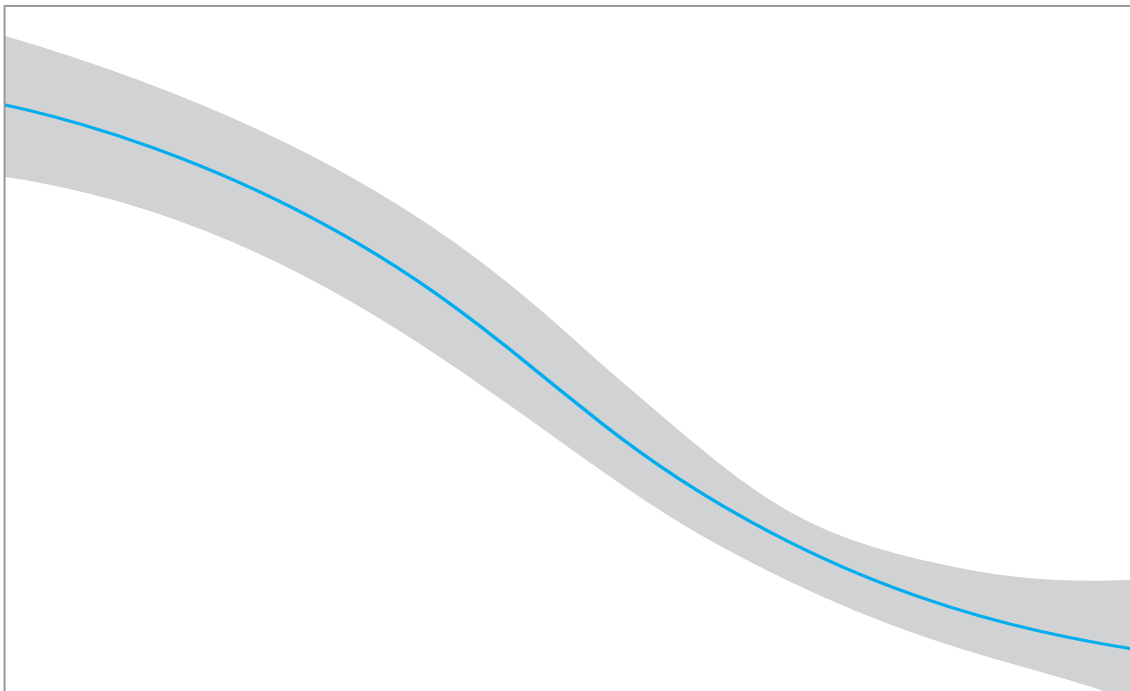Explanatory Notes

Child and youth mortality trend series to 2019

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

May 2020

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, 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 reduced 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 will release the new round of estimates in September 2020. 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 procedures to estimate child, adolescent, and young adult mortality differ for Member States depending on data availability and type of data. These 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[1] or World Health Statistics[2]. Additionally, at the close of country consultation, the estimation model will be run again incorporating any amendments to data arising during the consultation process. For this reason, please note that the final estimates may differ slightly from the provisional estimates reviewed during the country consultation, as they depend on the final results of all the countries.

1. Strategy

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 if 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 target year, in this case 2019.

To increase the transparency of the estimation process, the UN IGME has developed a Child Mortality Estimation (CME) web portal (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 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 rarely 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, in the developing world, most 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 have become the primary sources of data on childhood, adolescent and young adult (ages 0-24) mortality in developing 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 young adult mortality estimates for most developing countries.

The first step in the process of arriving at estimates of levels and recent trends of childhood, adolescent and young adult mortality is to compile all newly available data and add the data to the CME 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 mortality and neonatal mortality

For data from civil registration, the calculation of U5MR and IMR is derived from 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 $_4q_1 = 4* {_4M_1} /[1+ (4- {_4a_1}) * {_4M_1}]$

where $_4a_1$ 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$= {_5q_0}*1000$

For NMR, the number of deaths under one month of age and live births are used to calculate the neonatal mortality rate.

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[i].

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 that a child aged 5 years dies before reaching his or her fifteenth birthday, is derived from a standard period abridged life table. The inputs are 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 risk of dying between age 5 and 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 $_5q_{10}$.
- Finally, $_{10}q_5 = 1-(1-{_5q_5})(1-{_5q_{10}})$

The calculation of the probability $_{10}q_{15}$, the probability that an older adolescent aged 15 years dies before reaching his or her 25th birthday, 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 young adults, 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, 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"[3] and has been shown to perform better than the GGB and SEG methods in isolation. The GGBSEG method is implemented in the DDM package of the R statistical software[4]. Completeness was estimated for each country for periods between pairs of recent censuses for which an age distribution of the population was available in the Demographic Yearbook[5]. 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 inverse of the completeness rate by the number of deaths 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.

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.[6,7,8] UN IGME has re-calculated estimates for 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[9].

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, in particular in countries with relatively low fertility and mortality. The 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[10].

SBH data are not used to derive neonatal mortality.

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

Mortality estimates of children aged 5–14 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 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.[11,12,13]

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 in 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 magnitude 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[14], as detailed below. This model includes a data model that will estimate 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 30 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[15]. This method was applied to all DHS and MICS surveys with FBH. The model was improved to incorporate the impact of antiretroviral therapies (ART) and prevention of mother to child transmission (PMTCT)[16]. 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 $10q5$. For mortality at ages 15–24, the 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[17] 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 2019.
6. Add back estimates of deaths due to HIV/AIDS (from UNAIDS)
7. 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 2019. This method is described in the following section.

3. Estimates for levels and trends in under-5 mortality

3.1 Summary

Estimation and projection of under-5 mortality rates (U5MR) 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 the previous round of UN IGME child mortality estimates published in 2019[1]. 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.

In the B3 model, log(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.

An observed value for U5MR is considered to be the true value for U5MR multiplied by an error factor, i.e. observed U5MR = true U5MR * error, or on the log-scale, log(observed u5mr) = log(true U5MR) + log(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 so-called 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[14].
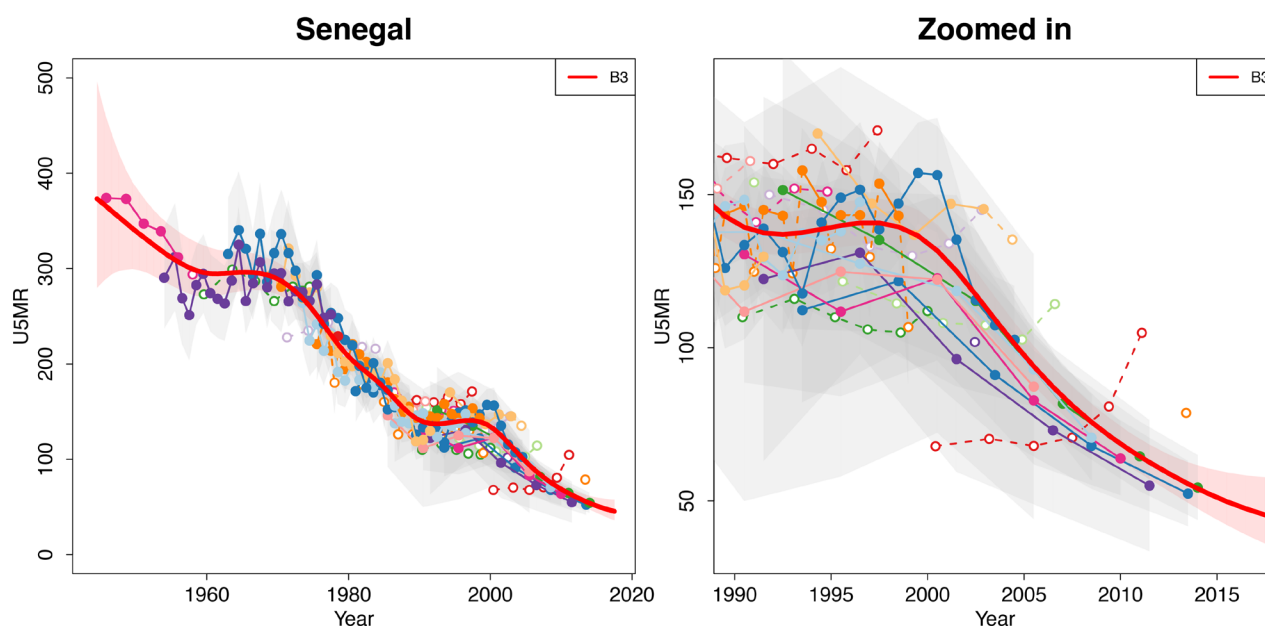

Figure 1: Illustration of the B3 model for Senegal. Left: Plot of the U5MR over time for Senegal, with the B3 estimates in red. Right: Zoomed in version of the plot on the left.

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 log(U5MR) is the sum of the non-zero splines in that year multiplied by the corresponding spline coefficients (displayed by dots). For example, log(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
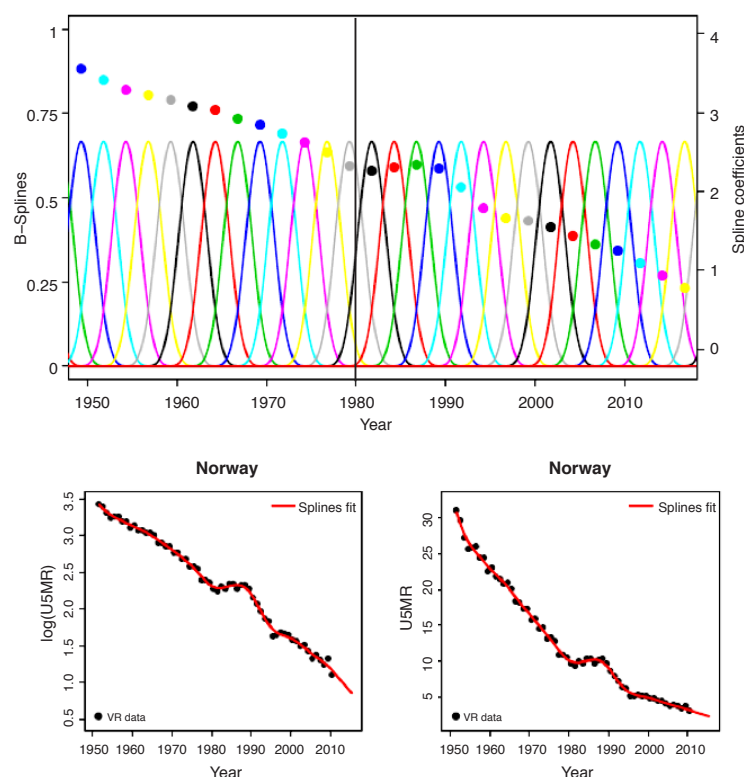

Figure 2: Illustration of the B-splines regression model for Norway.
Top row: B-splines and the estimated spline coefficients.
Bottom row: Observed log(U5MR) and U5MR (black dots) plotted against time, together with the spline estimates (red line).

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

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[18]. 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 are consistent with established norms. For Sahelian countries (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. Estimates by sex

In 2012, the UN IGME produced estimates of U5MR for males and females separately for the first time[19]. 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.[19,20]

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 $\beta1(c)$, 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 CMR 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 child mortality. *P4*(c,t) is also modelled with a time series model, whereby the multiplier fluctuates around country-specific level *β4(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 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. Estimates of neonatal mortality

The neonatal mortality rate (NMR) is defined as the probability of dying between birth and exact age 28 days per 1000 live births. In 2015 the UN IGME method for estimating NMR was updated. The new Bayesian methodology is 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[21].

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. $R(c,t) =$ NMR/(U5MR - 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 proportional share of mortality in the first month of life tends to increase. The W(c,t) term accounts for this
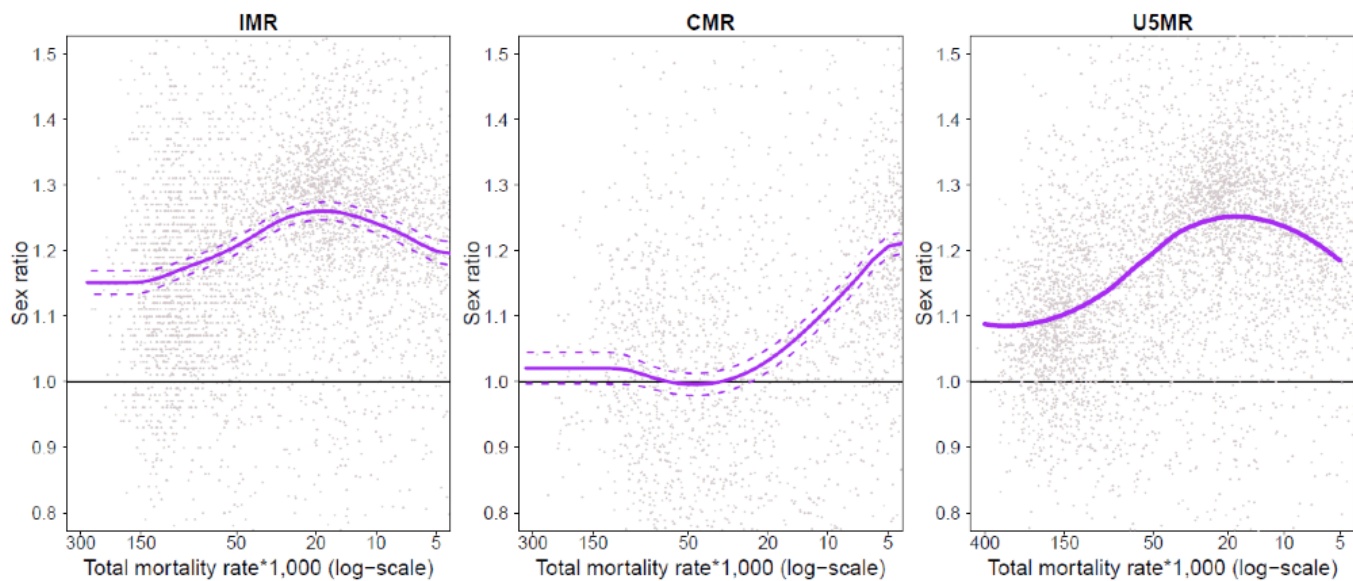

Figure 3: Observed sex ratios (grey dots) are plotted against estimated total mortality rates (on the log scale) for infants, children and the under-five year olds. The estimated global relation between expected sex ratios (W's) and total mortality for the IMR and CMR are in purple solid lines. Dashed 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.
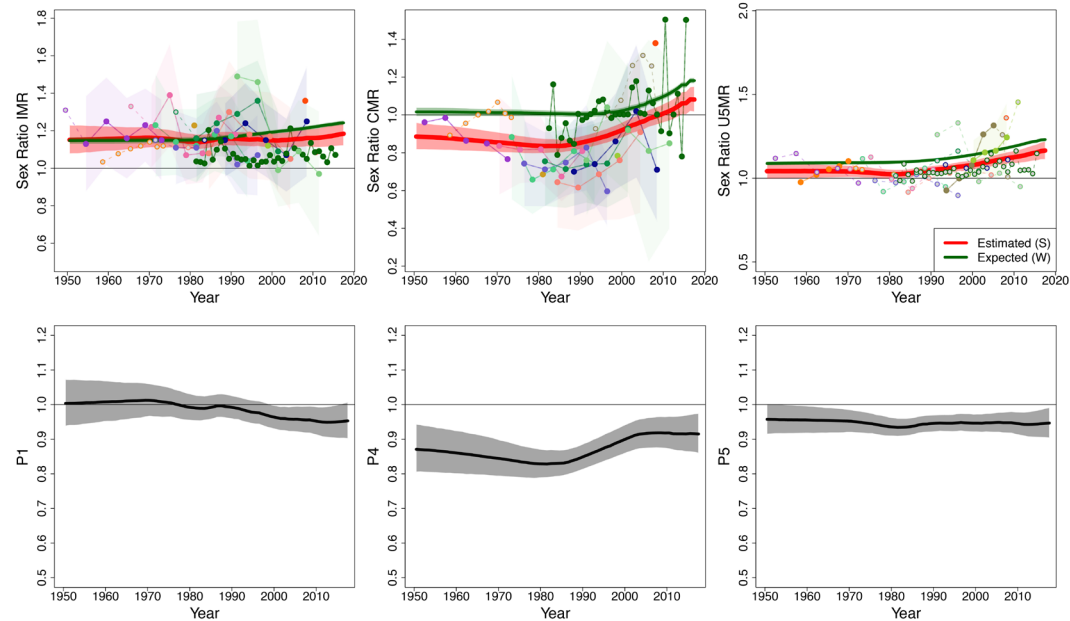
Country A
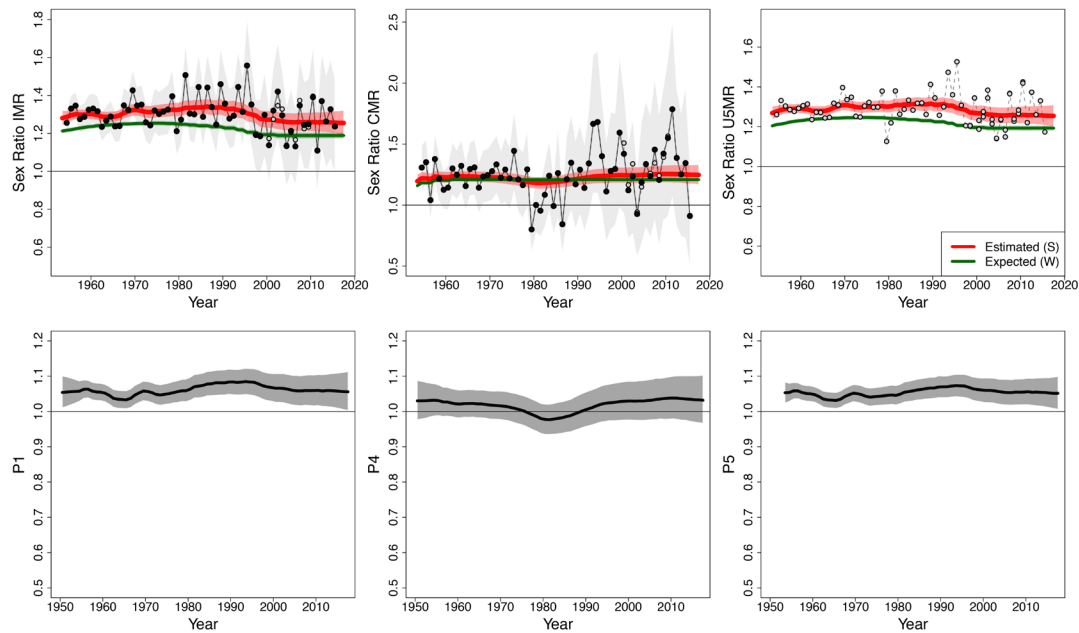
Country B

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

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:

$$W(c,t) = \beta_0 \qquad\qquad\qquad \text{if } U5MR(c,t) < U_{cut}$$
$$W(c,t) = \beta_0 + \beta_1 * U5MR(c,t) \quad \text{if } U5MR(c,t) \geq U_{cut}$$

U_{cut} is an estimated constant that represents the level of U5MR after which as U5MR increases, the ratio NMR/(U5MR - 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 overall 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 NMR/(U5MR - 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.

The TAG recommended that for neonatal mortality in HIV-affected populations, the NMR be estimated initially using neonatal and child mortality observations for non-AIDS deaths, calculated by subtracting the estimated HIV death rates from total death rates in the neonatal and 1-59 month periods respectively, and then AIDS neonatal deaths be added back on to the non-HIV neonatal deaths to compute the total estimated neonatal death rate.

7. Estimates of mortality among children aged 5–14 and youth aged 15–24

The B3 statistical model was also used to obtain a smooth trend curve in the probability of a 5-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 10q15 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 $_{10}q_5$ and $_{10}q_{15}$ 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(U5MR), allowing the relationships to vary across regions. The coefficients of these regressions were used to predict the probabilities $_{10}q_5$ and $_{10}q_{15}$ between 1990 and 2019 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. Through the country consultation, it is hoped that additional survey or census data will be reported to the UN IGME to directly model mortality trends beyond 5 years of age using the B3 model.

8. Child mortality due to crisis events

Estimated deaths for major crises including conflicts, natural disasters, and epidemics were derived from various data sources from 1990 to present. Data on child deaths from natural disasters were obtained from the CRED International Disaster Database[22], with under-five proportions estimated as described elsewhere[23], and conflict deaths were taken from Uppsala Conflict Data Program/Peace Research Institute Oslo datasets as well as reports prepared by the UN and other organizations. 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 22 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, 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. 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 49 countries, and into the 15–24 mortality estimates of 59 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.

8.1 Covid-19

While current evidence indicates the direct impact of Covid-19 on child and youth mortality to be very limited, the indirect effects stemming from strained and under-resourced health systems, limitations on care-seeking and preventative measures like vaccination and nutrition supplements, socioeconomic strain on parents and households resulting from job loss or economic downturns, and stress to children and parents associated with abrupt societal shifts may be substantial and widespread. Moreover, many of these indirect effects may not be apparent for some time after the pandemic recedes and may even reverberate for an extended period following the pandemic. The UN IGME is currently assessing the impact of Covid-19 on child and youth mortality for the year

2020 and will incorporate these effects in next year's estimates where applicable.

9. Calculating number of deaths

9.1 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 2019 revision[24] are used to calculate the numbers of deaths.

9.2 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 deaths rates are then multiplied by the country population estimates for the respective age groups from the World Population Prospects: the 2019 revision to calculate the number of deaths[24]. 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 $_5M20$, 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.[25,26] 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.[27,28]

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.

References

1 United Nations Inter-agency Group for Child Mortality Estimation (UN IGME). Levels & Trends in Child Mortality. New York: UNICEF, 2019. (available from: http://www.childmortality.org).

2 World Health Organization. World Health Statistics 2019: Monitoring Health for the SDGs. Geneva: WHO, 2019.

3 Moultrie TA, Dorrington RE, Hill AG, Hill K, Timæus IM and Zaba B (eds). 2013. Tools for Demographic Estimation. Paris: International Union for the Scientific Study of Population. demographicestimation.iussp.org

4 Riffe T, Lima E, and Queiroz B, DDM: Death Registration Coverage Estimation,2017. R package version 1.0-0.

5 https://unstats.un.org/unsd/demographic-social/products/dyb/dybcensusdata.cshtml

6 http://mics.unicef.org/tools

7 United States Agency for International Development (USAID): Guide to DHS statistics Demographic and Health Surveys Methodology. ORC Macro Calverton, Maryland September 2006

8 Hill, K. Chapter 15, Child Mortality in Moultrie TA, RE Dorrington, AG Hill, K Hill, IM Timæus and B Zaba (eds). 2013. Tools for Demographic Estimation. Paris: International Union for the Scientific Study of Population. demographicestimation.iussp.org

9 Pedersen J, Liu J. Child Mortality Estimation: Appropriate Time Periods for Child Mortality Estimates from Full Birth Histories. Plos Medicine. 2012;9(8).

10 Silva R. Child Mortality Estimation: Consistency of Under-Five Mortality Rate Estimates Using Full Birth Histories and Summary Birth Histories. Plos Medicine. 2012;9(8).

11 Timæus IM and Jasseh M. Adult mortality in Sub-Saharan Africa: evidence from demographic and health survey, Demography. 2004; 41, 4: 757-772, 2004.

12   Reniers G., Masquelier B., and Gerland P. Adult Mortality in Africa in International Handbook of Adult Mortality (R. Rogers and E. Crimmins, eds.), Springer, 2011.

13   Alkema L., et al. Global, regional, and national levels and trends in maternal mortality between 1990 and 2015, with scenario-based projections to 2030: a systematic analysis by the UN Maternal Mortality Estimation Inter-Agency Group. Lancet, 2016; 387, 462-474.

14   Alkema L, New JR. Global estimation of child mortality using a Bayesian B-spline bias-reduction method. The Annals of Applied Statistics. 2014; 8: 2122–49.

15   Walker N, Hill K, Zhao FM. Child Mortality Estimation: Methods Used to Adjust for Bias due to AIDS in Estimating Trends in Under-Five Mortality. Plos Medicine. 2012;9(8).

16   Johnson P, Mizoguchi N, Pantazis A. Improved Method for Adjusting for Bias due to HIV Mortality in Estimates of Child Mortality. Paper prepared for Population Association of America Annual Meeting April 22-25, 2020. Washington, DC (forthcoming).

17   UNAIDS 1990–2018 HIV and AIDS estimates, 2019.

18   Guillot M, Gerland P, Pelletier F, Saabneh A. Child Mortality Estimation: A Global Overview of Infant and Child Mortality Age Patterns in Light of New Empirical Data. Plos Medicine. 2012;9(8).

19   Sawyer CC. Child Mortality Estimation: Estimating Sex Differences in Childhood Mortality since the 1970s. Plos Medicine. 2012;9(8).

20   Alkema L, Chao F, You D, Pedersen J, Sawyer CC. National, regional, and global sex ratios of infant, child, and under-5 mortality and identification of countries with outlying ratios: a systematic assessment. The Lancet Global Health. 2014; 2(9): e521–e530.

21   Alexander, M. & Alkema, L. Global Estimation of Neonatal Mortality using a Bayesian Hierarchical Splines Regression Model Demographic Research, 2018, 38, 335-372.

22   CRED. EM-DAT: The CRED International Disaster Database. Belgium: Université Catholique de Louvain. (available from: http://www.emdat.be/)

23   World Health Organization. WHO methods and data sources for country-level causes of death 2000-2017. Global Health Estimates Technical Paper WHO/HMM/IER/GHE/2018.4. Geneva: WHO, 2018. (available from: <www.who.int/healthinfo/global_burden_disease/childcod_methods_2000_2017.pdf>).

24   United Nations Department of Economic and Social Affairs Population Division. World Population Prospects - the 2019 revision. New York: United Nations, 2019.

25   Zeitlin J, Wildman K. Indicators for monitoring and evaluating perinatal health in Europe. European Union Health Monitoring Programme, 2000.

26   Graafmans WC, Richardus JH, Macfarlane A, Rebagliato M, Blondel B, Verloove-Vanhorick SP, et al. Comparability of published perinatal mortality rates in Western Europe: the quantitative impact of differences in gestational age and birthweight criteria. British Journal of Obstetrics and Gynaecology. 2001;108 (12):1237-45.

27   Kramer MS, Platt RW, Yang H, Haglund B, Cnattingius S, Bergsjo P. Registration artifacts in international comparisons of infant mortality. Paediatric and Perinatal Epidemiology. 2014;16(1):16-22.

28   Kingkade WW, Cheryl CC. Infant Mortality in Eastern Europe and the Former Soviet Union Before and After the Breakup. Washington, DC: Population Division, US Bureau of the Census, 2001. (available from: 2001 Meetings of the International Union for the Scientific Study of Population, Salvador de Bahia, Brazil, August 19-24. www.iussp.org/Brazil2001/s40/S44_02_kingkade.pdf).