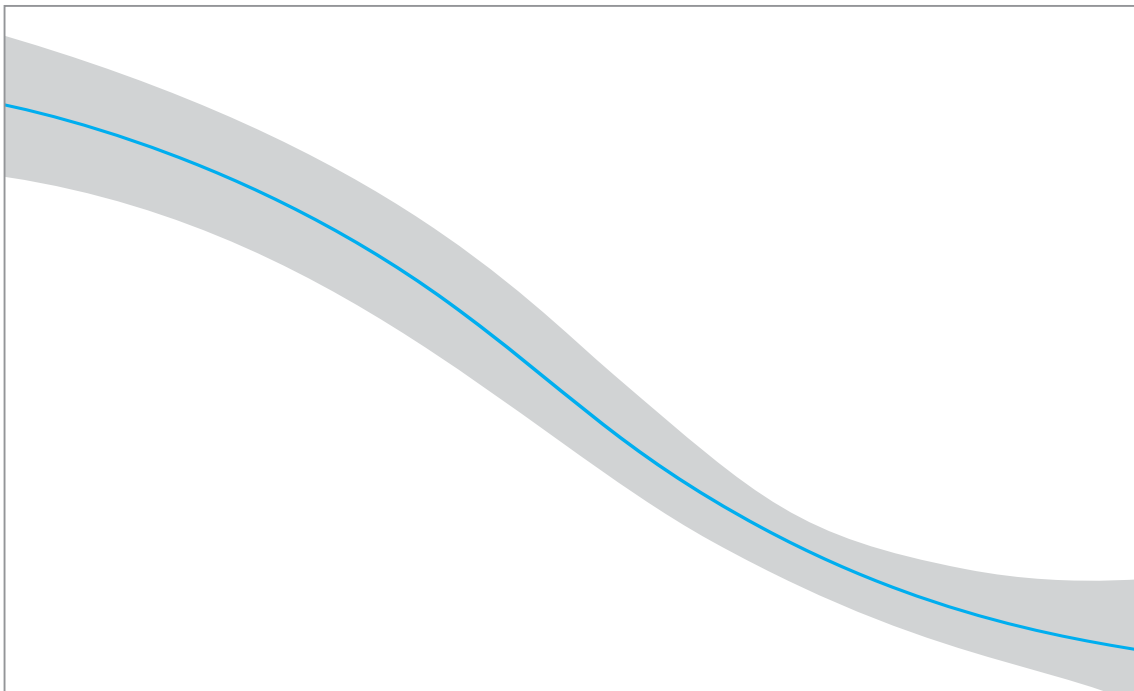


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Explanatory Notes

## Child, adolescent and youth mortality trend series to 2022



United Nations Inter-agency Group for Child Mortality Estimation (UN IGME)  
Member agencies: UNICEF, the WHO, the UN Population Division and  
the World Bank Group

March 2024

The United Nations Inter-agency Group for Child Mortality Estimation (UN IGME), which includes members from UNICEF, the World Health Organization (WHO), the United Nations Population Division (UNPD), and the World Bank Group, was established in 2004 to advance the work on monitoring progress towards the achievement of child survival goals.

In accordance with the decision by the Statistical Commission and the United Nations Economic and Social Council resolution 2006/6, UN IGME child mortality estimates are produced in consultation with countries. UNICEF and the WHO engage in joint country consultation on Sustainable Development Goal (SDG) indicators 3.2.1 (all countries aiming to reduce under-five mortality to at least as low as 25 deaths per 1,000 live births) and 3.2.2 (all countries aiming to reduce neonatal mortality to at least as low as 12 deaths per 1,000 live births), along with other related child mortality indicators.

The UN IGME released the new round of estimates in January 2024. The estimates will be also published in the United Nations SDG Indicators Global Database, *The State of the World's Children* by UNICEF and in the Global Health Observatory by WHO.

Methods used for the UN IGME child mortality estimates are summarized in this document, however methods to estimate child, adolescent, and youth mortality may differ for Member States depending on data availability and type of data. The UN IGME child mortality estimates have been revised to take account of new data. Therefore, this round of estimates may not be comparable with those published in the previous UN IGME reports<sup>1</sup> or World Health Statistics<sup>2</sup>.

## 1. Strategy

The UN IGME employs the following broad strategy to arrive at annual estimates of child mortality:

1. Compile and assess the quality of all available nationally representative data

relevant to the estimation of child and youth mortality including data from vital registration systems, population censuses, household surveys and sample registration systems;

2. Assess data quality, recalculate data inputs and make adjustments as needed by applying standard methods;
3. Fit a statistical model to these data to generate a smooth trend curve that averages over possibly disparate estimates from the different data sources for a country;
4. Extrapolate the model to a common target year for all countries (in this case, 2022).

To increase the transparency of the estimation process, the UN IGME has developed the Child Mortality Estimation (CME) web portal ([www.childmortality.org](http://www.childmortality.org)). This portal shows country, regional and global estimates, includes all available data on child mortality and indicates which data are currently officially used by the UN IGME. Once the new estimates are finalized, the CME web portal is updated to reflect all newly available data and the most recent estimates.

## 2. Data Sources

Nationally representative estimates of mortality can be derived from several different sources, including civil registration and sample surveys. Demographic surveillance sites and hospital data are excluded as they are not nationally representative. The preferred source of data is a civil registration system that records births and deaths on a continuous basis. If registration is complete and the system functions efficiently, the resulting estimates will be accurate and timely. However, many low- and middle-income countries do not have well-functioning vital registration systems, therefore, household surveys, such as the UNICEF-supported Multiple Indicator Cluster Surveys (MICS) and the USAID-supported Demographic and Health Surveys (DHS), and periodic population censuses remain the primary sources of data on childhood,

adolescent and youth (ages 0-24) mortality in these countries. These surveys ask women about the survival of their children and about the survival of their siblings, which provide the basis for childhood, adolescent, and youth mortality estimates for most low- and middle-income countries.

The first step in the process of arriving at estimates of levels and recent trends of childhood, adolescent and youth mortality is to compile all newly available data and add the data to the UN IGME databases. Newly available data will include newly released vital statistics from a civil registration system, results from recent censuses and household surveys and, occasionally, results from older censuses or surveys not previously available.

## 2.1 Data from civil registration systems

### 2.1.1 Under-five, infant and neonatal mortality

For data from civil registration, under-five mortality rates (U5MR, the probability of dying between birth and exactly 5 years of age, expressed per 1,000 live births) and infant mortality rates (IMR, the probability of dying between birth and exactly one year of age, expressed per 1,000 live births) are calculated using a standard period abridged life table. The inputs are number of deaths for age group <1 year (noted  $D_0$ ) and for the age group 1–4 years ( $D_{1-4}$ ), as well as the mid-year population for the same age groups ( $P_0$  and  $P_{1-4}$ ).

The formulae are as follows:

Given that:

${}_nq_x$  is the probability of dying between age  $x$  and age  $x+n$ ,

${}_1M_0 = D_0/P_0$ , death rate for age <1,

${}_4M_1 = D_{1-4}/P_{1-4}$ , death rate for age group 1-4,

Then:

$${}_1q_0 = {}_1M_0 / [1 + (1 - {}_1a_0) * {}_1M_0]$$

where  ${}_1a_0$  is the fraction of year lived by an infant who died

${}_1a_0 = 0.1$  for low mortality country and

${}_1a_0 = 0.3$  for high mortality country

$${}_5q_0 = 1 - (1 - {}_1q_0) * (1 - {}_4q_1)$$

where  ${}_4q_1 = 4 * {}_4M_1 / [1 + (4 - {}_4a_1) * {}_4M_1]$  and  ${}_4a_1$  is the fraction of years lived by a child aged 1-4 years who died

$${}_4a_1 = 1.6$$

Finally:  $IMR = {}_1q_0 * 1000$  and  $U5MR = {}_5q_0 * 1000$

The neonatal mortality rate (NMR, the probability of dying between birth and exactly 28 days of age, expressed per 1,000 live births) is calculated with the number of deaths of infants under 28 days of age and the number of live births each year.

In previous revisions UN IGME adjusted VR data for incompleteness in the reporting of early infant deaths in several European countries. For more details on the past adjustment see Notes<sup>i</sup>.

### 2.1.2 Mortality among older children aged 5–14 and youth aged 15–24

The calculation of the probability  ${}_{10}q_5$ , the probability a five-year-old would die before reaching age 15, is derived from a standard period abridged life table. The inputs are the number of deaths for age group 5–9 years (noted  $D_{5-9}$ ) and for the age group 10–14 years ( $D_{10-14}$ ), as well as the mid-year population for the same age groups ( $P_{5-9}$  and  $P_{10-14}$ ).

- The death rate for age group 5-9,  ${}_5M_5$  is obtained by dividing  $D_{5-9}$  by  $P_{5-9}$ .
- The probability  ${}_5q_5$ , which is the probability a five-year-old would die before reaching age 10, is obtained as  ${}_5q_5 = (5 * {}_5M_5) / [1 + (5 - {}_5a_5) * {}_5M_5]$ , where  ${}_5a_5$  is the average number of years lived by children who died in the age group 5-9 (set at 2.5 for all countries)
- The same calculation is applied for  ${}_5q_{10}$ , the probability a 10-year-old would die before reaching age 15.
- Finally,  ${}_{10}q_5 = 1 - (1 - {}_5q_5)(1 - {}_5q_{10})$

The calculation of the probability  ${}_{10}q_{15}$ , the probability a 15-year-old would die before reaching age 25, is also derived from the number of deaths for the age groups 15–19 years (noted  $D_{15-19}$ ) and 20–24 years ( $D_{20-24}$ ), as well as the mid-

year population for the same age groups ( $P_{15-19}$  and  $P_{20-24}$ ), using the approach detailed above.

In a few countries, vital registration data were incorporated to estimate mortality above age 5, despite being deemed too incomplete to be used for under-five mortality. Civil registration and vital statistics systems could capture a larger percentage of deaths of older children, adolescents and youth, as compared to the deaths of young children, which are more likely to be unreported, especially when they occur in the neonatal period.

To select country-years for which vital registration data are included for older children aged 5–14 and youth aged 15–24, and compute adjustment factors in case of incomplete registration, we used a hybrid of the generalized growth balance method (GGB) and the synthetic extinct generation method (SEG), the GGBSEG method, which is one several demographic methods known as “death distribution methods”<sup>3</sup> and has been shown to perform better than the GGB and SEG methods applied separately. The GGBSEG method is implemented in the DDM package of the R statistical software<sup>4</sup>. Completeness was estimated for each sex separately, for periods between pairs of recent censuses for which an age distribution of the population was available in the Demographic Yearbook<sup>5</sup>. The sex-specific completeness estimates were combined to obtain an estimate for both sexes. When the estimated completeness was less than 80 per cent, mortality rates derived from vital registration data were excluded from the model fit. When completeness was greater than or equal to 95 per cent, the registration was considered virtually complete, and no adjustment was used to adjust mortality estimates upwards. If completeness was between 80 and 95 per cent, we multiplied the number of deaths by the inverse of the completeness rate to obtain adjusted estimates. These adjustments are only applied to mortality data above age 5 as the death distribution methods cannot be applied to estimate completeness of registration of under-five deaths. No adjustment was applied

for countries included in the Human Mortality Database<sup>6</sup>, as their death registration data were considered complete. A more detailed description of the estimation of death registration completeness is provided elsewhere<sup>7</sup>.

### 2.1.3 Coefficient of variation

For civil registration data (with available data on the number of deaths and mid-year populations), annual observations were initially constructed for all observation years in a country. For country-years in which the coefficient of variation exceeded 10 per cent for children under 5 years or 20 per cent for children aged 5–24 years, deaths and midyear populations were pooled over longer periods. Starting from the most recent years, deaths and population were combined with adjacent previous years to reduce spurious fluctuations in countries where small numbers of births and deaths were observed. The coefficient of variation is defined to be the stochastic standard error of  ${}_5q_0$  ( ${}_5q_0 = \text{U5MR}/1,000$ ) or  ${}_1q_0$  ( ${}_1q_0 = \text{IMR}/1,000$ ) observation divided by the value of the  ${}_5q_0$  or  ${}_1q_0$  observation. The stochastic standard error of the observation is calculated with a Poisson approximation using live birth numbers, given by  $\sqrt{{}_5q_0 / \text{lb}}$  or similarly  $\sqrt{{}_1q_0 / \text{lb}}$ , where lb is the number of live births in the year of the observation. After this recalculation of the civil registration data, the standard errors are set to a minimum of 2.5 per cent for input into the model. A similar approach was used for neonatal mortality and mortality among children and youth aged 5–24 years.

## 2.2 Survey data

### 2.2.1 Under-five, infant mortality and neonatal mortality

The majority of survey data on under-five mortality is collected in one of two ways: the full birth history (FBH), whereby women are asked for the date of birth of each of their children, whether the child is still alive, and if not, the age at death; and the summary birth history (SBH), whereby women are asked only about

the number of their children ever born and the number that have died (or equivalently the number still alive).

FBH data, collected by all Demographic and Health Surveys (DHS) and increasingly also by Multiple Indicator Cluster Surveys (MICS), allow the calculation of child mortality indicators for specific time periods in the past. DHS and MICS usually publish under-five child mortality estimates for three 5-year periods before the survey, that is, 0 to 4, 5 to 9, and 10 to 14 years before the survey<sup>8,9,10</sup>. The UN IGME has re-calculated estimates to refer to calendar year periods, using single calendar years for periods shortly before the survey, and then gradually increasing the number of years for periods further in the past, whenever microdata from the survey are available. The cut-off points for a given survey for shifting from estimates for single calendar years to two years, or two years to three, etc., are based on the coefficients of variation (a measure of sampling uncertainty) of the estimates<sup>11</sup>.

In general, SBH data, collected by censuses and many household surveys, use the age of the woman as an indicator of the exposure time of her children to the risk of death and use models to estimate under-five mortality indicators for periods in the past for women aged 25 to 29 through 45 to 49. This method is well known but has several shortcomings. Starting with the 2014 round of estimation, the UN IGME changed the method of estimation for summary birth histories to one based on classification of women by the time that has passed since their first birth. This newer method has several benefits over the previous one: First, it generally has lower sampling errors. Second, it avoids the problematic assumption that the estimates derived for each age group adequately represent the mortality of the whole population. As a result, it has less susceptibility to the selection effect of young women who give birth early, since all women who give birth necessarily must have a first birth and therefore are not selected for. Third, the method tends to show less fluctuation across time, particularly in countries with relatively low

fertility and mortality. The UN IGME considers the improvements in the estimates based on time since first birth worthwhile when compared to the estimates derived from the classification by age of mother, hence in cases where the microdata is available, the UN IGME has reanalysed the data using the new method.

Moreover, following advice from the Technical Advisory Group (TAG) of the UN IGME, child mortality estimates from SBH data were not included if estimates from FBH data in the same survey were available<sup>12</sup>.

SBH data are not used to derive neonatal mortality.

### **2.2.2 Mortality among children aged 5–14 years and youth aged 15–24 years**

Mortality estimates of children aged 5–14 years can also be derived from the full birth history module. However, SBH data are not used to derive mortality among children aged 5–14 as the indirect methods have not been developed for this purpose.

Mortality estimates of adolescents and young adults aged 15–24 years were derived from the sibling survival histories (SSH). In SSH, women aged 15–49 years are asked to list all their siblings born to the same mother by birth order, and to report on each sibling's gender, survival status, current age, if alive, or age at death and years since death, if deceased. Sibling histories have been extensively used to model adult mortality in countries lacking vital registration and to monitor trends in maternal mortality.<sup>13,14,15</sup>

SSH were used to estimate the probability of a 15-year-old dying before reaching age 25 ( ${}_{10}q_{15}$ ) for a period of 0–12 years prior to each survey. This period was divided into intervals of various length (6, 4, 3, 2, 1 years) depending on the coefficient of the variation of the estimates. As with birth histories, sibling histories can be affected by under-reporting of deaths—living and deceased siblings can be omitted and ages

at survey or at death can be misreported. The time of death can also be affected by heaping or systematic misstatement. However, the magnitudes of these biases are likely to vary by age, and few studies have explored this issue for the 15–24 age group in particular. To account for the possibility of non-sampling bias in sibling histories, we used the Bayesian penalized B-splines bias-reduction model (or B3 model) developed by Alkema and New<sup>16</sup>, as detailed below. This model includes a data model that estimates the bias in SSH, both in terms of the level and the trend, as a function of the retrospective period. This bias is estimated by contrasting the sibling-based estimates with vital registration data for overlapping time periods (see section 3.1 below). Before adding the SSH estimates in the database, we also examined the age pattern of mortality contained in each DHS, contrasting the mortality rate of 15–24-year-olds ( $_{10}q_{15}$ ) from the SSH with the under-five mortality rate ( ${}_5q_0$ ) obtained from the FBH. We compared the  $_{10}q_{15}$ -to- ${}_5q_0$  relationship observed in the DHS with an expected pattern from life tables computed in complete vital registration data or other high-quality sources, such as Health and Demographic Surveillance Sites. In about 25 surveys, the  $_{10}q_{15}$  probability obtained from sibling histories was inconsistent with the level of under-five mortality, and these surveys were excluded from the model fitting.

### 2.3 Adjustment for missing mothers in high-HIV-prevalence settings

In populations severely affected by HIV/AIDS, HIV-positive (HIV+) children will be more likely to die than other children and will also be less likely to be reported since their mothers will have been more likely to die also. Child mortality estimates will thus be biased downwards. The magnitude of the bias will depend on the extent to which the elevated under-five mortality of HIV+ children is not reported because of the deaths of their mothers. The TAG of the UN IGME developed a method to adjust HIV/AIDS related mortality for each survey data observation from FBH during HIV/AIDS epidemics (1980-present), by adopting a set of simplified but reasonable assumptions

about the distribution of births to HIV+ women, primarily relating to the duration of their infection, vertical transmission rates, and survival times of both mothers and children from the time of the birth<sup>17</sup>. The method also incorporates the impact of antiretroviral therapies (ART) and prevention of mother to child transmission (PMTCT)<sup>18</sup>. This method was applied to all DHS and MICS surveys with FBH data. No adjustment was included for HIV-related biases in the age group 5–14, since no method currently exists to estimate the magnitude of this bias in the probability  $_{10}q_{5r}$  nor for mortality at ages 15–24, since vertical transmission of the virus is unlikely to introduce biases in the estimates, as mortality rates relate to the survival of the siblings of adult respondents.

### 2.4 Adjustment for rapidly changing child mortality driven by HIV/AIDS

To capture the extraordinarily rapid changes in child mortality driven by HIV/AIDS over the epidemic period in some countries, the regression model was fitted to data points for the U5MR from all causes other than HIV/AIDS, and then UNAIDS estimates of HIV/AIDS under-five mortality were added to the estimates from the regression model. This method was used for 17 countries where the HIV prevalence rate exceeded 5 per cent at any point in time since 1980. Steps were as follows:

1. Compile and assess the quality of all newly available nationally-representative data relevant to the estimation of child mortality;
2. Adjust survey data to account for possible biases in data collection and in HIV/AIDS epidemic;
3. Use UNAIDS estimates of HIV/AIDS child mortality<sup>19</sup> to adjust the data points from 1980 onwards to exclude HIV deaths;
4. Fit the standard statistical model (see Section 3) to the observations to HIV-free data points;
5. Extrapolate the model to the target year, in this case 2022;
6. Add back estimates of deaths due to HIV/AIDS (from UNAIDS); and

- For the epidemic period, a non-HIV curve of IMR is derived from U5MR using model life tables (see Section 4) and then the UNAIDS estimates of HIV/AIDS deaths for children under age 1 are added to generate the final IMR estimates.

## 2.5 Systematic and random measurement error

Data from these different sources require different calculation methods and may suffer from different errors, for example random errors in sample surveys or systematic errors due to misreporting. As a result, different surveys often yield widely different estimates of U5MR or other mortality indicators for a given time period. In order to reconcile these differences and take better account of the systematic biases associated with the various types of data inputs, the TAG has developed an estimation method to fit a smoothed trend curve to a set of observations and to extrapolate that trend to a defined time point, in this case, 2022. This method is described in the following section.

## 3. Estimation of under-five mortality rates (U5MR)

### 3.1 Summary of the statistical model

Estimation and projection of under-5 mortality rates was undertaken using the Bayesian B-splines bias-adjusted model, referred to as the B3 model. This model was developed, validated, and used to produce previous rounds of UN IGME child mortality estimates including those published in 2023. The infant mortality rate (IMR) is obtained by either applying the B3 estimation method or by applying a model life table to the U5MR estimates as described in Section 4. Mortality estimates in older children, adolescents and youth are also obtained from the B3 model, as described in Section 7. The model is introduced below in reference to the estimation of the under-five mortality rate.

In the B3 model,  $\log(\text{U5MR})$  is estimated with a flexible spline regression model, explained in section 3.2. The spline regression model is fitted to all U5MR observations in the country.

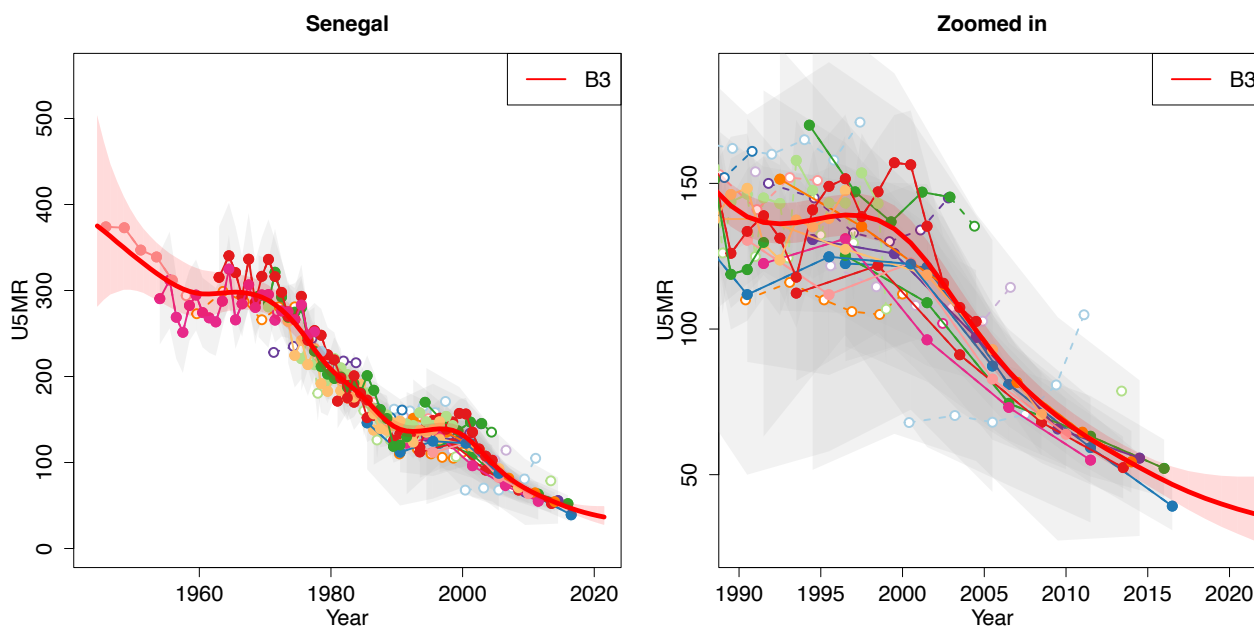


Figure 1: Illustration of the B3 model for Senegal. Left: Plot of the U5MR over time for Senegal, with the B3 estimates in red. Right: Zoomed in version of the plot on the left.

An observed value for U5MR is considered to be the true value for U5MR multiplied by an error factor, i.e.  $\text{observed U5MR} = \text{true U5MR} * \text{error}$ , or on the log-scale,  $\log(\text{observed u5mr}) = \log(\text{true U5MR}) + \log(\text{error})$ , where error refers to the relative difference between an observation and the truth. While estimating the true U5MR, properties of the errors that provide information about the quality of the observation, or in other words, the extent of error that we expect, are taken into account. These properties include the standard error of the observation, its source type (e.g. DHS versus census) and if the observation is part of a data series from a specific survey (and how far the data series is from other series with overlapping observation periods). These properties are summarized in the “data model.” When estimating the U5MR, the data model adjusts for the errors in the observations, including the average systematic biases associated with different types of data sources, using information on data quality for different source types from all countries in the world.

Figure 1 displays plots of the U5MR over time for Senegal, used here for illustrative purposes. The B3 estimates are in red. Ninety per cent uncertainty intervals for the U5MR are given by the pink bands. All data available for the country are shown as coloured points, with observations from the same data series joined by lines. Solid points and lines represent data series/ observations that were included for curve-fitting. Grey bands represent the standard errors of the observations where available.

The B3 method was developed and implemented for the UN IGME by Leontine Alkema and Jin Rou New from the National University of Singapore with guidance and review by the TAG of the UN IGME. A more complete technical description of the B3 model is available elsewhere<sup>16</sup>.

### 3.2 Splines regression

The splines regression fitting method is illustrated in Figure 2 for Norway. Splines are smooth curves, placed 2.5 years apart, that add up to 1 at any point in time. For any year, the estimated

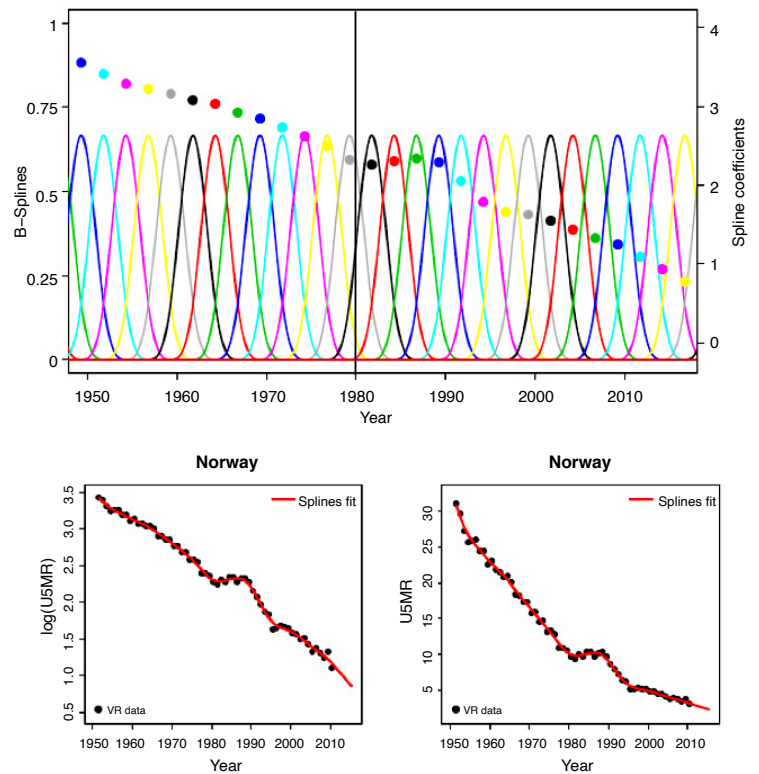


Figure 2: Illustration of the B-splines regression model for Norway. Top row: B-splines and the estimated spline coefficients. Bottom row: Observed log(U5MR) and U5MR (black dots) plotted against time, together with the spline estimates (red line).

$\log(\text{U5MR})$  is the sum of the non-zero splines in that year multiplied by the corresponding spline coefficients (displayed by dots). For example,  $\log(\text{U5MR})$  in 1980 in Norway is given by the sum of the yellow and grey splines to the left of black line (at the year 1980) and the black and red splines to the right, multiplied by their respective spline coefficients in the same colour.

The spline coefficients determine what the resulting fitted curve looks like. When estimating the spline coefficients, we obtain a flexible yet reasonably smooth U5MR curve by assuming that the difference between two adjacent coefficients (for example for years 1981 and 1983.5) is given by the difference between the previous two coefficients (for years 1978.5 and 1981) with an estimated data-driven “distortion term” added to it. For example, in Norway during the early 1980s, these distortion terms are estimated to be around zero when U5MR did not



change much, but they are negative in the late 1980s when the U5MR started to decline again. The resulting fit in Norway illustrates that the spline fit is able to follow the observed changes in the data closely.

The variance of the distortion terms determines the smoothness of the fit during the observation period; large fluctuations in these distortion terms imply that the trend can vary greatly from one period to the next. The amount of smoothing is country-specific for the majority of countries. An average global level of smoothing is used for countries with a small number of live births, countries with both vital registration (VR) and non-VR data included in the fitting and countries with a gap of more than five years in their VR data.

Due to the nature of the data in such countries, a small variance for the distortion terms tends to be estimated, so a global level of smoothing helps to reduce fluctuations in the trend.

After the most recent observation period ends, country-specific U5MR projections are obtained through the estimation of “future spline coefficients”, or equivalently, by projecting the differences between adjacent spline coefficients. The mean projected difference in spline coefficients is given by the estimated difference in the two most recent adjacent spline coefficients, and the uncertainty therein is based on the variability in the observed distortions in the country’s past. Based on out-of-sample validation exercises, this approach is shown to work well for the majority of countries but leads to unnecessarily wide uncertainty intervals (or extreme extrapolations) for a subset of countries where the most recent change in spline coefficients is very uncertain (or an extreme value). We avoid such uncertain and extreme U5MR extrapolations in longer-term projections by combining the country-specific projected differences in spline coefficients with a global distribution of observed differences in the past. This final step results in the removal of very extreme U5MR extrapolations in the country-specific U5MR projections.

#### 4. Estimation of infant mortality rates (IMR)

In general, the B3 model described above is applied to the U5MR for all countries (except for the Democratic People’s Republic of Korea, where a nonstandard method was employed). For countries with high-quality VR data (covering a sufficient period of time and deemed to have high levels of completeness and coverage), the B3 model is also used, but is fitted to the logit transform of  $r$ , i.e.  $\log(r/1-r)$ , where  $r$  is the ratio of the IMR to the median B3 estimates of U5MR in the corresponding country-year. This is to restrict the IMR to be lower than the U5MR. For the remaining countries, the IMR is derived from the U5MR using model life tables that contain known regularities in age patterns of child mortality<sup>20</sup>. The advantage of this approach is that it avoids potential problems with the under-reporting of neonatal deaths in some countries and ensures that the internal relationships of the three indicators (U5MR, IMR and NMR) are consistent with established norms. For countries in the Sahel region of Africa (Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger and Senegal), the relationship between infant and child mortality from model life tables does not apply, thus a logit transform of the ratio of IMR/U5MR is used to estimate IMR from U5MR using data from full birth histories and a multilevel regression with country-specific intercept.

#### 5. Estimation of U5MR and IMR by sex

In 2012, the UN IGME produced estimates of U5MR by sex for the first time<sup>21</sup>. In many countries, fewer sources have provided data by sex than have provided data for both sexes combined. For this reason, the UN IGME, rather than estimate U5MR trends by sex directly from reported mortality levels by sex, uses the available data by sex to estimate a time trend in the sex ratio (male/female ratio) of U5MR instead. Bayesian methods for the UN IGME estimation of sex ratios with a focus on the estimation and identification of countries with outlying levels or trends were used.<sup>21,22</sup>

For each country-year, we assume that the sex ratio of infant mortality  $S1(c,t)$ , which refers to the ratio of the probability of dying before age one for boys as compared to girls for country  $c$  in year  $t$  is given by:

$$S1(c,t) = W1(c,t) * P1(c,t),$$

where

- $W1(c,t)$  refers to the expected sex ratio for that country-year,
- Country multiplier  $P1(c,t)$  represents the relative advantage or disadvantage of infant girls to boys compared to other countries at similar levels of infant mortality.

Sex ratios of mortality tend to change as overall mortality decreases. To account for the relation between the level of infant mortality and the expected sex ratio, the term  $W$  gives the expected sex ratio for the country-year based on the UN IGME-estimated IMR for that country-year. The relation between the IMR level and the expected sex ratio,  $W1(c,t) = f(IMR(c,t))$  is modelled using a B-splines regression model. The parameters of this model are estimated based

on all available data such that  $f(IMR)$  represents a “global relation” between infant mortality and sex ratios. The country multiplier  $P1(c,t)$  is modelled with a time series model, whereby the multiplier fluctuates around country-specific level  $\theta 1$ , which is estimated using a hierarchical model.

For children aged 1–4, the sex ratio of child mortality is modelled as  $S4(c,t) = W4(c,t) * P4(c,t)$ , where  $W4$  refers to the expected sex ratio for the country-year given the country-year-specific child mortality rate (CMR, the probability a one-year-old dies before reaching age 5 years) for both sexes combined (again modelled with a B-splines regression model) and country multiplier  $P4$  represents the relative advantage or disadvantage of girls to boys compared to other countries at similar levels of CMR.  $P4(c,t)$  is also modelled with a time series model, whereby the multiplier fluctuates around country-specific level(c), which is estimated using a hierarchical model.

Estimates of the sex ratio of under-5 mortality are obtained from estimates of the sex ratios of infant and child mortality. If data are available

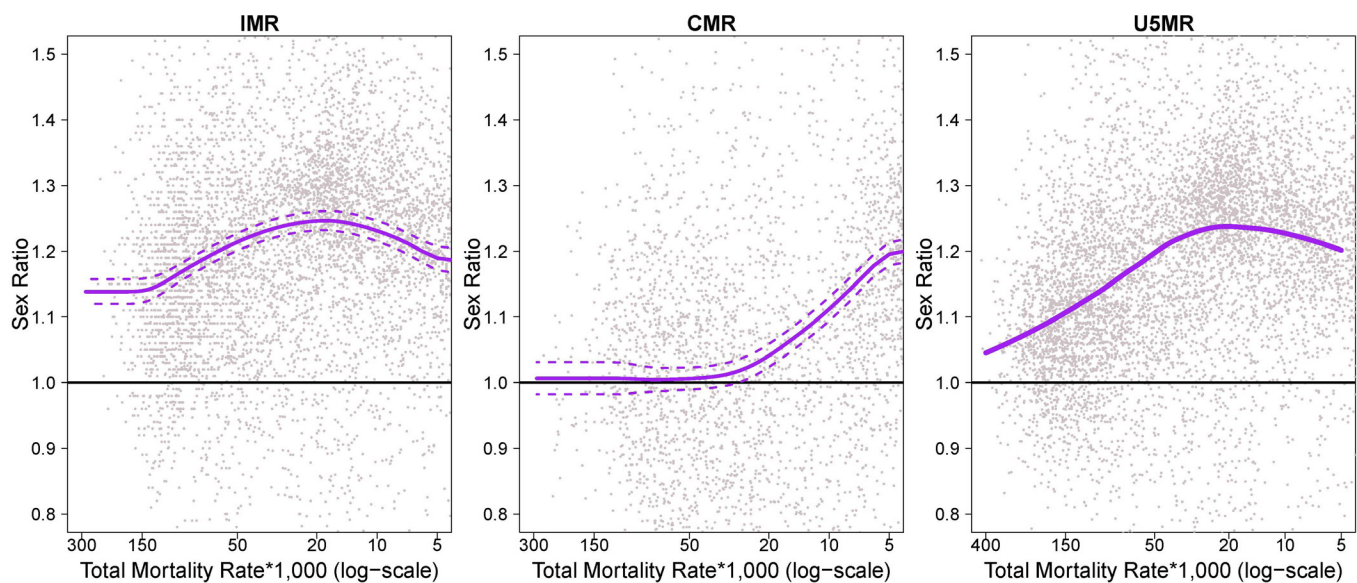
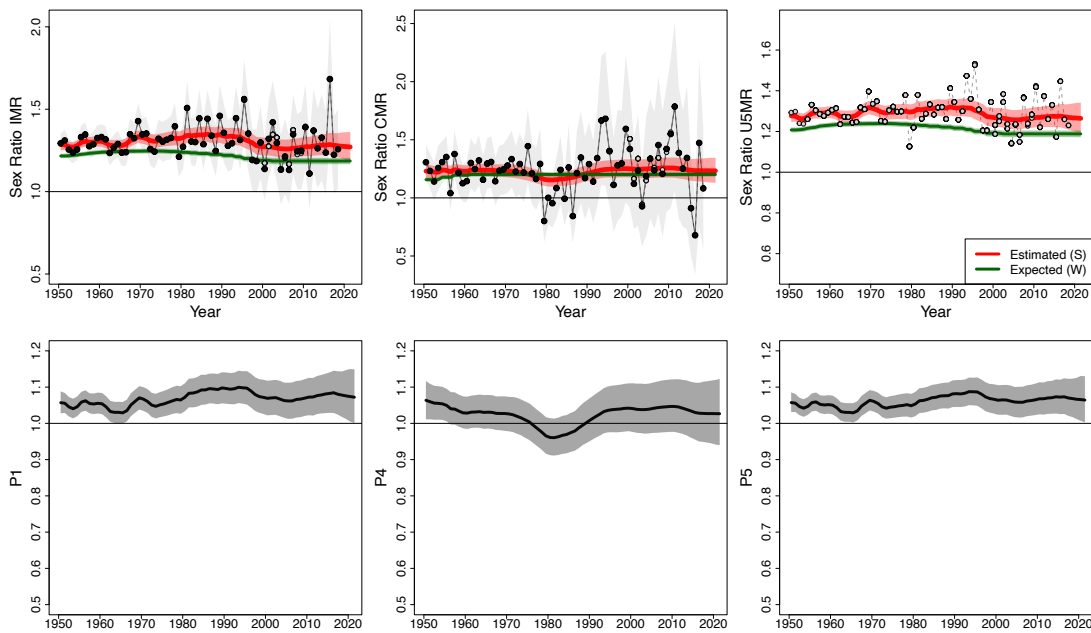


Figure 3: Observed sex ratios (grey dots) are plotted against estimated total mortality rates (on the log scale) for infants, children and the under-five year olds. The estimated global relation between expected sex ratios ( $W$ 's) and total mortality for the IMR and CMR are in purple solid lines. Dashed lines represent 90% uncertainty intervals. For U5MR, the purple line illustrates the relation between sex ratios and total U5MR based on the relations for IMR and CMR for all included country-years.

### Country A



### Country B

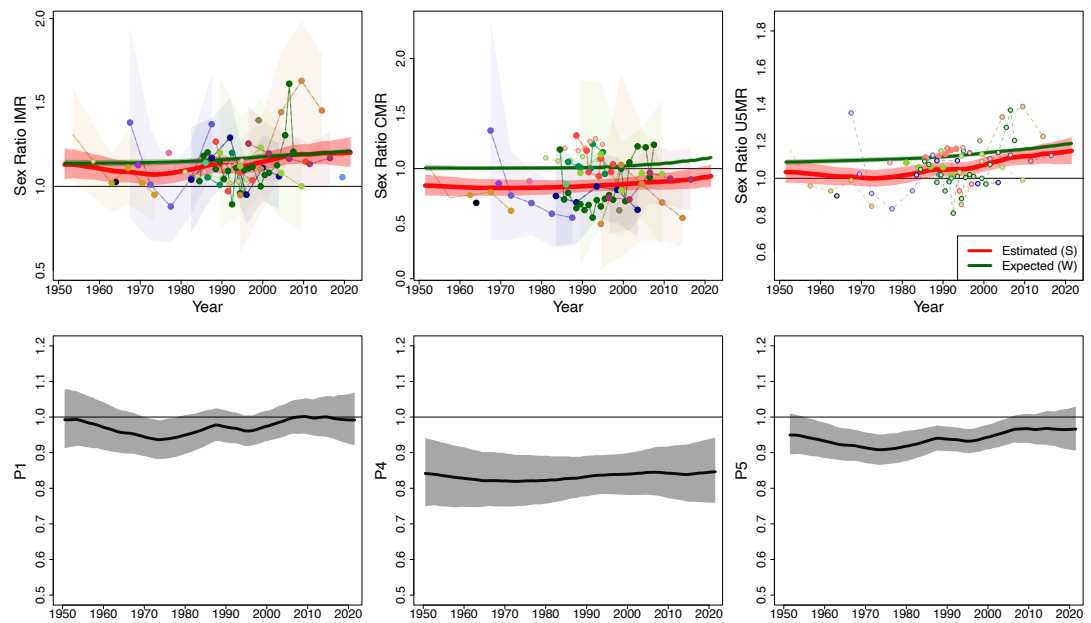


Figure 4: Illustrative example of country estimates of sex ratios  $S$  and country multipliers  $P$  for two countries. In country A, for a subset of observed country-years for infants and under-five year olds, the sex ratio of mortality of boys versus girls is higher than expected based on the estimated world level relation between sex ratios and mortality levels. In country B, for a subset of observed country-years for infants and for all years for the 1-4 and under-five year olds, the sex ratio of mortality of boys versus girls is lower than expected based on the estimated world level relation between sex ratios and mortality levels.

Explanation of each country plot: Top row: Estimated country-specific sex ratio  $S$  (red) for the three age groups and expected sex ratio  $W$  (green), with observations displayed by dots. Shaded areas around observations illustrate sampling errors (where available) and different colours differentiate data series. Bottom row: Estimated country multipliers  $P$  for the three age groups. Shaded areas illustrate the 90 per cent credible bounds

on the sex ratio for under-5 mortality but not on the sex ratio of infant mortality (e.g., based on summary birth histories), the data on under-5 mortality are used to inform the estimates for infant and child mortality sex ratios.

Figure 3 shows observed sex ratios for infant, child and under-5 mortality, with the estimated global relation between these ratios and the overall level of mortality. Figure 4 shows two illustrative examples of country estimates.

## 6. Estimation of neonatal mortality rates

The neonatal mortality rate (NMR) is defined as the probability of dying between birth and exact age 28 days per 1,000 live births. In 2015, the UN IGME method for estimating NMR was updated to a Bayesian methodology similar to that used to estimate U5MR and derive estimates by sex. It has the advantage that, compared to the previous model, it can capture data-driven trends in NMR within countries and over time for all countries. A more complete technical description of the model is available elsewhere<sup>23</sup>.

We model the ratio  $R(c,t)$ , which refers to the ratio of NMR to the difference of U5MR and NMR in country  $c$  and year  $t$ , i.e.  $R(c,t) = \text{NMR}/(\text{U5MR} - \text{NMR})$ . For each country-year, we assume that the ratio is given by:

$$R(c,t) = W(c,t) * P(c,t),$$

where

- $W(c,t)$  refers to the expected ratio for that country-year,
- Country multiplier  $P(c,t)$  represents country-specific trends in the ratio over time that differ from the expected level.

As U5MR decreases, the proportion of under-five deaths occurring in the first month of life tends to increase. The  $W(c,t)$  term accounts for this relationship; it is the expected ratio for the country-year based on the UN IGME-estimated U5MR for that country-year. It is modelled as a linear function of U5MR with a changing slope:

$$W(c,t) = \theta_0 \quad \text{if } U5MR(c,t) < U_{cut}$$

$$W(c,t) = \theta_0 + \theta_1 * U5MR(c,t) \quad \text{if } U5MR(c,t) \geq U_{cut}$$

$U_{cut}$  is an estimated constant that represents the level of U5MR after which as U5MR increases, the ratio  $\text{NMR}/(\text{U5MR} - \text{NMR})$  decreases. The parameters of this model are estimated based on all available data such that  $W(c,t)$  represents a “global relation” between the ratio and U5MR.

The country multiplier  $P(c,t)$  is modelled with a B-splines regression model. The  $P(c,t)$  represents a country-specific intercept, which is modelled hierarchically, and fluctuations around that intercept over time. For any particular country, the ratio can be higher- or lower-than-expected given the level of U5MR in that country, but the fluctuations allow this relationship to change over time within a country. A degree of smoothness is imposed on the fluctuations to ensure relatively smooth trajectories for any given country through time. We model the ratio of  $\text{NMR}/(\text{U5MR} - \text{NMR})$ ; estimates of NMR are obtained by recombining the estimates of the ratio with UN IGME-estimated U5MR.

For neonatal mortality in HIV-affected and crisis-affected populations, the ratio is estimated initially for non-AIDS and non-crisis mortality. After estimation, crisis neonatal deaths are added back on to the neonatal deaths to compute the total estimated neonatal mortality rate. No AIDS deaths are added back to the NMR, thereby assuming that HIV/AIDS-related deaths only affect child mortality after the first month of life.

## 7. Estimation of mortality rates among children aged 5–14 years and youth aged 15–24 years

The B3 statistical model was also used to obtain a smooth trend curve in the probability of a five-year-old dying before age 15 ( ${}_{10}q_5$ ) and the probability of a 15-year-old dying before age 25 ( ${}_{10}q_{15}$ ).

It is worth noting that for all non-VR data series, non-sampling biases specific to data series are

estimated with the B3 model. We observed that full birth histories from surveys tend to slightly under-estimate mortality in the age group 5–14, when compared to other data series. Sibling histories used to model the probability  $10q_{15}$  also tend to under-estimate mortality in the age group 15–24, especially for reference periods that are located further in the past from the survey date. This is likely due to omissions of some deaths or systematic age misstatements. As a result, in countries where the trend in mortality is largely informed by survey data, the final estimates are adjusted upwards, and therefore, the final estimated series may fall slightly above the original survey data points.

In some countries, there were not enough data inputs to estimate risks of dying in the age groups 5–14 and 15–24 from vital registration, surveys or censuses. In these cases, the probabilities  $10q_5$  and  $10q_{15}$  were modelled based on the estimates of the under-five mortality rate and an expected relation between mortality in the age groups 0–4 and 5–14, or 0–4 and 15–24, as observed in countries with sufficient data series. Multilevel regressions were used to

regress  $\log({}_{10}q_5)$  or  $\log({}_{10}q_{15})$  against  $\log(\text{U5MR})$ , allowing the relationships to vary across regions. The coefficients of these regressions were used to predict the probabilities  $10q_5$  and  $10q_{15}$  between 1990 and 2022 for countries with insufficient data sources. No model life tables are used here, because such life tables are based on the historical experience of countries with high quality vital registration data and do not always adequately reflect age patterns of mortality in low- and middle- income countries. However, the resulting estimates are based on trends in child mortality, and ideally this relational approach should be reserved for cases where there are no other possibilities for estimating risks of death by age.

## 8. Estimation of mortality rates among children aged 5–14 and youth aged 15–24 by sex

The estimation model builds upon the main model structure of the sex ratio for IMR, CMR and U5MR (see section 5) but with reconsideration of model choices. In particular,

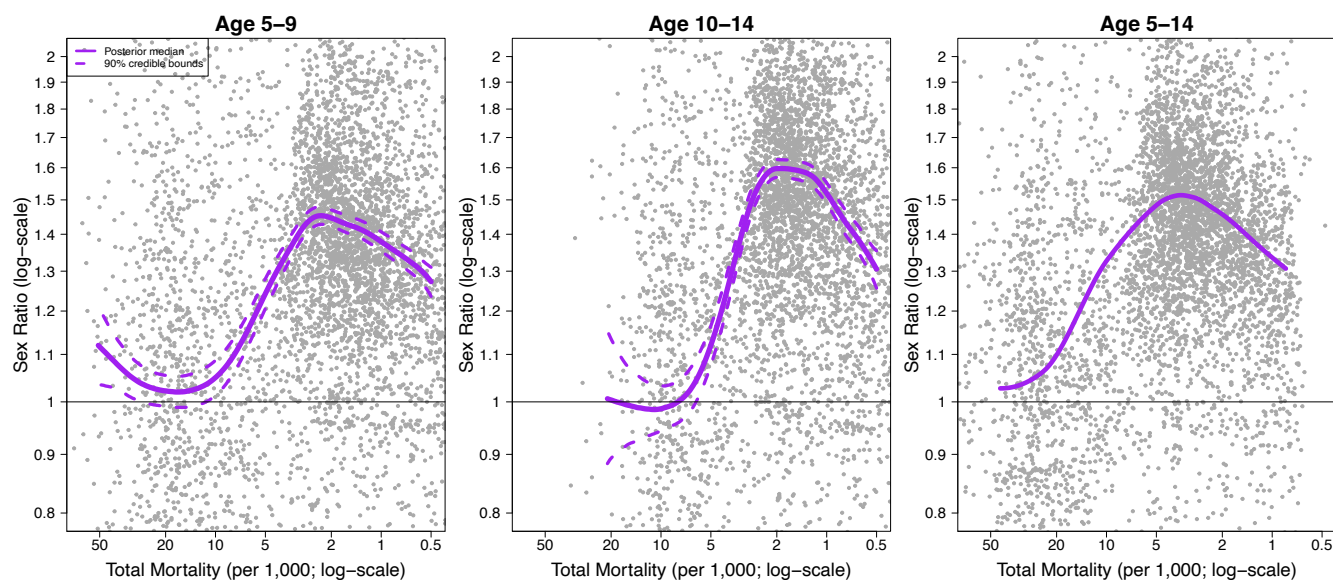


Figure 5: Observed sex ratios (grey dots) are plotted against estimated total mortality rates (on the log scale) for 5–9, 10–14 and 5–14 years old. The estimated global relation between expected sex ratios ( $W$ 's) and total mortality for the 5–9 and 10–14 are in purple solid lines. Dashed lines represent 90% uncertainty intervals. For 5–14, the purple line illustrates the relation between sex ratios and total mortality for 5–14 based on the relations for mortality for the 5–9 and 10–14 for all included country-years.

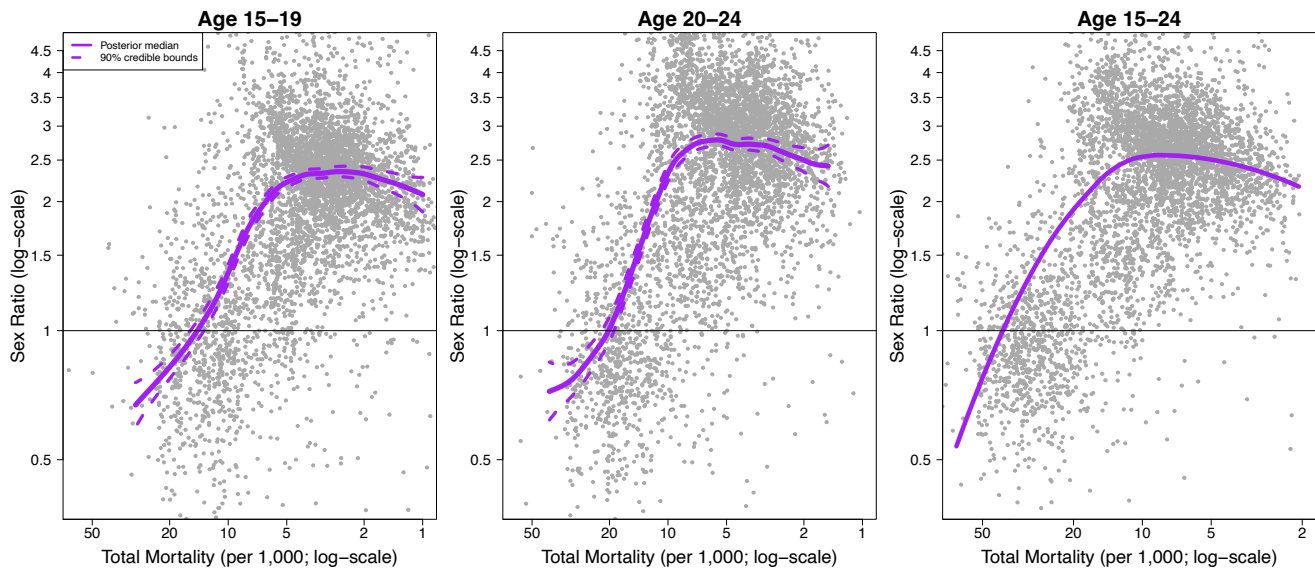


Figure 6: Observed sex ratios (grey dots) are plotted against estimated total mortality rates (on the log scale) for 15–19, 20–24 and 15–24 years old. The estimated global relation between expected sex ratios ( $W$ 's) and total mortality for the 15–19 and 20–24 are in purple solid lines. Dashed lines represent 90% uncertainty intervals. For 15–24, the purple line illustrates the relation between sex ratios and total mortality for 15–24 based on the relations for mortality for the 15–19 and 20–24 for all included country-years.

the expected sex ratio (denoted as  $W(c,t)$ ), is modelled with a second-order random walk (RW2) model instead of a B-splines model. The within-country fluctuation time series  $P(c,t)$  is modelled with a first-order random walk (RW1) model rather than an AR(1) model. Furthermore, the statistical computing is carried out using Integrated Nested Laplace Approximations (INLA) instead of Markov chain Monte Carlo (MCMC).

Figure 5 shows observed sex ratios for 5–9, 10–14 and 5–14, with the estimated global relation between these ratios and the overall level of mortality.

Figure 6 shows observed sex ratios for 15–19, 20–24 and 15–24, with the estimated global relation between these ratios and the overall level of mortality.

## 9. Child mortality due to crisis events

Estimated deaths for major crises including conflicts, natural disasters, and epidemics were derived from various data sources from 1950 to present. Data on deaths from natural disasters were obtained from the CRED International

Disaster Database<sup>24</sup>, and conflict deaths were taken from Uppsala Conflict Data Program/Peace Research Institute Oslo datasets<sup>25,26</sup>, Armed Conflict Location & Event Data Project<sup>27</sup>, from Center for Systemic Peace/Integrated Network for Societal Conflict Research dataset<sup>28</sup> as well as reports prepared by the UN and other organizations.

For crises where deaths were adequately recorded in death registration data, age-specific deaths were obtained directly from the data. For many countries, age-sex specific data on crisis deaths is not available and in previous years, the UN IGME estimated age-specific proportions of crisis deaths for under 5, and 5–14 years using age-sex proportions for various crisis types prepared by WHO from a small number of reported age-sex distributions. These proportions were applied to estimates of total crisis deaths.

For this update, the UN IGME undertook a comprehensive analysis of more than 1,000 articles and books on crisis mortality compiled over the years by the UNPD and WHO to identify studies and datasets with age-patterns for crisis deaths. Additionally, death registration data in

the WHO Mortality Database and the Human Mortality Database, DHS, MICS and World Fertility Surveys for the period 1960 to 2017 were analysed for regions and years determined to have experienced crisis events. From all these sources, information on age-sex distributions was obtained for 174 events: 51 conflicts, 32 earthquakes, 35 famines, 30 epidemics, 10 floods, 9 tsunamis, 4 genocides and 3 cyclones. These data were analysed to prepare age-sex distributions by five-year age groups and for more detailed age groups under 5 for each of the event types as described elsewhere. The revised age-sex patterns result in higher proportions of deaths under 5 for some event types compared to distributions used previously.

Estimated child deaths due to major crises were included if they met the following criteria:

1. The crisis was isolated to a few years
2. Under-five crisis deaths were >10% of under-five non-crisis deaths
3. Crisis U5MR > 0.2 per 1,000
4. Number of under-five crisis deaths >10 deaths.

These criteria resulted in crises being incorporated into the UN IGME under-five mortality estimates for 40 countries. Crisis deaths were included in the U5MR estimates by first excluding data points from crisis years, fitting the B3 model to the remaining data, and then adding the crisis-specific death rate to the fitted B3 curve. Crisis death estimates are uncertain, but presently no uncertainty around crisis deaths is included in the U5MR uncertainty intervals. Instead, we assume the relative uncertainty in the adjusted U5MR is equal to the relative uncertainty in the non-adjusted U5MR; this assumption will be revisited in the near future. The UN IGME has assessed recent crises and based on the scarcity of currently available data and the difficulties of estimating the broader impact of these crises on health systems, the UN IGME holds the under-five estimates constant from the start of the crisis while increasing the uncertainty over the crisis time for three countries: South Sudan, Venezuela (Bolivarian

Republic of) and Yemen. Where applicable, direct crisis deaths have been added to the constant trend estimate. The UN IGME will review new data, if available, in the next estimation round and revise estimates accordingly.

The approach for adjusting the mortality estimates for ages 5–14 and 15–24 due to conflict and natural disasters is identical to the one taken for under-five mortality. The criteria resulted in crises being incorporated into the 5–14 mortality estimates of 55 countries, and into the 15–24 mortality estimates of 50 countries. Because the background mortality rates are lower in these age groups compared to under-five mortality, crisis deaths represent a larger share of 5–14 or 15–24 deaths, and therefore there are more crises meeting these criteria than for under-five mortality.

## 9.1 COVID-19

These estimates do not include any adjustment in the years 2020, 2021 or 2022 for COVID-19-related mortality as the available evidence is insufficient to support an adjustment at this time. First, direct COVID-19 deaths in the age groups estimated here are rare, and thus unlikely to impact national-level estimates. Second, to assess whether any substantial indirect mortality—possibly resulting from pandemic-related disruption to critical care and interventions—occurred among children, adolescents or youth in 2020, 2021 or 2022, the UN IGME analysed available data on age-specific deaths from more than 100 countries or areas for 2020–2022, and found no evidence of wide-spread, systematic excess mortality among the age groups estimated here in any year since the pandemic began in 2020. It should be noted that geographic and income variation in the data on excess deaths reviewed by the UN IGME thus far is limited, and data collection continues to gather a more complete picture of COVID-19-related mortality among children and adolescents in various settings. While available data do not support national-level adjustments for COVID-19-related mortality, the pandemic continues to evolve in unpredictable ways due

to uneven vaccine rollouts, the emergence of more infectious variants and ongoing variation in pandemic response policy, among other factors. Thus, the UN IGME will continue to collect data for assessing excess deaths in pandemic years. Should new evidence warrant, the UN IGME will revisit this issue and generate adjustments where applicable.

## 10. Calculating number of deaths

### 10.1 Under-five, infant, and neonatal deaths

A birth-week cohort method is used to calculate the absolute number of deaths among neonates, infants, and children under age 5. First, each annual birth cohort is divided into 52 equal birth-week cohorts. Then, each birth-week cohort is exposed throughout the first five years of life to the appropriate calendar year- and age-specific mortality rates depending on cohort age. For example, the 20th birth week cohort of the year 2000 will be exposed to the infant mortality rates in both 2000 and 2001. All deaths from birth-week cohorts occurring as a result of exposure to the mortality rate for a given calendar year are allocated to that year and are summed by age group at death to get the total number of deaths for a given year and age group. Continuing with the above example, deaths from the 20th birth-week cohort of the year 2000 would contribute to infant deaths in year 2000 and 2001. Any deaths occurring among the 20th birth-week cohort of year 2000 after the 20th week in 2001 would contribute to under-5 deaths for year 2001 and so forth. Under-five deaths in each calendar year are calculated by summing up all the deaths under age five across all age group cohorts in that year. The annual estimate of the number of live births in each country from the World Population Prospects: the 2022 revision<sup>30</sup> are used to calculate the numbers of deaths.

### 10.2 Deaths among children aged 5–14 and youth aged 15–24

The absolute number of deaths among those aged 5–14 in a given year and country is

calculated using the central death rates of age groups 5–9 and 10–14 years,  ${}_5M_5$  and  ${}_5M_{10}$ , computed from the estimated  ${}_5q_5$  and  ${}_5q_{10}$ . The central death rates are then multiplied by the country population estimates for the respective age groups from the World Population Prospects: the 2022 revision<sup>30</sup> to calculate the number of deaths. A similar approach is used for calculating the number of deaths in the age group 15–24: the estimated  ${}_5q_{15}$  and  ${}_5q_{20}$  are converted in central death rates  ${}_5M_{15}$  and  ${}_5M_{20}$ , and multiplied by the population estimates.



## Notes

i There were concerns about incompleteness of early infant mortality data from civil registration. A European report on perinatal indicators, for example, noted a wide variation in how European countries define infant mortality, due to differences in birth and death registration practices (that is, differences in the cut-off points for acceptable weight or estimated gestation period to be registered as a birth and subsequent death.<sup>31,32</sup> This discrepancy can lead to under-reporting of infant deaths by some countries, particularly when compared with countries that use a broader definition for live birth.<sup>33,34</sup>

The UN IGME previously carried out an analysis of the ratio of early neonatal (under 7 days) deaths to total neonatal deaths, which showed that several countries, many in Eastern Europe, had significantly lower values than what would be expected, suggesting an undercounting of early infant deaths. The results of this analysis were used as an upwards adjustment of 10 per cent or 20 per cent to under-five mortality rates across all years for several countries in previous UN IGME reports.

This assessment was revisited in the 2017 estimation round using the latest data, and the clear signal of underreporting was no longer apparent across countries. Therefore, the UN IGME has removed these adjustment factors in the estimates for this publication. Going forward, the UN IGME will assemble finer age-specific child mortality data, and attempt to determine the current level of underreporting bias in different countries, and how that bias has changed over time. This analysis could lead to a different adjustment approach in future estimates.

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