Sex differences in survival chances among children, adolescents, and youth ages 0–24: A systematic assessment of national, regional, and global trends from 1990 to 2021

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Abstract

Background: Differences in survival chances exist between sexes due to biological factors and sex discrimination, which are well documented in children younger than 5. However, sex differentials in mortality have not been systematically examined for ages 5–24 based on empirical data.

Methods: We estimate the sex ratio of mortality from birth to 25 and reconstruct trends in sex-specific mortality between 1990 and 2021 for 200 countries, major regions, and globally. We compiled comprehensive databases on the sex ratio of mortality (ratio of male to female mortality rates) for infants (<1 year), young children (1–4 years), older children and young adolescents (5–14 years), and older adolescents and youth (15–24 years). The databases contain mortality rates from (sample) death registration systems, surveys collecting full birth and sibling histories, and reports on recent household deaths in censuses and nationally representative surveys. We adjusted mortality rates for the incompleteness of death registration for each sex and accounted for recall biases. In each age group, the sex ratio of mortality was modelled as a function of the mortality level achieved for both sexes using Bayesian hierarchical time series models. We report on the levels and trends of sex ratios and estimate the expected and excess female mortality rates to identify countries with outlying sex ratios.

Findings: Globally, the sex ratio of mortality was 1·13 for ages 0–4 years [90% uncertainty interval (UI) 1·11–1·15] in 2021. This ratio increases with age to 1·16 [90% UI 1·12–1·20] for those 5–14 years old, reaching 1·65 for 15–24 years old [1·52–1·75]. In all age groups, the global sex ratio of mortality increased between 1990 and 2021, driven by faster declines in female mortality. In 2021, the probability of a male newborn reaching his 25th birthday was 94·1% [93·7%–94·4%], compared to 95·1% for girls [94·7%–95·3%]. A disadvantage of girls to boys (compared to countries with similar total mortality levels) in 2021 was observed in five countries for ages 0–4 (Algeria, Bangladesh, Egypt, India, and Iran), one country (Suriname) for ages 5–14, and 13 countries for ages 15–24 (including Bangladesh and India). The reverse pattern (significant disadvantage of boys to girls) was observed in one country in children ages 0–4 (Vietnam), no country in the age group 5–14, and eight countries in youth ages 15–24 (including Brazil and Mexico). Globally, the total number of excess female deaths from birth to 25 was 86,563 [-6,059–164,000] in 2021, from 544,636 [453,982–633,265] in 1990.

Interpretation: Globally, the sex ratio of mortality for all age groups before 25 increased between 1990 and 2021. The survival chances to age 25 improved more rapidly for girls than boys as total mortality decreased, reversing this trend at very low mortality. Targeted interventions should focus on countries with outlying sex ratios of mortality.

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Introduction

In infants and young children, survival chances are unequally distributed between boys and girls. Under natural circumstances, mortality is higher for boys than for girls. For example, boys are more likely to be born prematurely and are less resistant to infections, and the burden of congenital malformations and respiratory conditions is heavier in boys.[1,2] However, this biological advantage for girls is often reduced due to discriminatory practices related to healthcare and nutrition.[3–5] The sex ratio is generally the highest in infants younger than one year and decreases in children between one and four years. This reduction of the advantage in the survival of females over males as children age reflects the greater importance beyond the first birthday of preventable infectious diseases whose outcomes are primarily determined by parental and medical management and the nutritional status of children.

The sex ratio of mortality also tends to increase over time as mortality rates for both sexes decrease because the mortality decline leads to a concentration of deaths in the neonatal period, where cause-of-death patterns are particularly disadvantageous to boys.[4] The share of under-five deaths due to infections, such as infection in the intestinal tract that causes diarrhoea, lower respiratory infections, malaria, and measles, declines as mortality rates at this age reduce. The percentage of under-five deaths occurring at the youngest ages due to congenital abnormalities and perinatal period trouble increases. This relationship between the mortality level of both sexes and the sex ratio enables identifying countries with outlying sex ratios, where girls' mortality is higher than expected, compared with countries with the same mortality levels. In 2014, Alkema et al.[5] identified 15 countries with outlying sex ratios in the under-five mortality rate (U5MR), primarily observed in South Asia (Bangladesh, India, Nepal, Pakistan, etc.) and China.

These differences in mortality extend beyond the fifth birthday but have been less studied in older children and adolescents ages 5–14 or older adolescents and youths ages 15–24. Nevertheless, older children, adolescents, and youth comprise about a third of the global population and account for a large fraction of premature deaths. In 2021, 2·1 million deaths occurred between ages 5 and 24, most of them preventable.[6,7] Previous research on sex differences among older children and adolescents has focused on specific age groups (often ages 10–19 years) based on varying methodologies across age groups and particular data. Most recently, Ward et al. analysed sex differences in survival between ages 10 and 24 in estimates from the *Global Burden of Disease* (GBD) 2019 Study.[8] They observed that 61% of deaths at these ages in 2019 occurred among boys and that sex differences have widened in recent decades due to a more rapid decline in girls' mortality since 1950 (a decrease of 30% among girls versus 15% among boys). However, their estimates of sex differences in mortality in the population ages 10–24 were not data-driven; they were inferred from a combination of differences in survival in those under five and the mortality between 15 and 60, including model age patterns of mortality and covariates.[9] In addition, they did not produce uncertainty intervals (UIs) regarding sex ratios and could not pinpoint countries with outlying sex ratios.

In this study, we estimated the levels and trends in the sex ratio of mortality by five-year age group from birth to 25 years for 200 countries from 1990 to 2021. In this model, the relationship between sex ratios of mortality and national-level mortality for each age group was assessed using all available data. The relationship was modelled with flexible Bayesian hierarchical models. We used the national-level mortality estimates[6,10,11] to construct sex-specific mortality rates for all country-years, including those without empirical data. This approach accounts for the varying quality and availability of data across sources and countries and addresses data scarcity. Most deaths before age 25 occur in low- and middle-income countries (97·7% in 2021, 90% UI 97·5%–97·9%), where death registration systems are often incomplete. In low- and middle-income countries, surveys and censuses are the primary data sources; however, they can provide inconsistent estimates of the sex ratios due to sampling and non-sampling errors caused by non-responses, recall errors, and possible selection biases. These errors and biases are explicitly considered in this study.

Methods

Database construction

The *United Nations Inter-agency Group for Child Mortality Estimation* (UN IGME), which includes members from the United Nations Children's Fund (UNICEF), the World Health Organization (WHO), the World Bank Group, and the United Nations Department of Economic and Social Affairs, Population Division, compiles and assesses the quality of all available nationally representative data on neonatal mortality and U5MR and estimates these indicators for tracking country progress towards the achievement of the Sustainable Development Goal targets for child survival. The UN IGME also produces all-cause mortality estimates that are internationally comparable for older children, adolescents, and youth (ages 5–24).[6] Empirical databases are updated annually with final estimates and are available in the public domain (http://www.childmortality.org). For this study, we used the same data sources. We extracted the sex ratios for the mortality rate for six age groups: 0–1 (infant), 1–4 (child), 5–9 (older child), 10–14 (younger adolescent), 15–19 (older adolescent), and 20–24 (youth) years. The construction of the databases for both sexes has been detailed elsewhere.[10–12] We explain the steps explicitly related to estimating sex ratios.

Vital registration data – Nationally representative vital registration data were extracted from the WHO mortality database and the Human Mortality Database. Death registration was only included for children ages 0–4 if the record was complete. Completeness of death registration data for the age group 0–4 was estimated as the reported U5MR in vital registration data divided by the corresponding UN IGME estimates, which may rely on other data sources, such as surveys and census data. Loess regression (for smaller gaps in years) and linear interpolation (for larger gaps in years, e.g. gaps greater than five years) were applied to generate the time series using the available estimates of child completeness to impute completeness in years when vital registration data were unavailable. We estimated the completeness of death registration for the age groups 5–14 and 15–24 using death distribution methods, comparing the age distribution of deaths between two censuses with the age distribution of the population enumerated.[13] The stochastic standard error of the observation was calculated using the Poisson approximation based on the number of births or the population turning 5 or 15 in a given year, estimated from the 2022 *World Population Prospects* (WPP).[14] We also included estimates from sample vital registration systems in India[15] and Bangladesh,[16] the Chinese national mortality surveillance system,[17] and the Rapid Mortality Surveillance in South Africa.[18]

Birth and sibling histories in surveys – Data from full birth histories collected in Demographic and Health Surveys, Multiple Indicator Cluster Surveys, World Health Surveys, World Fertility Surveys, Reproductive Health Surveys, and selected surveys from the Pan-Arab Programme on Family Health, were used to compute sex ratios for children ages 0–4 and adolescents ages 5–14, for periods of varying lengths, optimised to capture shorter-term changes for country-years with sufficient information.[19] Data from full sibling survival histories from Demographic and Health Surveys and Multiple Indicator Cluster Surveys were used to estimate the sex ratio in youth ages 15–24 for optimised reference periods. In all age groups, the sampling variance was calculated using the Jackknife estimation to account for the survey sample design. Indirect methods based on the number of children ever born and surviving reported for women of reproductive age, called summary birth histories, were used for U5MR.

Censuses – Reports on recent household deaths were used to compute sex-specific estimates. The calculation of age-specific mortality rates was derived from standard life table methods. Data from the summary birth histories were also used for U5MR.

The inclusion criteria for the sex ratio observations followed the same criteria as for observations of total mortality for each age group. Additionally, extreme observations, defined as sex ratios greater than 10 or smaller than 0·1, were removed (2% were removed because of this criterion; the excluded observations were primarily from vital registration systems in small countries). An overview of all employed data sources, broken down by country and age group, is provided in the web appendix (supplementary Tables 21–27).

Statistical analysis

Estimating sex ratios – For sex ratios in children under age five, we used the model detailed by Alkema et al.[5] Above age five, we adapted the model to facilitate more efficient computation while attaining estimation quality and flexibility. Differences in databases between ages under and above five enabled us to update the model.

Among the under-five age group, some indirect estimates based on proportions of surviving children by age group of mothers (or time since first birth) are not disaggregated by age (between infant and child mortality), making the estimation of sex ratios in U5MR more complex. Beyond the age of five, the database contains only direct estimates, which can be disaggregated by age to make the modelling approach more efficient. Both models, for mortality below and above age five, use the sex ratio from empirical data and the estimates of national-level mortality rates (for females and males combined) published by the UN IGME in 2023 as input.[6] The model for children below age five is detailed by Alkema et al.,[5] and the estimation model for the sex ratio above the age of five is summarised below. Details on the model specification, implementation, and validation are also presented in the web appendix.

We used a flexible model to model the non-linear global relation between sex ratios and total mortality rates above the age of five. Country-specific sex ratios were modelled using the product of the expected sex ratio (based on the flexible global model and total mortality rate in the country-year) and a country-specific multiplier, capturing the temporal effect and representing the relative difference in sex ratio compared to other countries at similar total mortality rates. These multipliers were modelled with a national-level flexible function in which country-specific levels were assumed to fluctuate around 1. The Bayesian hierarchical model estimates the global sex ratio given the total mortality rates and within-country temporal fluctuations simultaneously, allowing the two model elements to inform each other.

The data quality model incorporated (i) stochastic and sampling variance caused by a limited number of person-years and deaths or by small samples from the overall population and (ii) non-sampling variance, which is assumed to differ across data-source types. The Bayesian estimates are pooled towards informative observations (corresponding to small variances) and are less influenced by weakly informative observations (i.e. with large variances).

We used the integrated nested Laplace approximation (INLA) algorithm to generate samples from the posterior distribution of the parameters.[20] This approach produced a set of trajectories of sex ratios for all age groups for each country and associated measures of sex-specific mortality, excess female mortality, and deaths. Estimates of the final sex ratios were combined with national-level mortality rate estimates to obtain country-year, sex-specific mortality rates, accounting for the uncertainty in the national-level mortality rates.[6] Estimates for countries without data were imputed from the model assumptions and parameter estimates. They were based on the expected sex ratios (determined by the national-level mortality rate for that country), the uncertainty in country-specific deviations based on simulations of the country-year-specific multiplier (that captured the variability unexplained by the expected sex ratios), and the uncertainty in national-level mortality rates.

Aggregated mortality rates by sex were derived by applying the proportions of sex-specific deaths within a region to the aggregated UN IGME mortality rate in a region.[6] We computed 90% UIs for all indicators of interest using the 5^{th} and 95^{th} percentiles of the posterior distributions. We used 'significantly' to refer to the 90% UI of an estimate above or below the reference level (with 0 as the reference for difference and 1 for the ratio).

Model performance was assessed through an out-of-sample validation (web appendix pp 10–11). The validation results suggested that the proposed model was reasonably well calibrated, with generally conservative UIs (i.e. wider than expected). The INLA algorithm was implemented using the R-package INLA,[21] and the analysis was conducted in R version 4·1·0.[22] Software programs are available from the corresponding author upon request.

Adjustment for crises – The sex-specific mortality rates and related deaths were adjusted to account for crisis-related deaths. Adjustments were made in 36 countries for ages 0–4, 53 countries for ages 5–14, and 48 countries for ages 15–24 to account for crisis-related deaths. Excess deaths due to conflicts or epidemics were estimated based on the Uppsala Conflict Data Programme dataset,[23] the Armed Conflict Location and Event Data Project,[24] and other country-specific data sources.[25] Deaths from natural disasters were obtained from the international disasters database called EM-DAT.[26] No specific adjustment was made for the coronavirus disease 2019 (COVID-19) pandemic because the UN IGME did not find sufficient evidence to warrant a systematic adjustment for national both-sex estimates based on available data from over 110 countries in 2020 and over 80 countries in 2021.[6] Moreover, estimates from vital statistics data already reflect the potential disruptions introduced by the pandemic. Data are lacking in other countries to conclude differential effects on sex-specific mortality under 25.

Calculation of excess deaths and identification of outlying sex ratios – We used male mortality as a reference level to compute the expected and estimated female mortality based on the total mortality and expected and estimated sex ratios. We defined and calculated excess female mortality as the difference between the expected and estimated female mortality rate for the country-year (where a negative excess female mortality is equivalent to lower-than-expected female mortality). The sex ratio for a country-year is considered outlying if two conditions hold. The first condition is that the posterior probability that excess female mortality is greater or less than zero is at least 95%, or in other words, that at least 95% of the posterior samples of the excess female mortality rate are either all below zero or all greater than zero. The second condition is that the absolute value of the median excess female mortality is greater than one death per 1,000 population.

Role of the funding source

The study sponsors had no role in the study design, data analysis or interpretation, or report writing. The corresponding author had full access to all data in the study and had final responsibility for the decision to submit for publication.

Results

We provide sex ratio-related results with median estimates and 90% UIs for 200 countries, seven regions, and world in 1990 and 2021, disaggregating infant (0–1), child (1–4), and age-specific mortality by five-year age groups (from 5 to 24). These results are in the web appendix Tables 12–20. All input data and final estimates are available online (http://www.childmortality.org).

Table 1 displays sex ratios for the 0–4, 5–14, and 15–24 age groups for 1990 and 2021 for the world and UNICEF regions (classification of the country by UNICEF region is available in the web appendix Table 9). Globally, the sex ratio in 2021 was 1·13 for ages 0–4 [90% UI 1·11–1·15], and it increased as children and adolescents aged, from 1·16 [1·12–1·20] in children ages 5–14, up to 1·65 [1·52–1·75] in youth ages 15–24. In 2021, there was relatively little regional variation in the sex ratio for 0–4 years old, ranging from 1·05 [1·01–1·09] in South Asia to 1·24 [1·21–1·27] in Europe and Central Asia. In 2021, the sex ratio was higher in older children and adolescents ages 5–14 than in children younger than five in all regions except sub-Saharan Africa. All regions observed a more pronounced increase from 5–14 to 15–24 years of age. There was also a wider geographical variation in this age group; the sex ratio among youths ages 15–24 was only 1·30 [1·17–1·42] in sub-Saharan Africa and 1·44 [1·21–1·70] in South Asia, but it was greater than 2 in all other regions and reached 3·33 [3·05–3·54] in Latin America and the Caribbean.

In all age groups, the global sex ratio increased significantly over the period from 1990 to 2021, from 1·06 [1·05–1·07] to 1·13 [1·11–1·15] in children ages 0–4, from 1·06 [1·04–1·09] to 1·16 [1·12–1·20] in the age group 5–14 and from 1·29 [1·23–1·35] to 1·65 [1·52–1·75] in older adolescents and youth ages 15–24. Regional trends since 1990 reflect, in part, the varying paces of the mortality decline and, in part, sociocultural changes related to, for example, less discrimination against girls or greater exposure of boys to specific causes of violent death. In 2021, sub-Saharan Africa had the lowest sex ratio in the 5–14 and 15–24 age groups at 1·09 [1·04–1·14] and 1·30 [1·17–1·42], respectively. Moreover, the highest sex ratio in 2021 for the age group 5–14 is estimated in East Asia and Pacific at 1·49 [1·37–1·61] and for the age group 15–24 in Latin America and Caribbean at 3·33 [3·05–3·54]. In 1990, the sex ratio of mortality was the lowest in South Asia, at levels significantly below 1 from ages 0 to 24, a clear sign of discrimination against females under age 25. The South Asia ratios were respectively 0·97 [0·95–0·99] for 0–4 years old, 0·94 [0·89–0·98] for 5–14 years old, and 0·82 [0·76–0·89] for 15–24 years old. From 1990 to 2021, the sex ratio in South Asia increased significantly in all age groups, with males now facing higher risks of dying from birth to age 25. Despite the increased sex ratios for all age groups, in 2021, South Asia was still characterised by the lowest sex ratio under five years of age (1·05 [1·01–1·09]) and the second lowest sex ratio between ages 5 and 14 at 1·27 [1·16–1·38] and between ages 15 and 24 at 1·44 [1·21–1·70]. Among the seven regions, the sex ratio increased significantly in three regions among ages 5–14, with the largest absolute increase estimated in South Asia at 0·33 [0·21–0·45]. For the sex ratio among youths ages 15–24, all regions except East Asia and Pacific changed significantly, with four experiencing increasing sex ratios and two decreasing sex ratios. The greatest absolute increases in older adolescent and youth sex ratios were estimated in Latin America and Caribbean (from 2·34 [2·22–2·45] in 1990 to 3·33 [3·05–3·54] in 2021) and in the Middle East and North Africa (from 1·81 [1·64–2·04] in 1990 to 2·72 [2·35–3·04] in 2021). In contrast, North America's sex ratios of mortality declined significantly for all age groups, as did Europe and Central Asia for ages 5–24.

Overall, in 2021, a newborn male's probability of reaching his 25th birthday was 94·1% [93·7%–94·4%], compared to 95·1% [94·7%–95·3%] for a newborn girl. Combined with more male births, this resulted in a higher proportion of male deaths in the first 25 years of life (Table 2). Males accounted for 56·2% [55·7%–56·7%] of deaths between ages 0 and 24 in 2021, compared to 53·4 [53·2%–53·7%] in 1990. This increased proportion in 2021 is a combination of the rise in sex ratios of mortality over time and the growing concentration of mortality in older age groups. In 2021, among young children ages 0–4, between 53% (in South Asia) and 57% (in Europe and Central Asia, and East Asia and Pacific) of deaths were in males. These proportions among children ages 5–14 vary between 53% in Sub-Saharan Africa and 62% in East Asia and the Pacific. For older adolescents and youth ages 15–24, the lowest proportion of male deaths is 57% in Sub-Saharan Africa, and the highest proportion is 77% in Latin America and Caribbean.

Figure 1 illustrates the expected sex ratios for total mortality based on the global relationship between mortality levels and sex ratios for the 0–4, 5–14, and 15–24 age groups. Similar patterns occur for all age groups; as the total mortality declines, the sex ratio initially increases until it reaches a maximum, followed by a slight reduction when the total mortality further decreases. The relationship between total U5MR and its sex ratio based on all country-years suggests an increase in the U5MR sex ratio from 1·07 to 1·24 as the U5MR decreases from 340 to 18 deaths per 1,000 live births. A drop follows this increase in the expected sex ratio to 1·15 as U5MR further reduces to four deaths per 1,000 live births. The expected sex ratio for 5–14 starts at 1·04 when the total mortality for ages 5–14 is around 90 deaths per 1,000 children at precisely 5. The 5–14 sex ratio steadily climbs to its maximum at 1·52 when the total mortality rate declines to four deaths per 1,000 population. When the total mortality further decreases to 1 death per 1,000 population, the sex ratio for 5–14 declines to 1·31. For the age group 15–24, the expected sex ratio increases from 0·62 to 2·53 as the total mortality reduces from 60 to 7 deaths per 1,000 population. The sex ratio 15–24 decreases slightly to 2·23 when the total mortality further reduces to 2 deaths per 1,000 population.

Figure 2 displays the country-specific sex ratios in ${}_5q_0$ (the probability of a newborn dying before reaching age five), ${}_{10}q_5$ (the probability of children alive at age five dying before reaching 15), and ${}_{10}q_{15}$ (the probability of youth alive at age 15 passing before reaching 25) in 2021. There was a strong correlation in 1990 between the sex ratio of mortality between 0–4 and 5–14 years of age (0·64, $p < 0{\cdot}01$) and between 5–14 and 15–24 years of age (0·58, $p < 0{\cdot}01$). However, these correlations were much lower in 2021: 0·20 ($p < 0{\cdot}01$) between 0–4 and 5–14 years and 0·43 between 5–14 and 15–24 years ($p < 0{\cdot}01$), reflecting distinct developments by age group over the past 30 years.

The observed sex ratio should be compared to an expected level to account for the biological advantage of girls. Table 3 summarises excess female mortality and displays the corresponding number of excess deaths. In five countries (Algeria, Bangladesh, Egypt, India, and Iran), females faced significantly higher risks of dying than males before their fifth birthday in 2021. In children and adolescents ages 5–14, Suriname was the only country identified with an outlying sex ratio in 2021. However, its excess female mortality is estimated at 1·9 [1·3–2·5] deaths per 1,000 population, resulting in fewer than a dozen female deaths yearly. Among youth ages 15–24, 21 countries had an outlying sex ratio in 2021, where 13 countries had higher-than-expected female mortality, and eight countries had lower-than-expected female mortality. Afghanistan is estimated with the largest excess female ${}_{10}q_{15}$ at 20·8 [3·3–38·5] deaths per 1,000 population, followed by Eswatini with an excess female ${}_{10}q_{15}$ at 13·5 [1·5–23·1] deaths per 1,000 population. After considering the population sizes, the highest number of excess female deaths is estimated in India at 37,200 [23,600–52,300] in 2021.

The estimates of the sex ratio at less than five years of age are very close to those developed in the GBD Study 2019 or WPP 2022 revision (Figure 4), but there are essential discrepancies when assessing children and young adolescents ages 5–14 years or youths ages 15–24 years. The GBD estimates predict higher mortality for boys ages 5–24 than in this study, except in 2018 and 2019 for youths ages 15–24. By contrast, WPP demonstrates lower sex ratios of mortality among children ages 5–14 years since 1990 and in youth ages 15–24 over the past 16 years. The results also suggest that the sex ratio of mortality at 5–24 years of age has increased steadily, with no clear sign of stabilisation. In other words, the decline in the sex ratio observed in countries with lower mortality levels has not yet translated into an inflexion in sex ratios at the global level. Differences between this study and results from GBD 2019 and WPP 2022 are magnified when considering the national level. Between ages 5 and 14, the sex ratio estimated in this study for 2019 differs by more than 20% from GBD estimates in 36 countries (62 countries compared to WPP). These discrepancies were more common between ages 15 and 24 in 2019 (GBD produced results up to 2019): for 53 countries, the sex ratio we estimated differs by more than 20% from GBD, which is the case for 73 countries for WPP. These differences in sex ratio are combined with differences in mortality levels, which we have documented elsewhere.[10,11] Due to data scarcity, such discrepancies between these studies illustrate the uncertainty surrounding the mortality of children, adolescents, and youths ages 5–24.

Discussion

Inequalities in survival chances between sexes arise for biological reasons and because of differences in nutrition and health care. Quantifying these differences in survival is difficult because sex ratios of mortality vary naturally with the level of mortality due to changes in the relative contribution of underlying causes of death. This study is the first to provide estimates of sex ratios with UIs up to age 25 and to quantify the excess mortality over the expected sex ratio for the same level of mortality. We modelled sex ratios at each age group as a function of the total mortality level achieved at that age, allowing for country-specific deviations. We exploited the set of age-specific estimates available in the public domain.

Using a consistent approach from birth to 25, we demonstrate that the sex ratio rapidly increases as children age, with a particularly notable increase between the 5–14 group [1·16; 1·12–1·20] and the 15–24 group [1·65; 1·52–1·75]. Regional estimates present very contrasting patterns, reflecting the state of the health transition in different regions (and thus the levels of mortality for both sexes and the associated cause-of-death distribution), the extent of discrimination against girls, and the disproportionate exposure of boys to specific causes of death (e.g., violent mortality). In particular, in 1990, South Asia had atypically low sex ratios at all ages, falling below unity, reflecting the extent of discrimination against girls in that region. The region has since experienced rapid growth in the sex ratio to the point at which it now has a higher sex ratio of mortality than sub-Saharan Africa in the age groups 5–14 and 15–24.

Sex inequalities manifest as excess female mortality under five years of age, with few countries where boys experience significant disadvantages. However, as children age and reach adolescence and early adulthood, some countries experience widening gaps to the disadvantage of boys. Latin America and the Caribbean, in particular, stand out as regions with high sex ratios, particularly above age 15, deviating from the experience of other regions, presumably because of the increased contribution of violent deaths at these ages.

Since 1990, sex ratios have increased in all age groups due to rapid progress against girls' mortality. The world and most regions have registered such a rise, although the sex ratio tends to stabilise or decline in countries with low mortality levels, as observed in North America. The increase in the sex ratio between five and 24 years of age as mortality declines can be explained by changes in the cause-specific distribution of deaths. Recent cause-specific estimates for 5–19-year-olds have revealed that mortality rates due to road traffic injuries have declined moderately compared to other causes, such as measles, whereas mortality due to collective violence has increased from 2010–2019.[7] However, the mechanism to explain the stabilisation and subsequent decline in the sex ratio when mortality reaches lower levels is still unclear and requires further research.

At ages less than five years, the WPP and GBD estimates align with each other, but the differences are substantial for children ages 5–14 years and youths ages 15–24. There are several advantages in the proposed approach over the existing estimates, for example, using estimates that refer to these age groups without resorting to inferences based on sex differentials observed at other ages, modelling sex inequalities by specific 1- or 5-year age groups, accounting for sampling and reporting errors in surveys and census data, and measuring the sex-specific completeness of death registration.

However, the proposed approach also has limitations. First, for countries without age- and sex-disaggregated mortality data (36, 53, and 48 countries for age groups 0–4, 5–14, and 15–24, respectively), these estimates are based on the global pattern only. Second, relying on the relationship between the sex ratio and mortality level, we could introduce errors in the sex ratio if the mortality envelopes for both sexes are biased. Third, we do not use covariates that would improve the estimates, such as the cause-of-death distribution or information on sex differentials in health status (nutrition, immunisation, etc.). Such estimates are unavailable for all countries worldwide or result from complex modelling. Fourth, the proposed model can produce plausible estimates and short-term projections in recent periods of about 20 years (as verified by the validation results in the web appendix pp 10–11); however, the model requires further updates to produce reliable long-term projections. Finally, we sought to use the same statistical approach for all age groups, applying the method used by the UN IGME for several years to disaggregate U5MR by sex. We found strong and positive correlations of sex ratios between neighbouring age groups in 1990, but these correlations were much reduced in 2021. The reduced correlation over time in sex ratios between neighbouring age groups suggests that it may be misleading to estimate sex ratios in older age groups from those observed in young children.

A myriad of complex mechanisms is at play, giving rise to sex disparities in survival in the first 25 years of life. We produced Bayesian estimates with uncertainty assessments using extensive databases to describe the development of these sex disparities since 1990. Now that these disparities have been quantified in each specific age group and contrasted with the expected level given the mortality transition status, we can better identify the mechanisms at work and target countries where specific interventions are needed. Several thousand excess deaths still occur among girls ages 0–25 due to discriminatory practices, despite significant progress since 1990.

Research in context

Evidence before this study
Existing studies on disparities in survival chances between sexes primarily concentrate on neonates and young children under five. The sex differentials in mortality have not been systematically examined in older children, adolescents, and youth ages five to 24 based on empirical measurements referring specifically to this age group.

The added value of this study
We systematically assessed the sex disparity of mortality rates in the early life course, from birth to age 25, for all assessed countries from 1990 to 2021. We compiled three extensive databases, including publicly available data sources for children, adolescents, and youth ages 0–4, 5–14, and 15–24. We modelled the relationship between the sex ratio and total mortality rate for each age group. This study provides insight on sex ratios worldwide, the association between sex ratios and total mortality levels, and pinpoints countries with outlying sex ratios. It reveals that chances of survival up to age 25 tend to improve more rapidly for girls than boys as total mortality decreases, with a reversal of this trend at very low mortality.

Implications of all available evidence
Further research should focus on explaining differences across countries and regions, and actions should be taken to reduce sex disparities due to discrimination or excessive exposure to violence.

Conflicts of interest

We declare no competing interests.

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Contributors

FC conducted the analysis, drafted the initial manuscript, developed the Bayesian statistical model, interpreted the results, and drafted the web appendix. BM proposed the study, oversaw database construction, assessed and compiled the databases, conducted the literature review, interpreted the results, and edited the web appendix. DY, LH, YL, and DS interpreted the results and provided policy implications. LA contributed to the Bayesian model and interpreted the results. HR contributed to the Bayesian model and INLA specifications. HO contributed to the Bayesian model. All authors reviewed the model results, edited the manuscript, and agreed on the final manuscript.

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	Sex ratio 5q0			Estimated/Expected female 5q0		
	1990	2021	Change (1990–2021)	1990	2021	Change (1990–2021)
World ¶§	1.06 [1.05; 1.07]	1.13 [1.11; 1.15]	0.07 [0.05; 0.09]†	1.06 [1.05; 1.07]*	1.03 [1.01; 1.05]*	-0.03 [-0.06; -0.01]†
South Asia¶§	0.97 [0.95; 0.99]	1.05 [1.01; 1.09]	0.08 [0.04; 0.12]†	1.16 [1.13; 1.18]*	1.16 [1.11; 1.20]*	0.00 [-0.05; 0.05]
Europe and Central Asia	1.21 [1.19; 1.23]	1.24 [1.21; 1.27]	0.03 [0.00; 0.06]†	0.99 [0.97; 1.01]	0.98 [0.96; 1.00]	-0.01 [-0.03; 0.02]
Middle East and North Africa¶	1.07 [1.05; 1.08]	1.16 [1.12; 1.20]	0.10 [0.05; 0.14]†	1.10 [1.08; 1.12]*	1.05 [1.00; 1.09]	-0.05 [-0.10; -0.01]†
Sub-Saharan Africa¶	1.11 [1.10; 1.12]	1.16 [1.13; 1.18]	0.05 [0.02; 0.08]†	0.98 [0.97; 0.99]*	0.98 [0.96; 1.01]	0.00 [-0.02; 0.03]
Latin America and Caribbean	1.18 [1.15; 1.22]	1.22 [1.19; 1.26]	0.04 [0.00; 0.08]	1.00 [0.97; 1.03]	1.00 [0.97; 1.03]	0.00 [-0.03; 0.03]
East Asia and Pacific¶	1.12 [1.08; 1.17]	1.20 [1.16; 1.24]	0.08 [0.02; 0.13]†	1.05 [1.01; 1.09]*	1.01 [0.97; 1.04]	-0.04 [-0.09; 0.01]
North America	1.25 [1.24; 1.27]	1.20 [1.16; 1.24]	-0.05 [-0.09; -0.01]†	0.97 [0.96; 0.99]*	0.99 [0.96; 1.03]	0.02 [-0.01; 0.05]
	Sex ratio 10q5			Estimated/Expected female 10q5		
	1990	2021	Change (1990–2021)	1990	2021	Change (1990–2021)
World	1.06 [1.04; 1.09]	1.16 [1.12; 1.20]	0.10 [0.06; 0.13]†	1.03 [1.00; 1.06]*	1.00 [0.96; 1.04]	-0.03 [-0.06; 0.01]
South Asia¶	0.94 [0.89; 0.98]	1.27 [1.16; 1.38]	0.33 [0.21; 0.45]†	1.10 [1.05; 1.17]*	1.13 [1.01; 1.24]*	0.02 [-0.11; 0.15]
Europe and Central Asia	1.51 [1.47; 1.54]	1.36 [1.33; 1.39]	-0.14 [-0.19; -0.10]†	0.92 [0.89; 0.95]*	1.04 [1.02; 1.06]*	0.12 [0.08; 0.16]†
Middle East and North Africa	1.15 [1.11; 1.19]	1.43 [1.35; 1.52]	0.28 [0.19; 0.38]†	0.99 [0.93; 1.03]	0.98 [0.87; 1.06]	0.00 [-0.12; 0.10]
Sub-Saharan Africa	1.05 [1.01; 1.09]	1.09 [1.04; 1.14]	0.04 [-0.03; 0.10]	0.99 [0.97; 1.02]	0.97 [0.93; 1.03]	-0.02 [-0.08; 0.05]
Latin America and Caribbean	1.34 [1.31; 1.37]	1.32 [1.27; 1.37]	-0.02 [-0.09; 0.04]	1.02 [0.99; 1.04]	1.08 [1.02; 1.13]*	0.06 [0.00; 0.12]
East Asia and Pacific	1.23 [1.16; 1.30]	1.49 [1.37; 1.61]	0.25 [0.12; 0.40]†	1.00 [0.93; 1.07]	0.95 [0.87; 1.04]	-0.05 [-0.16; 0.07]
North America	1.50 [1.46; 1.53]	1.30 [1.23; 1.38]	-0.20 [-0.28; -0.11]†	1.00 [0.97; 1.02]	1.05 [0.99; 1.11]	0.05 [-0.01; 0.12]
	Sex ratio 10q15			Estimated/Expected female 10q15		
	1990	2021	Change (1990–2021)	1990	2021	Change (1990–2021)
World¶	1.29 [1.23; 1.35]	1.65 [1.52; 1.75]	0.36 [0.22; 0.49]†	1.25 [1.16; 1.34]*	1.04 [0.89; 1.16]	-0.21 [-0.38; -0.07]†
South Asia¶	0.82 [0.76; 0.89]	1.44 [1.21; 1.70]	0.61 [0.38; 0.89]†	2.47 [2.18; 2.75]*	1.62 [0.99; 1.96]	-0.85 [-1.51; -0.39]†
Europe and Central Asia	2.62 [2.49; 2.75]	2.20 [2.12; 2.28]	-0.42 [-0.57; -0.27]†	0.88 [0.71; 0.94]*	1.12 [1.07; 1.17]*	0.23 [0.16; 0.41]†
Middle East and North Africa	1.81 [1.64; 2.04]	2.72 [2.35; 3.04]	0.91 [0.44; 1.27]†	1.11 [0.67; 1.32]	1.03 [0.87; 1.18]	-0.09 [-0.35; 0.37]
Sub-Saharan Africa	1.06 [0.98; 1.13]	1.30 [1.17; 1.42]	0.24 [0.09; 0.40]†	0.90 [0.80; 1.01]	0.96 [0.78; 1.16]	0.06 [-0.15; 0.27]
Latin America and Caribbean	2.34 [2.22; 2.45]	3.33 [3.05; 3.54]	0.99 [0.69; 1.24]†	0.78 [0.70; 0.88]*	0.59 [0.51; 0.68]*	-0.19 [-0.32; -0.08]†
East Asia and Pacific	1.85 [1.62; 2.09]	2.29 [1.88; 2.70]	0.44 [-0.05; 0.93]	1.14 [0.98; 1.33]	1.05 [0.73; 1.27]	-0.09 [-0.44; 0.19]
North America	2.98 [2.92; 3.03]	2.55 [2.21; 2.91]	-0.43 [-0.77; -0.06]†	0.82 [0.80; 0.85]*	0.99 [0.87; 1.14]	0.17 [0.04; 0.32]†

Table 1: Estimates and 90% uncertainty intervals for sex ratios and ratios of estimated to expected female mortality for the U5MR, 10q5, and 10q15 for the world and UNICEF regions, for 1990 and 2021, and the change from 1990 to 2021. ¶: Sex ratio is outlying for 1990; §: Sex ratio is outlying for 2021; *: Ratio of estimated to expected female mortality is significantly different from one; †: Change is significantly different from zero.

Number of deaths (in thousands) in 1990 Proportion of deaths among total death in an age group in 1990						
Age group	0–4 years		5–14 years		15–24 years	
Sex	Female	Male	Female	Male	Female	Male
World	6,040 [5,980; 6,190] 47%	6,790 [6,760; 7,000] 53%	771 [756; 802] 47%	861 [842; 898] 53%	727 [703; 797] 43%	975 [943; 1,060] 57%
South Asia	2,400 [2,340; 2,480] 49%	2,480 [2,440; 2,580] 51%	290 [278; 304] 50%	291 [279; 306] 50%	290 [269; 314] 53%	254 [236; 276] 47%
Europe and Central Asia	173 [170; 181] 44%	221 [217; 230] 56%	21 [20; 22] 39%	33 [32; 34] 61%	33 [32; 37] 27%	91 [88; 99] 73%
Middle East and North Africa	265 [260; 276] 47%	295 [290; 308] 53%	34 [32; 37] 45%	41 [39; 44] 55%	25 [22; 30] 34%	48 [43; 60] 66%
Sub-Saharan Africa	1,830 [1,800; 1,880] 47%	2,100 [2,080; 2,180] 53%	267 [256; 288] 48%	286 [275; 307] 52%	201 [190; 262] 49%	211 [198; 258] 51%
Latin America and Caribbean	291 [282; 302] 45%	359 [350; 374] 55%	25 [24; 26] 42%	34 [33; 35] 58%	38 [37; 40] 30%	89 [86; 92] 70%
East Asia and Pacific	1,070 [1,020; 1,140] 45%	1,310 [1,260; 1,410] 55%	131 [121; 145] 44%	170 [156; 191] 56%	130 [114; 156] 34%	252 [222; 295] 66%
North America	21 [20; 21] 43%	28 [26; 27] 57%	4 [4; 4] 40%	6 [6; 6] 60%	10 [9; 10] 25%	30 [30; 31] 75%
Number of deaths (in thousands) in 2021 Proportion of deaths among total death in an age group in 2021						
Age group	0–4 years		5–14 years		15–24 years	
Sex	Female	Male	Female	Male	Female	Male
World	2,300 [2,180; 2,580] 46%	2,740 [2,610; 3,070] 54%	370 [359; 409] 45%	459 [446; 505] 55%	472 [453; 543] 36%	831 [799; 939] 64%
South Asia	607 [554; 671] 47%	681 [621; 752] 53%	69 [61; 84] 42%	95 [85; 113] 58%	129 [112; 158] 39%	201 [172; 251] 61%
Europe and Central Asia	34 [32; 37] 44%	44 [42; 49] 56%	7 [6; 7] 41%	10 [9; 10] 59%	14 [14; 15] 30%	33 [32; 34] 70%
Middle East and North Africa	96 [79; 134] 45%	118 [96; 164] 55%	14 [13; 18] 39%	22 [20; 26] 61%	18 [16; 21] 26%	51 [46; 59] 74%
Sub-Saharan Africa	1,320 [1,200; 1,580] 46%	1,580 [1,450; 1,880] 54%	233 [222; 265] 47%	260 [247; 296] 53%	224 [206; 277] 43%	296 [275; 358] 57%
Latin America and Caribbean	68 [64; 75] 44%	87 [82; 96] 56%	12 [11; 13] 43%	16 [16; 18] 57%	28 [26; 31] 23%	96 [92; 103] 77%
East Asia and Pacific	160 [146; 182] 43%	210 [191; 239] 57%	32 [27; 40] 38%	53 [45; 67] 62%	49 [39; 72] 28%	125 [98; 181] 72%
North America	11 [11; 12] 44%	14 [13; 15] 56%	3 [2; 3] 43%	4 [3; 4] 57%	11 [10; 12] 28%	29 [27; 32] 72%

Table 2: Estimates and 90% uncertainty intervals for the sex-specific number of deaths (in thousands) for age groups 0–4, 5–14, and 15–24 for the world and UNICEF regions, in 1990 and 2021. Regional deaths may not sum up to the global deaths due to rounding. The proportion of sex-specific deaths among total death in an age group for the world and each region. The proportions may not sum up to 1 due to rounding.

Country	Sex Ratio	Estimated/Expected female	Excess female (per 1,000)	Excess female death	% of death
Age group 0–4: 5q0					
Algeria	1.16 [1.09; 1.24]	1.06 [1.00; 1.13]	1.2 [0.0; 2.5]	596 [24; 1,220]	2.8
Bangladesh	1.16 [1.10; 1.23]	1.06 [1.01; 1.13]	1.5 [0.1; 3.0]	2,270 [190; 4,480]	2.8
Egypt	1.14 [1.05; 1.24]	1.08 [1.00; 1.18]	1.3 [0.0; 3.2]	1,610 [0; 3,920]	3.4
India	0.98 [0.92; 1.04]	1.26 [1.19; 1.34]	6.5 [4.7; 8.2]	73,200 [53,700; 93,700]	10.3
Iran (Islamic Republic of)	1.10 [1.01; 1.20]	1.11 [1.02; 1.21]	1.2 [0.2; 2.9]	725 [128; 1,830]	4.6
Vietnam	1.42 [1.33; 1.51]	0.87 [0.81; 0.93]	-2.6 [-3.8; -1.4]	-1,830 [-2,700; -990]	-6
Age group 5–14: 10q5					
Suriname	0.84 [0.74; 0.94]	1.79 [1.57; 2.03]	1.9 [1.3; 2.5]	10 [7; 14]	23.9
Age group 15–24: 10q15					
Afghanistan	0.62 [0.44; 0.88]	2.85 [1.07; 5.06]	20.8 [3.3; 38.5]	9,050 [1,730; 16,700]	34.1
Algeria	1.80 [1.60; 2.02]	1.38 [1.23; 1.55]	1.1 [0.7; 1.5]	312 [197; 433]	9.6
Bangladesh	1.34 [1.03; 1.75]	1.91 [1.47; 2.48]	3.2 [1.8; 4.9]	5,290 [2,960; 7,980]	19.9
Brazil	4.33 [3.58; 5.20]	0.54 [0.44; 0.66]	-3.8 [-5.0; -2.7]	-6,290 [-8,230; -4,370]	-15.6
Colombia	3.80 [3.13; 4.57]	0.64 [0.53; 0.78]	-2.5 [-3.5; -1.4]	-1,050 [-1,500; -600]	-11.5
El Salvador	4.90 [4.00; 5.99]	0.49 [0.40; 0.60]	-3.6 [-4.7; -2.6]	-220 [-290; -160]	-16.7
Eswatini	0.90 [0.58; 1.43]	2.30 [1.08; 3.94]	13.5 [1.5; 23.1]	153 [18; 263]	27.9
Fiji	1.50 [1.12; 1.96]	1.68 [1.27; 2.24]	3.2 [1.4; 5.3]	24 [11; 41]	15.9
India	1.41 [1.16; 1.71]	1.79 [1.47; 2.17]	3.1 [1.9; 4.3]	37,200 [23,600; 52,300]	17.2
Kyrgyzstan	1.59 [1.46; 1.74]	1.59 [1.45; 1.75]	2.1 [1.7; 2.6]	110 [90; 130]	14.2
Mexico	2.98 [2.67; 3.32]	0.80 [0.71; 0.91]	-1.5 [-2.3; -0.7]	-1,610 [-2,520; -730]	-6.2
Nepal	1.43 [0.96; 2.10]	1.69 [1.07; 2.55]	3.2 [0.4; 7.4]	1,020 [120; 2,430]	16.3
Papua New Guinea	1.29 [0.90; 1.85]	1.86 [1.24; 2.72]	5.8 [1.9; 10.2]	539 [184; 951]	19
Suriname	1.33 [1.10; 1.60]	1.86 [1.52; 2.27]	4.5 [2.9; 6.4]	24 [16; 34]	19.6
Tajikistan	1.50 [1.36; 1.64]	1.61 [1.46; 1.79]	1.3 [1.0; 1.6]	111 [87; 136]	14.8
Thailand	3.30 [2.63; 4.07]	0.69 [0.55; 0.87]	-2.5 [-4.1; -0.9]	-1,070 [-1,750; -380]	-9.7
Trinidad and Tobago	3.20 [2.46; 4.09]	0.69 [0.32; 0.94]	-2.7 [-17.8; -0.5]	-26 [-172; -4]	-9.6
Turkmenistan	1.35 [1.01; 1.79]	1.84 [1.35; 2.49]	3.8 [1.7; 6.8]	188 [85; 336]	18.6
Uruguay	3.34 [2.84; 3.91]	0.75 [0.63; 0.88]	-1.4 [-2.2; -0.6]	-34 [-54; -15]	-7.5
Uzbekistan	1.21 [1.04; 1.40]	2.07 [1.78; 2.39]	3.4 [2.6; 4.2]	874 [678; 1,070]	22.9
Venezuela (Bolivarian Republic of)	5.00 [3.68; 6.68]	0.17 [0.11; 0.28]	-44.5 [-71.2; -20.0]	-10,000 [-20,000; 0]	-77.5

Table 3: Estimates and 90% uncertainty intervals for sex ratios, ratios of estimated to expected female mortality, excess female mortality, and associated number of excess deaths (as a percentage of the total number of deaths within each age group) for age groups 0–4, 5–14, and 15–24 for countries with outlying sex ratios in 2021. Countries are ordered alphabetically.

Figures

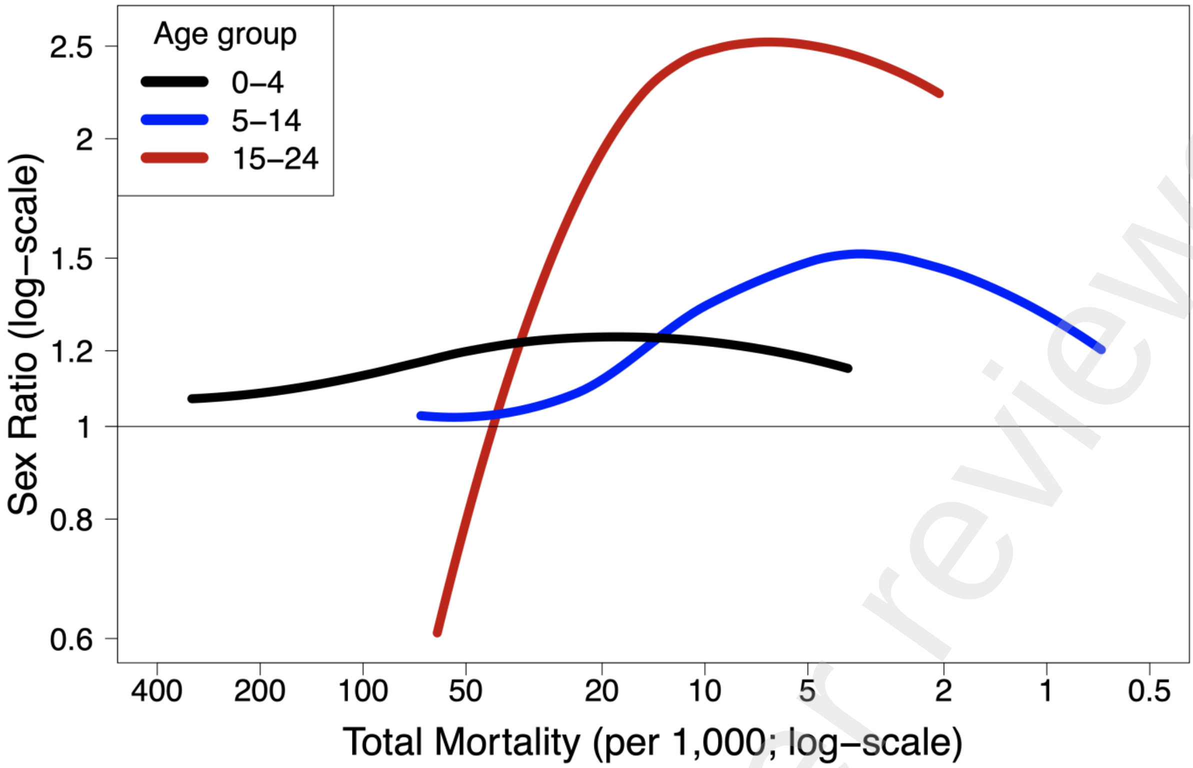

Figure 1: Overview of the global relations between sex ratios and total mortality levels. The curves illustrate the relation between sex ratios and total mortality based on the Bayesian models.

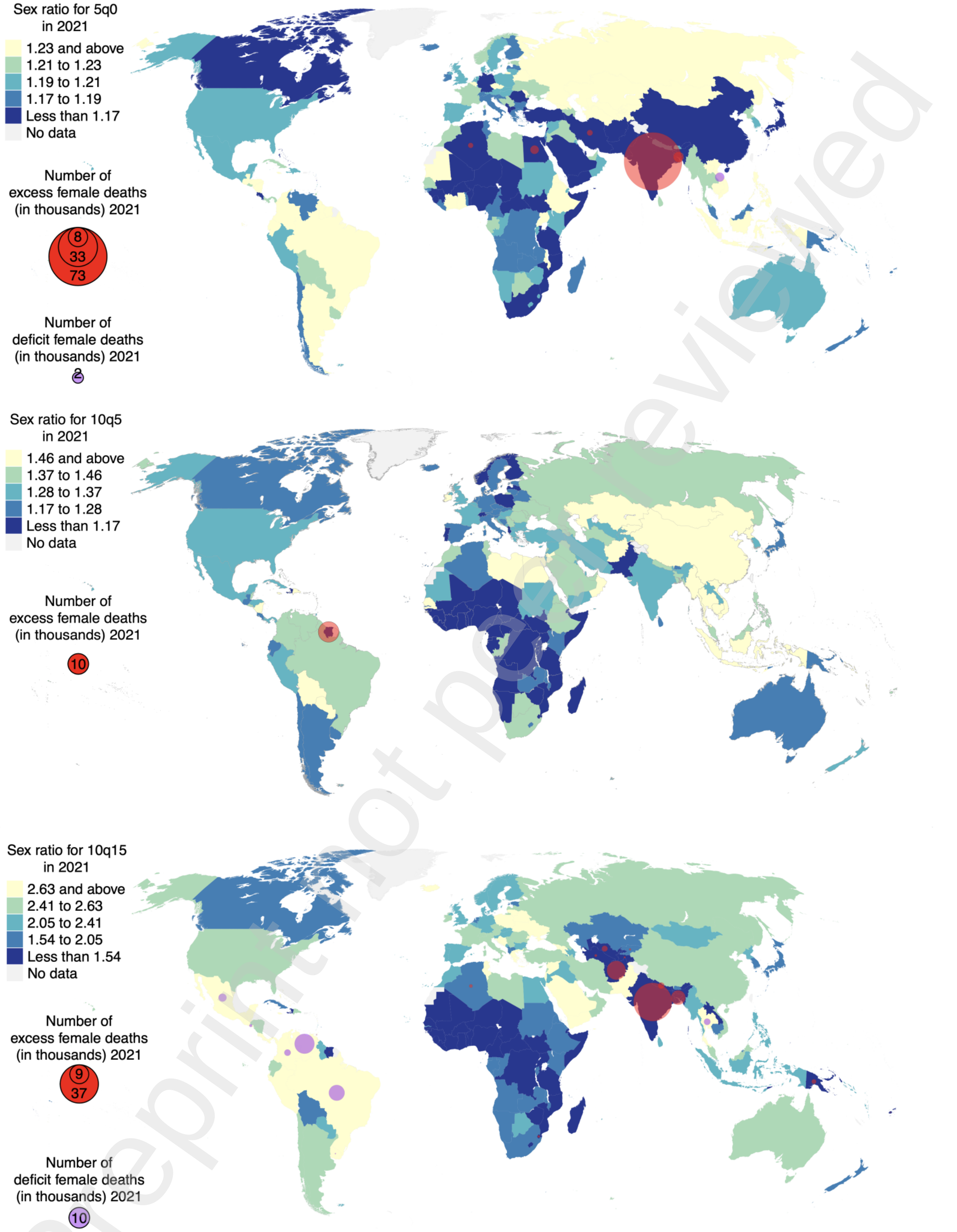

Figure 2: Sex ratios for the mortality rate and number of excess female deaths for age groups 0–4, 5–14 and 15–24 in 2021. Median estimates are shown in the plot. Numbers of excess and deficit female deaths are only shown for countries with outlying sex ratio in 2021. The color codes are quintiles of the sex ratio median estimates across all countries in 2021 for each age group.

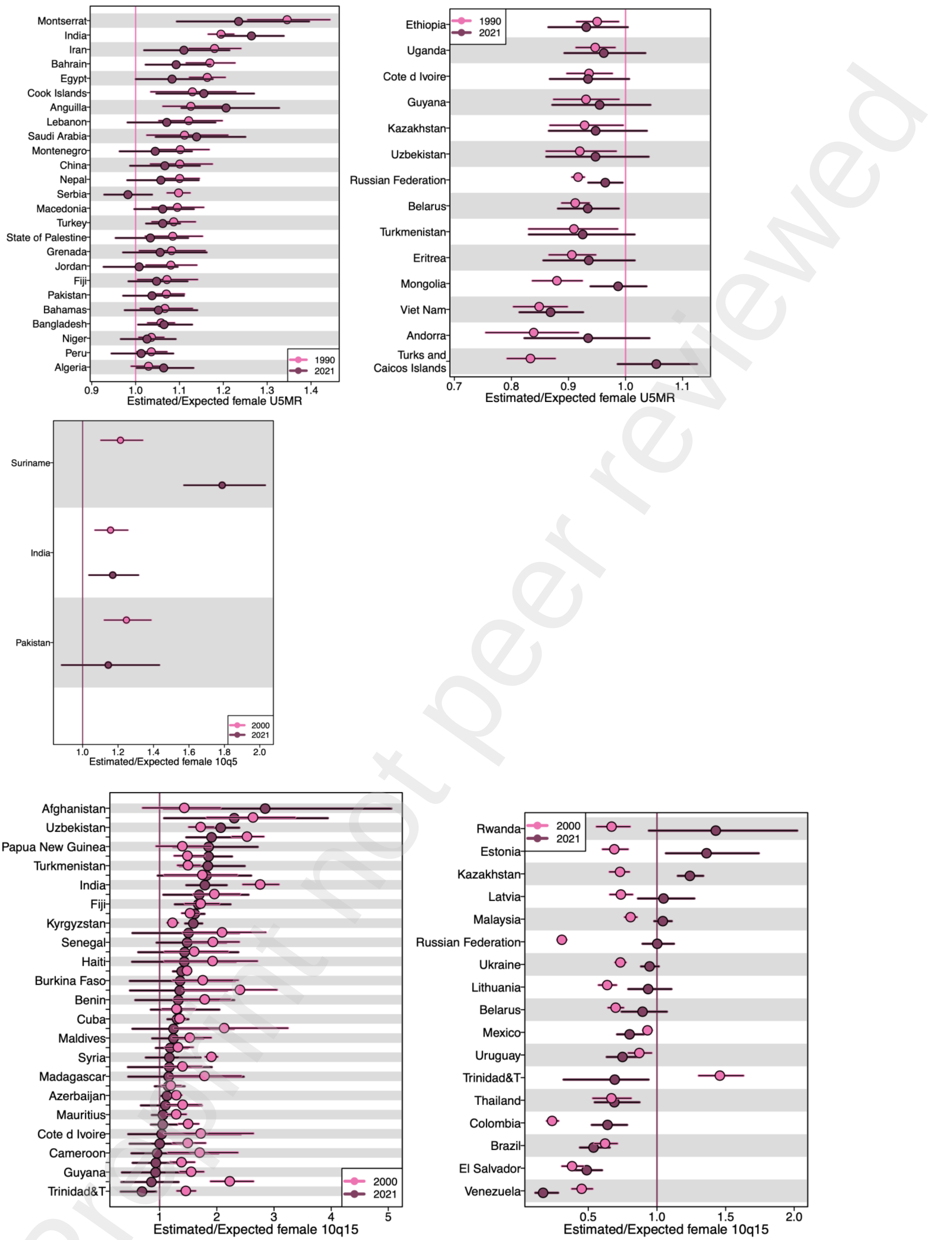

Figure 3: Overview of the ratio of estimated-to-expected female mortality, for 5q0 (top), 10q5 (middle), and 10q15 (bottom), for countries with outlying sex ratios and higher-than-expected female mortality (left) and lower-than-expected female mortality (right) in 1990 and/or 2021. Countries are ordered by decreasing point estimates for the year 2021. Error bars are 90% uncertainty intervals.

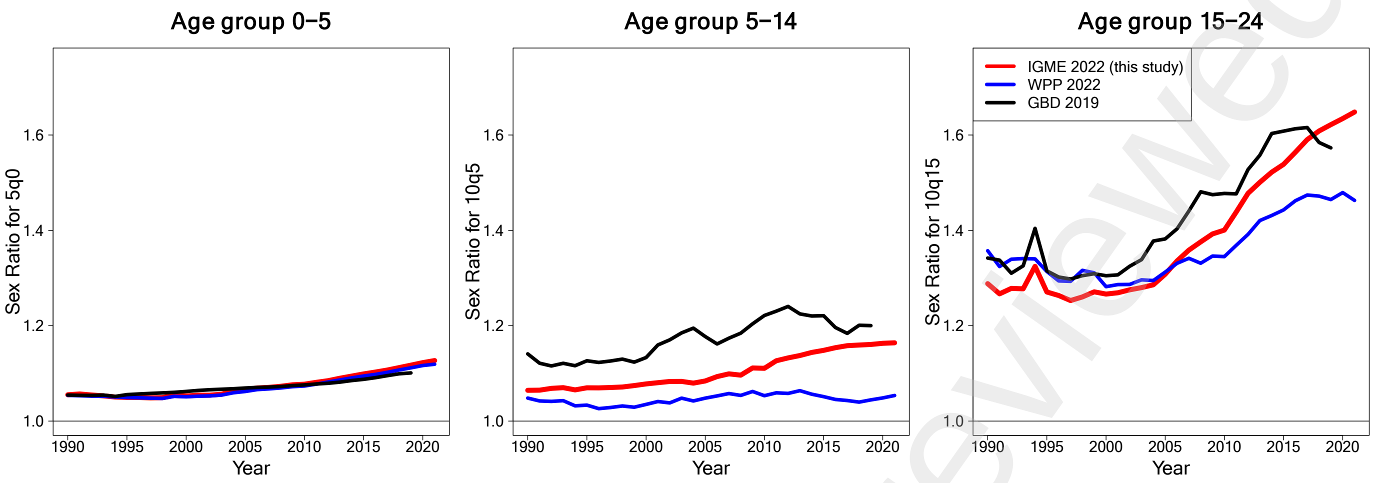

Figure 4: Global trends in the sex ratio of 5q0 (age 0–4), mortality of older children and young adolescents (10q5; age 5–14) and youth (10q15; age 15–24) between 1990 and 2021, with 90% uncertainty intervals from the IGME 2022 results.