Openly acknowledging limitations and carrying out sensitivity analyses to explore the possible impact of these limitations on the estimates;
- Presenting ranges of mortality as much as possible, rather than misleadingly accurate point estimates.

A common criticism by non-technical stakeholders, when large projected death tolls are presented, is that "so many deaths could not possibly have gone unnoticed." This belies several misunderstandings: (i) in a large population, substantial excess death tolls can result from even moderate, hardly perceptible elevations in mortality (for example, a rise in CDR from 0.3 to 0.5 per 10,000 person-days over 12 months in a population of 3 million equates to about 22,000 excess deaths): even in resource-rich Western Europe, some 70,000 estimated excess deaths resulting from a 2003 heat wave[55] went largely unnoticed until demographic surveillance data became available; (ii) unless the population utilises only a few visible, demarcated burial sites, even an unusually large number of deaths will be difficult to physically notice; (iii) humanitarian actors do not necessarily have strong awareness of what the population is experiencing – this only happens when communication with beneficiaries is proactive and based on trust.

Despite the above measures and explanations, there may be situations in which governments or other warring parties are simply unwilling to sanction or accept the findings of mortality estimation. Conducting mortality estimation in spite of this opposition may, however, still be warranted on humanitarian or war crimes investigation grounds.

4.3 Common pitfalls of mortality data

When interpreting mortality information in the humanitarian sector, end-users of the data should cast a critical eye on how data were collected, and be aware of several common pitfalls:

Bias

- Humanitarian documents, e.g. citing disease surveillance data, often report deaths occurring in health facilities: in nearly all crises these are only a fraction and usually a minority of all deaths, and can thus not be used to quantify population mortality;
- Cause-of-death information may be reported, but, unless it is known to be the result of recommended verbal autopsy methods, it should not be heavily relied upon for action, unless the cause of death being reported is relatively unequivocal, e.g. violent trauma or an epidemic disease

with very specific signs and symptoms, e.g. measles rash. Deaths reported as due to malnutrition are particularly problematic, as in fact most people with malnutrition die of infections;

- Declining mortality trends from prospective community surveillance may genuinely reflect improving conditions, but may also be due to an inadequately supervised, deteriorating surveillance system;
- Unexpectedly low CDR and/or U5DR estimates from retrospective surveys may also reflect poor data collection practices, e.g. hurried administration of questionnaires or a lack of training and field piloting: this may occur in particular when the survey is done primarily for reasons other than mortality estimation, e.g. SMART anthropometric surveys; under-reporting of neonatal and infant deaths is a particular concern;
- Further bias may result from poor sampling design; while nuances of sampling methods can be complex to interpret, obvious problems include failure to sample areas or populations (e.g. due to insecurity) where mortality may plausibly be assumed to be higher, or clearly non-representative sampling designs (e.g. communities or households to sample are selected purposively, not at random);

Imprecision

- Whether or not the estimate is biased towards over- or under-estimation, it may be subject to considerable imprecision if it is based on any method other than exhaustive community surveillance or systematic “body counts”. The extent of imprecision should be presented as a **confidence interval** (failure to do so indicates poorly competent analysis). A 95% confidence interval means that one is 95% certain that the true value of mortality lies somewhere within the interval; the point estimate is the most likely value, and values closer to the point estimate are more likely than at the periphery. Presenting 95% confidence intervals is a convention; for humanitarian applications, a lower level of confidence may well be acceptable to inform urgent decisions, i.e. one could instead compute an 80% interval.

Inaccurate extrapolation

- Extrapolation refers to applying mortality data collected from a given period and population to a different period or population. For example, one might take estimates from a survey and assume they will continue to apply into a period into the future. This is rarely advisable as it involves assumptions that are untestable at best and inappropriate at worst. Mortality reports based on extrapolation should be treated with scepticism.

4.4 Interpretation and action

The extent to which a mortality estimate should be used to influence humanitarian decision-making depends on three questions:

1. **How critical is mortality information?** Otherwise put, what steps or decisions cannot be confidently taken without the mortality estimate?
2. **How robust is the mortality estimate?** Which direction is any bias likely to have? How wide is the confidence interval? The answer relies on critical review of data collection and analysis, ideally with the advice of method experts;
3. **What are the risks of acting based on poor information?** If mortality were substantially over-estimated, would this result in unacceptable waste of resources or opportunity costs (e.g. diversion of funding away from other needy crises)? If mortality were substantially under-estimated, would this result in a neglect of the affected population, and an inadequate humanitarian response, with obvious consequences for human health?

Table 5 suggests appropriate decisions on using the estimate, based on the above questions.

Table 5. Suggested matrix for deciding whether to use mortality estimates.

		What are the risks of using the mortality estimate?			
		No major issues with robustness, no foreseeable risk of using the estimate	The estimate is very imprecise (wide confidence interval), though not necessarily biased	There is possible over-estimation bias, and this entails risk (e.g. inefficient resource allocation)	There is possible under-estimation bias, and this entails risk (e.g. neglect of affected population)
How critical is mortality information?	Critical – Could enable major decisions to be taken	Use the estimate confidently	Use the estimate cautiously, weighing it with other available contextual information	Use the estimate cautiously, weighing it with other available contextual information	Refrain from using the estimate
	Useful – Could improve decision-making, though decisions would be taken either way	Use the estimate confidently	Use the estimate cautiously, weighing it with other available contextual information	Refrain from using the estimate	Refrain from using the estimate
	Not critical – Would not result in important decisions	Keep the estimate on record and prepare to use it if/when relevant	Keep the estimate on record and prepare to use it if/when relevant	Refrain from using the estimate	Refrain from using the estimate

A few **good practices in interpretation** are worth noting:

- Arbitrary **emergency thresholds** for CDR (e.g. 1 death per 10,000 person-days, or a doubling compared to the regional average) and U5DR (as for CDR, but about twice as high) have been widely adopted in the past decades, but are in fact overemphasised.[2] What matters much more is *how elevated* the death rate is (i.e. the excess death rate compared to a plausible baseline), *how long* this elevation lasts for, and *how many people* experience this elevation: these three parameters multiply to yield the excess death toll. In this respect, one may readily demonstrate that the relatively small elevations from the baseline that probably characterise large protracted crises (e.g. in the Central African Republic or northern Mali) ultimately cause a far higher death toll than short-lived spikes in CDR within small, accessible refugee camps. On the other hand, such acute elevations do usually indicate a failure of securing humanitarian access and/or preventing fairly predictable problems such as food insecurity or measles and cholera epidemics.
- When presented with multiple mortality estimates for an overlapping period or population, the best approach is to, at least qualitatively, come up with a rough average after weighting each concurrent estimate based on its relative robustness;
- Whatever the level of mortality observed, it is crucial to always interpret findings in context, and as part of a wider situation analysis. This will help on the one hand to explain and externally validate the findings, and on the other hand to refine the analysis of public health needs or violations of international law by grounding them in objective mortality data.

Ultimately, a **range of actions** may be considered in response to mortality information, corresponding to its possible applications (Table 2):

- Increase financial contributions to the humanitarian response;
- Address inadequacies in the design of public health interventions (e.g. gaps in the package of public health services; the modality with which these services are being offered to the population);
- Rapidly identify and respond to emergent threats to health, e.g. unrecognised epidemics or treatment interruptions for chronic diseases;

- Identify and ameliorate geographical gaps in service availability, instances of low coverage or problems with quality;
- Advocate for increased protection of civilians, and implement measures to reduce exposure to violence (e.g. relocate IDPs to safer areas);
- Refer findings to legal instruments for investigation and prosecution of war crimes.

Generally, information is critical to shape and improve humanitarian responses. Population mortality estimates, too, should never be overlooked or simply dismissed; rather, they should be considered critically and integrated, to the extent appropriate, into humanitarian decision-making at the highest level.

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