Estimates of global causes of death for children and adolescents aged 5-19 in 2000-24: secondary data analysis using bayesian multinomial logistic regression

Hallie Eilerts-Spinelli, [1] Francisco Villavicencio, [1,2] Jamie Perin, [1] David Prieto-Merino, [3] Astha Wahi, [1] Lucia Hug, [4] Kathleen L Strong, [5] Robert E Black, [1] Li Liu[1,6]

[1] Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

[2] Department of Economic, Financial and Actuarial Mathematics, University of Barcelona, Barcelona, Spain

[3] Faculty of Medicine, University of Alcalá, Alcalá de Henares, Spain

[4] UNICEF Office of Strategy and Evidence—Innocenti, Florence, Italy

[5] Department of Sexual, Reproductive, Maternal, Child, Adolescent and Aging Health, World Health Organization, Geneva, Switzerland

[6] Department of Population, Family and Reproductive Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

Correspondence to: F Villavicencio
villavicencio@ub.edu
https://orcid.org/0000-0003-3951-7341

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ABSTRACT

OBJECTIVE

To estimate cause specific mortality among children and adolescents aged 5-19 years for 195 countries from 2000 to 2024.

DESIGN

Secondary data analysis using a bayesian multinomial logistic regression model to estimate cause specific mortality fractions.

DATA SOURCES

PubMed, Embase, Web of Science, Scopus, Cochrane Library, Global Index Medicus, Pan American Health Organization, Global Health Ovid, Africa-Wide Information, IndMed, WHO Mortality Database, Demographic and Health Surveys, Multiple Indicator Cluster Surveys, and Health and Demographic and Surveillance Systems.

INCLUSION CRITERIA

Studies of the general population reporting cause specific mortality based on primary data for at least two causes in the age groups of interest, with a specified method for determining cause. For studies identifying causes of mortality with verbal autopsy, eligibility required between 15 and 5000 total deaths, with 25% or fewer of these deaths with unknown cause. For vital registration, country data points were limited to those with at least five years of data from 2010 or later with a minimum of 80% of total deaths assigned to a meaningful cause of death determined by international classification of diseases, ninth or 10th revision.

RESULTS

Cause specific mortality fractions were calculated from vital registration data for 64 countries, disease surveillance points data for China, and modelled for the remainder. Of the 1.4 million global deaths among children and adolescents aged 5-19 years in 2024, the leading cause of death was road traffic injuries with 113 138 deaths (90% uncertainty interval 106 901 to 119 375), followed by malaria (99 219, 85 840 to 112 597) and neoplasms (87 827, 81 143 to 94 511). Deaths attributed to communicable, maternal, perinatal, and nutritional conditions comprised close to 50% of global deaths in 5-14 year olds, but less than 23% among those aged 15-19 years. In 15-19 year olds, self-harm was most prevalent in female adolescents (27 239 deaths, 24 537 to 29 941), while road traffic injuries caused the largest number of deaths in male adolescents (48 211, 44 607 to 51 816). Age and cause specific patterns varied considerably by region. In high mortality settings, the decline in most communicable, maternal, perinatal, and nutritional conditions has slowed since 2015 compared with the previous 15 years.

CONCLUSION

The estimates presented here can help countries determine the most appropriate course of action to reduce child and adolescent mortality. As mortality rates from leading causes have declined over the years, maintaining the same pace of reduction becomes more challenging, making it necessary to focus on causes that have not previously been prioritised for children and adolescents, such as child cancer and other non-communicable diseases. Maternal mortality is another area of concern where progress has stalled since 2015 and more than 80% of countries risk missing the sustainable development goal target of less than 70 deaths per 100 000 live births by 2030.

Global Patterns in Neonatal, Child, and Adolescent Mortality

Introduction

Although children and adolescents aged 5-19 years make up a quarter of the global population,[1] funding for adolescent health remains insufficient, with only 2.4% of total health development aid allocated to this group between 2016 and 2021.[2] These ages experience a trough in mortality risk, particularly in 5-14 year olds, after the increased risks of infancy and early childhood, but before rates begin to rise in late adolescence and adulthood. In 2024, 1.4 million global deaths were reported among children and adolescents aged 5-19, and in recent years, mortality in this group has decreased at a slower rate than children under 5.[3] Although the number of deaths among 5-19 year olds is relatively low compared with those occurring in younger and older age groups, nearly all of these deaths are attributable to preventable causes.[4 5]

Accurate information on causes of death afflicting children and adolescents is crucial to identifying health needs and intervention priorities, preserving gains in survival, and supporting the health, prosperity, and stability of societies going forward.[6] In the last few decades, improving people's health and wellbeing has become a central aim of the international community with the millennium development goals (2000-15), later followed by the sustainable development goals (2015-30). Much progress was achieved in reducing mortality, especially for children under 5, during the millennium development goal period.[7] With mortality levels considerably lower than in earlier decades, sustaining further improvements during the sustainable

development goal period has posed a challenge.[8] Sustainable development goal 3 focuses on ensuring healthy lives and promoting wellbeing for people of all ages,[9] but unlike younger children, there are no specific targets in mortality reduction for 5-19 year olds, contributing to their reduced global attention. Continued progress will require targeted, data driven investments with established effectiveness.

Building on previous research conducted in collaboration with the World Health Organization (WHO) and Unicef,[7 10 -13] the Child and Adolescent Causes of Death Estimation (CA CODE) group is working to produce updated estimates of causes of death among children and adolescents younger than 20 years.[14] Mortality in children under 5 is addressed elsewhere,[15] and the focus here is on the age group 5-19 years. Data are limited for the regions with the highest rates of mortality, and for this often overlooked age group in particular. We provide national, regional, and global estimates of causes of death from 2000 to 2024. The analyses incorporate the latest available evidence on causes of death from vital registries, surveys, and community based studies.

Methods

We produce annual estimates of cause specific mortality fractions (proportions), number of deaths, and mortality rates for 195 countries and four age-sex groups between 2000 and 2024: 5-9 year olds, 10-14 year olds, 15-19 year old female adolescents, and 15-19 year old male adolescents. Mortality rates are defined as probabilities of dying within the age interval among survivors to the start of that interval.[3] We aggregate national level estimates for global and regional reporting and combine them to produce figures for the age groups 5-14, 5-19, and 15-19 without sex disaggregation. Sex specific estimates are provided only for adolescents aged 15-19 years owing to limited availability of sex specific data for younger age groups in high mortality settings. Estimates were calculated from high quality vital registration data when available and otherwise modelled using the low or high mortality models. Countries were classified as low or high mortality based on their corresponding all cause mortality rate from 5 to 19 years reported by the United Nations Inter-agency Group for Child Mortality Estimation (UN IGME; supplementary information S1).[3] Estimates were calculated from high quality vital registration data for 64 countries, modelled with the low mortality model for 54 countries and the high mortality model for 76 countries.

Data

Vital registration data were obtained from the WHO Mortality Database and assessed against the quality and completeness standards established by WHO's Division of Data Analytics and Delivery for Impact.[16] Countries were considered to have high quality vital registration data if they reported at least five years of data from 2010 or later, used the international classification of diseases, ninth or 10th revision (ICD-9 or ICD-10) cause of death coding, and the joint percentage of registered deaths and those assigned a meaningful cause of death was greater than 80. We report results for 64 countries with high quality vital registration data with minimal adjustments. Data were provided as cause specific death counts and grouped into the age specific cause of death categories listed in supplementary table S1. We converted death counts to cause specific mortality fractions. Values for years with missing data were linearly interpolated between empirical data points and extrapolated as constant outside the observed period.

We generated age and sex specific model input datasets for low and high mortality model countries separately, each of which included data points with cause of death information for the relevant age group. For the 54 low mortality model countries, input data consisted of empirical data points (ie, excluding those that were interpolated or extrapolated) from high quality vital registration countries. For the 76 high mortality model countries, input data primarily consisted of verbal autopsy studies. A verbal autopsy—an interview with the family of the deceased about the signs, symptoms, and circumstances preceding death—is a vital method for determining causes of death in settings where many people die outside the health system and would otherwise remain unclassified.[17] We also procured data through known investigator tracing for high mortality model countries. These sources include the Bangladesh Maternal Mortality Survey,[18 -20] Country wide Mortality Surveillance for Action Mozambique[21] and Sierra Leone,[22] Ghana Maternal Health Survey,[23 24] Million Death Study in India (personal communication, P Rodriguez, Unity Health Toronto, July 2024), Magu Health and Demographic Surveillance System (personal communication, S Kagoye, National Institute for Medical Research, Mwanza Research Centre, Tanzania, September 2024), and Pakistan Maternal Mortality Survey (personal communication, Z Bhutta, University of Toronto, December 2024).

We identified verbal autopsy studies for the high mortality model input datasets by extending a previous systematic review of such studies[13] to 31 December 2023. Detailed methods of the systematic review are described elsewhere,[25] and a summary of the components most relevant to the present analysis is provided in supplementary information S2. Briefly, study data points were excluded if they only reported causes of deaths that were combined into other categories (eg, other communicable, other non-communicable, or other injuries), reported fewer than two cause defined causes of death, attributed more than a quarter of total deaths to an undetermined cause, or reported fewer and more than our minimum and maximum thresholds for total number of deaths (15 and 5000, respectively) for quality control.

Cause specific mortality fractions were estimated separately for China using data from the disease surveillance points.[26] The China disease surveillance points is a nationally representative sample registration system that generates cause specific mortality statistics. Cause of death data collected by the system is a mix of medical records and verbal autopsies. Reported causes were aggregated to align with the cause groupings applied in this analysis and adjusted to account for the complex survey design.[27] For provinces lacking empirical data from 2000 to 2003, the 2004 cause specific mortality fractions were extrapolated backwards. Cause specific mortality fractions were extrapolated forward at the national level from 2019 to 2024.

Across all country-years, empirically derived (high quality vital registration countries and China) or model based (low and high mortality model countries) mortality fractions were converted to cause specific mortality rates and death counts by scaling to the mortality envelopes (all cause mortality rates and death counts) produced by UN IGME for the estimation period.[3]

Modelling

We implemented a bayesian multinomial logistic regression model with country level random effects for low and high mortality model countries. The model has been described in greater detail elsewhere[28] and supplementary information S3 gives an extended description. We summarise the key components of the model here. Each input data point in the training set consisted of deaths classified by cause and was modelled as arising from a multinomial distribution. The log odds of each cause relative to a reference cause are modelled as linear functions of explanatory variables (fixed

effects), with country level random effects included to account for between country heterogeneity. To generate annual cause specific mortality fraction estimates for all modelled countries, we applied the estimated posterior parameters to complete time series of covariates from 2000 to 2024.

The model incorporates a least absolute shrinkage and selection operator (LASSO)[29] to penalise model fixed effects and prevent overfitting. We used 10-fold cross validation to select the LASSO parameter and upper limit of the standard deviation of the random effect for each of the age and sex specific low and high mortality models. The model was trained on data from ninefold cross validation and used to predict the cause of death distribution for data points in the held out fold. Model performance was quantified by the mean absolute difference between observed and predicted cause specific mortality fractions, and hyperparameters were selected to minimise the mean absolute difference.

In high mortality model countries, country level random effects were only incorporated into predictions when nationally representative data were included in the model training set. Otherwise, a random effect was randomly drawn from the posterior distribution. For India, state level random effects were estimated and subsequently combined into a national level random effect through a weighted average, using the total number of reported deaths in studies or sample registration data from each state as weights.

All models were implemented using the open source statistical software R (version 4.4.3)[30] and estimated using the Stan probabilistic programming language[31] through the rstan package (version 2.32.7).[32]

Covariates

We compiled a national level covariate database for predicting the distribution of causes of death in low and high mortality model countries. The database consisted of annual values from 2000 to 2024 for 99 indicators from sources such as Demographic and Health Surveys, Multiple Indicator Cluster Surveys, International Labour Organisation, Malaria Atlas Project, NASA, UN IGME, Unicef, the United Nations Development Programme, WHO/Unicef Joint Monitoring Programme, and the World Bank. Covariates deemed relevant for specific age groups based on literature and widely available across countries were included to improve model prediction. When a covariate was considered important for inclusion but lacked observations for some countries, missing values were imputed to retain the covariate in the model. Covariates span several domains, including maternal and reproductive health, behavioural and lifestyle factors, mental health, education and socioeconomic status, fertility and demographic structure, nutrition, mortality, environmental and living conditions. Supplementary information S4 provides additional details on the selection criteria and the final list of covariates for each age-sex group.

Single cause estimates

After modelling causes for low and high mortality model countries, we incorporated data for causes with irregular patterns in a series of adjustments. These included HIV/AIDS, tuberculosis, measles, collective violence, and natural disasters. HIV/AIDS data were also incorporated into estimates for China. As in a previous round of systematic estimates,[13] mortality fractions for HIV/AIDS, non-respiratory tuberculosis, and endemic measles were split out of the modelled fraction for other communicable diseases, while respiratory tuberculosis was split out of the modelled fraction of lower respiratory infections. Data on HIV/AIDS and tuberculosis deaths were obtained from UNAIDS[33] and the Global Tuberculosis Programme,[34] respectively. The WHO Immunization, Vaccines and Biologicals Department provided information on measles deaths for children aged 5-9 years.[35]

Malaria was only modelled for children aged 5-14 years. Malaria mortality declines steeply with age, and most malaria deaths occur among young children.[36] Among those aged 15-19 years, malaria mortality is likely too low to warrant modelling (ie, comprising less than 3% of global deaths in 2016; see supplementary table S1). Consistent with this low burden, relatively few studies report malaria mortality for adolescents aged 15-19 years,[37] leaving insufficient data to inform our model. Based on existing evidence, malaria fractions among 5-9 and 10-14 year olds were not allowed to exceed the level observed among those aged 1-59 months in the corresponding country-year.[15] Additionally, in low mortality model countries, malaria was assumed to be zero in country-years in which the Global Malaria Programme reported no incidence.[38] Estimates of crisis mortality were obtained from the Emergency Events Database,[39] and cholera outbreaks officially reported to WHO by member states and the Global Health Observatory.[40] Supplementary information S5 gives additional details on the single cause estimates.

Uncertainty

We accounted for uncertainty in modelled and empirically derived mortality estimates based on the uncertainty of the model outputs, UN IGME envelopes, and single cause data. Uncertainty for modelled proportions was quantified from the posterior distribution of the bayesian LASSO fixed and random effect parameters obtained through Hamiltonian Monte Carlo sampling. For high quality vital registration countries and China, empirical cause specific mortality fractions were treated as multinomial probabilities, from which random samples were drawn to represent uncertainty. The same approach was applied to single cause data for crisis mortality using the relative distribution of cause specific crisis deaths. For HIV/AIDS, tuberculosis, and measles, samples were drawn from the reported uncertainty intervals of the input data. Uncertainty in the all cause deaths and mortality rates was propagated by sampling from the posterior distribution of the UN IGME envelopes (supplementary information S6).[3]Figure 1 summarises the modelling process and all the estimation steps.

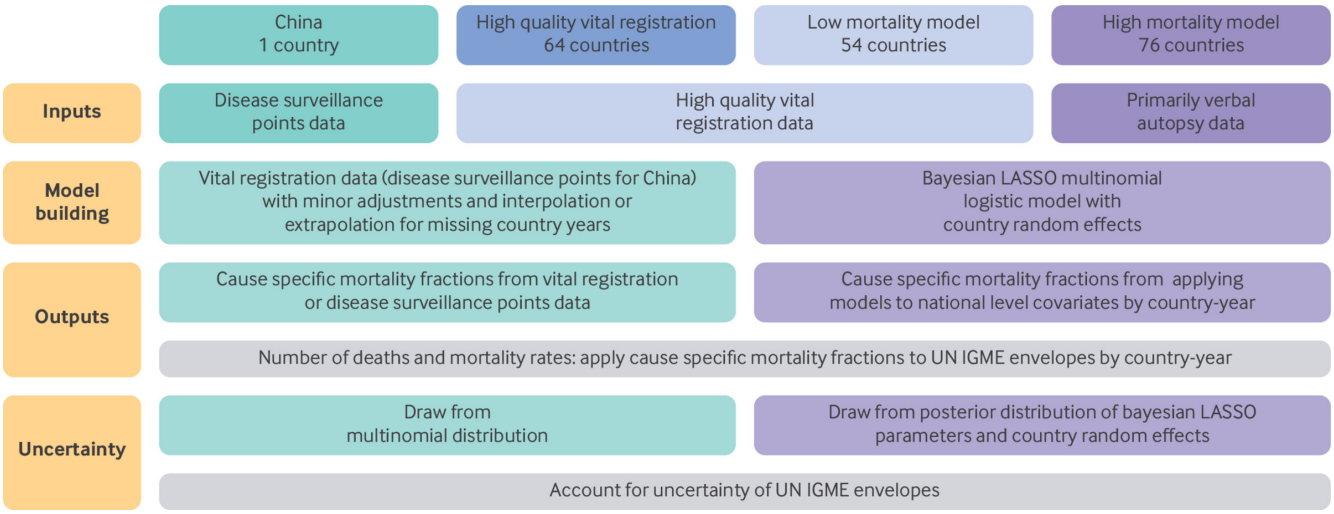

Fig 1 | Summary of modelling and estimation strategies. LASSO=least absolute shrinkage and selection operator; UN IGME=United Nations Inter-agency Group for Child Mortality Estimation

PRISMA 2020 checklist

We followed PRISMA (preferred reporting items for systematic review and meta-analysis) guidelines[41] for reporting systematic analyses and global health estimates. Supplementary table S2 includes the PRISMA 2020 checklist for transparency and replicability.

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our research.

Results

For the 64 countries with high quality vital registration data, we relied on 5275 empirical data points from 2000 to 2021. Missing country-years were obtained through interpolation and extrapolation. The training dataset for low mortality model countries incorporated 4286 of these from 56 countries after applying exclusion criteria relating to total deaths and number and distribution of reported causes of death. For high mortality model countries, we relied on a total of 752 data points from 31 countries (supplementary table S3). To improve model stability, these included eight data points for high mortality years in eight countries with vital registration data for each age-sex group (supplementary table S4). Table 1 provides an overview of the input data used in each method and age-sex group, identifying the number of data points, deaths, and countries. In all age-sex groups there were more than five times as many input data points from high quality vital registration countries than high mortality model countries. As for high mortality model countries, the age group with the most data points was 5-9 years at 258, while 15-19 year old male adolescents had the fewest at 170. The outputs columns on the right of table 1 show that the high mortality model countries for which we have limited data are also where most deaths take place. Fifty five high mortality model countries did not contribute any data points to the model input, as reflected in the input data map in supplementary figure S1.

Table 1 | Inputs and outputs by estimation methods

Estimation methods	Inputs			Outputs	
	Data points	Deaths	Countries	Deaths in 2024	Countries
5-9 year olds					
High quality vital registration data	1318	599 735	64	19 447 (4.2)	64
Low mortality model	—	—	—	26 167 (5.6)	54
High mortality model	258	65 305	31	407 993 (87.2)	76
China DSP	20	527 060	1	14 142 (3.0)	1
Total	—	—	—	467 749 (100.0)	195
10-14 year olds					
High quality vital registration data	1319	573 323	64	25 473 (6.9)	64
Low mortality model	—	—	—	30 070 (8.1)	54
High mortality model	262	84 397	30	298 106 (80.7)	76
China DSP	20	521 545	1	15 594 (4.2)	1
Total	—	—	—	369 243 (100.0)	195
15-19 year old female adolescents					
High quality vital registration data	1318	446 009	64	19 616 (9.4)	64
Low mortality model	—	—	—	14 801 (7.1)	54
High mortality model	182	26 390	21	168 213 (80.9)	76
China DSP	20	298 828	1	5,307 (2.6)	1
Total	—	—	—	207 937 (100.0)	195
15-19 year old male adolescents					
High quality VR data	1320	1 191 691	64	47 825 (13.5)	64
Low mortality model	—	—	—	39 781 (11.3)	54
High mortality model	170	29 338	18	250 997 (71.0)	76
China DSP	20	597 627	1	14 678 (4.2)	1
Total	—	—	—	353 281 (100.0)	195

Data are numbers (%).

Inputs on the left provide information on sources of data informing empirical calculations for high quality vital registration countries and China, and modelling of cause specific mortality fractions for high mortality model countries. For high quality vital registration data and China disease surveillance points (DSP), data points refer to the number of country-year observations of cause specific death counts whereas for high mortality model countries data points refer to community based verbal autopsy studies. The low mortality model was trained on data from high quality vital registration countries. Deaths were summed across data points and countries indicates number of distinct countries contributing data. For outputs on the right, deaths in 2024 show distribution of estimated deaths, while countries indicate the number of countries for which estimates were produced by each method.

For each age-sex specific low and high mortality model country, supplementary figures S2 and S3 present the results of the cross validation using out-of-sample prediction with the lowest mean absolute difference to identify the best LASSO parameter and upper limit of the standard deviation of the random effect. Supplementary table S5 lists the final set of hyperparameters used.

Of the 1.4 million global deaths among children and adolescents aged 5-19 years in 2024, more than 38% were because of communicable, maternal, perinatal, and nutritional (CMPN) conditions, followed by 36% of injuries, and 25% of non-communicable diseases. Road traffic injuries stand out as the leading specific cause with 113 138 deaths (90% uncertainty interval (UI) 106 901 to 119 375; 8.09%, 7.74% to 8.44%) followed by malaria (99 219 deaths, 85 840 to 112 597; 7.10%, 6.32% to 7.87%), and neoplasms (87 827 deaths, 81 143 to 94 511; 6.28%, 5.89% to 6.67%). However, differences arise when looking at age groups separately. Figure 2 and supplementary table S6 show that CMPN conditions comprised close to 50% of global deaths among 5-14 year olds, but less than 23% among 15-19 year olds (both sexes). The opposite trend is observed for injuries, especially driven by the impact of intentional injuries in those older than 15 years, including self-harm (59 322 deaths, 55 561 to 63 083; 10.57%, 10.13% to 11.01%), interpersonal violence (48 459, 44 326 to 52 591; 8.63%, 7.98% to 9.29%), and collective violence (30 355, 27 540 to 33 170; 5.41%, 4.90% to 5.92%).

Global causes of death for 5-19 year olds in 2024

Age group	Number of deaths	Communicable, perinatal, and nutritional conditions	Non-communicable diseases	Injuries
Children aged 5-14 years	837 000	48.7%	22.5%	28.8%
Adolescents aged 15-19 years	561 000	22.5%	30.0%	47.5%

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Fig 2 | Global distribution of causes of death in children aged 5-14 years and adolescents aged 15-19 years in 2024. Causes are colour coded into three groups: communicable, maternal, perinatal, and nutritional conditions (blue); non-communicable diseases (amber); and injuries (pink). Uncertainty intervals and corresponding estimates of mortality rates are provided in supplementary table S6. An interactive version of this graphic and downloadable data are available at https://public.flourish.studio/visualisation/29148247/

Figure 3 reveals significant regional variation in the number of deaths and mortality fractions. Approximately 80% of global deaths in 2024 took place in countries categorised as high mortality models. These were also the areas with the largest number of deaths caused

by communicable diseases. In West and Central Africa, more than 64% of deaths among 5-19 year olds were attributed to CMPN conditions such as malaria (71 414 deaths, 90% UI 59 448 to 83 379; 16.20%, 14.42% to 17.99%), diarrhoea (39 737, 32 612 to 46 862; 9.02%, 8.06% to 9.97%), and lower respiratory infections (27 663, 21 860 to 33 465; 6.28%, 5.34% to 7.22%). In Eastern and Southern Africa, the total share of CMPN conditions was 40%, with malaria the leading communicable cause (21 314 deaths, 15 694 to 26 934; 7.45%, 6.00% to 8.90%) followed by HIV/AIDS (15 820 deaths, 14 698 to 16 943; 5.53%, 4.93% to 6.13%). In South Asia, CMPN conditions comprised about 29% of the total, while in all other regions they made up less than 15%. In North America and Western Europe, deaths because of CMPN conditions accounted for roughly 5% of the total.

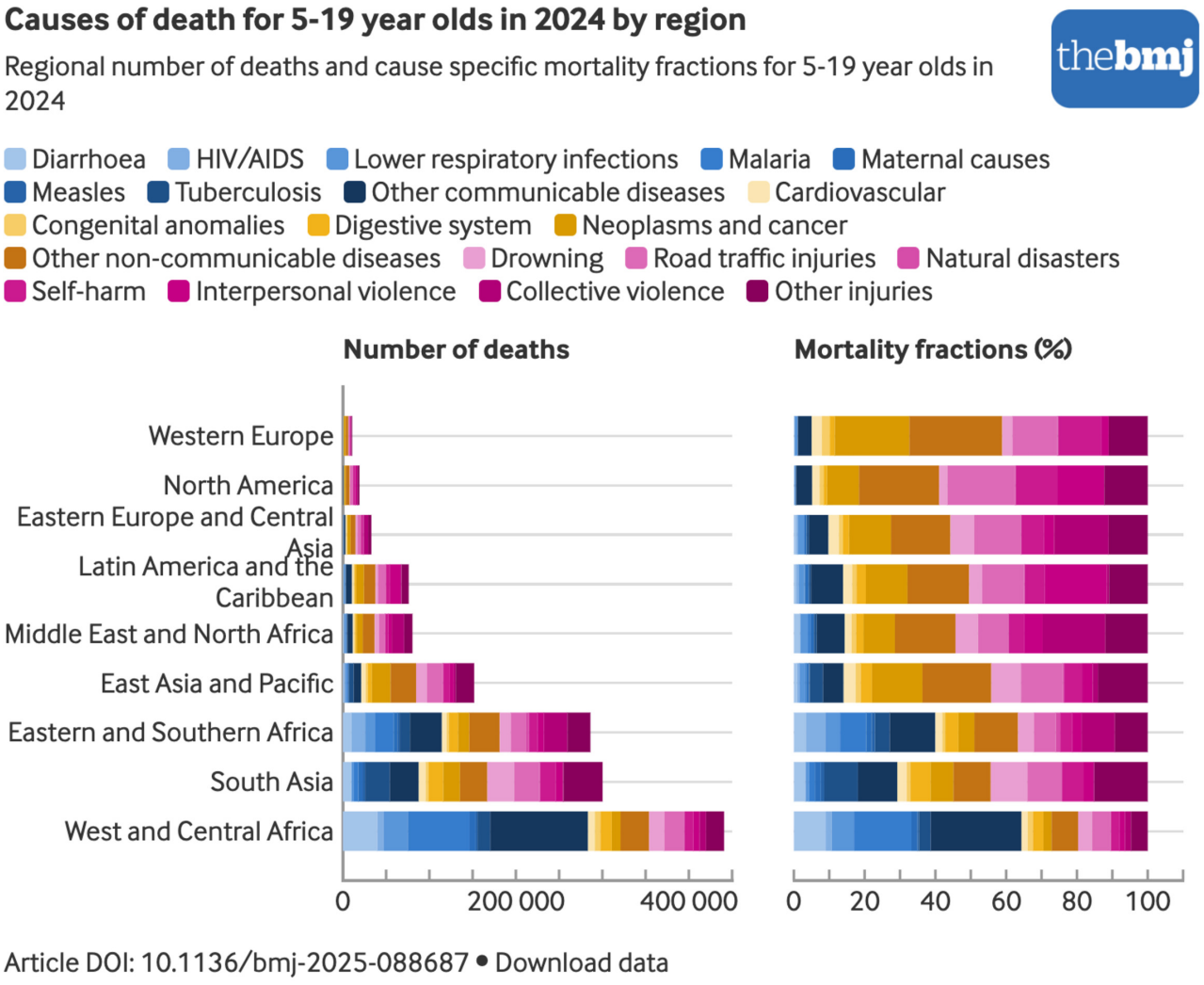

Fig 3 | Causes of deaths for 5-19 year olds in 2024 by region. An interactive version of this graphic and downloadable data are available at https://public.flourish.studio/visualisation/29053008/

Deaths caused by injuries comprised most of the total deaths among children and adolescents aged 5-19 years in four regions (59% in North America, 56% in Eastern Europe and Central Asia, 54% in Middle East and North Africa, and 51% in Latin America and the Caribbean) and the largest share in South Asia and East Asia and Pacific (44% in both). The leading injury related cause of death in North America was road traffic injuries (3667 deaths, 90% UI 3507 to 3826; 19.13%, 18.63% to 19.64%), while collective violence was the leading cause in Eastern Europe and Central Asia (5069 deaths, 4677 to 5460; 15.39%, 14.41% to 16.36%) and Middle East and North Africa (14 262 deaths, 8406 to 20 117; 17.72%, 12.17% to 23.28%). Interpersonal violence made up the largest share of injury related deaths in Latin America and the Caribbean (13 294 deaths, 12 197 to 14 390; 17.46%, 16.23% to 18.70%).

Deaths caused by non-communicable diseases made up the largest share in Western Europe (more than 50%), with 2261 deaths (90% UI 2182 to 2340; 21.07%, 20.42% to 21.71%) because of neoplasms. The highest burden region for non-communicable diseases was South Asia, followed by West and Central Africa, Eastern and Southern Africa, and East Asia and Pacific, with estimates that ranged between 63 000 and 80 000 deaths caused by non-communicable diseases. Neoplasms were the leading non-communicable cause in East Asia and Pacific (21 595 deaths, 15 992 to 27 198; 14.23%, 12.39% to 16.06%), South Asia (19 327, 17 120 to 21 533; 6.44%, 6.09% to 6.79%), and Eastern and Southern

Africa (12 843, 10 985 to 14 701; 4.49%, 4.07% to 4.90%). In West and Central Africa, diseases of the digestive system were the leading non-communicable cause (13 206 deaths, 11 130 to 15 281; 3.00%, 2.65% to 3.34%).

Figure 4 identifies the leading causes of mortality among 5-19 year olds in 2000 in each of the four highest burden regions. Time trends of the cause specific mortality rates are displayed, together with the corresponding average annual rates of reduction in the millennium development goal (2000-15) and sustainable development goal (2015-24) periods. During the millennium development goal period, sub-Saharan Africa saw major reductions in mortality from CMPN conditions, such as malaria, diarrhoea, and measles, which were particularly high at the start of the millennium. Mortality rates continued to decline in 2015-24 for malaria and diarrhoea at a similar pace in West and Central Africa, but at a lower rate in East and Southern Africa. The negative average annual rate of reduction for measles during the sustainable development goal period is attributed to higher rates in 2024 compared with 2015, although conclusions should be formulated with caution owing to the uncertainty of the rates, which were already quite low at the start of the period. In West and Central Africa, for instance, the measles mortality rate in 5-9 year olds shifted from 0.11 (90% UI 0.00 to 0.26) deaths per 1000 children in 2015 to 0.15 (0.00 to 0.39) in 2024. In contrast, HIV/AIDS saw greater progress after 2015. In South Asia and East Asia and Pacific, declines in cause specific mortality rates that began in 2000-15 mostly continued in 2015-24 at a similar pace. Supplementary table S7 reports cause specific mortality rates in 2000, 2015, and 2024, and average annual rate of reduction estimates for all the regions.

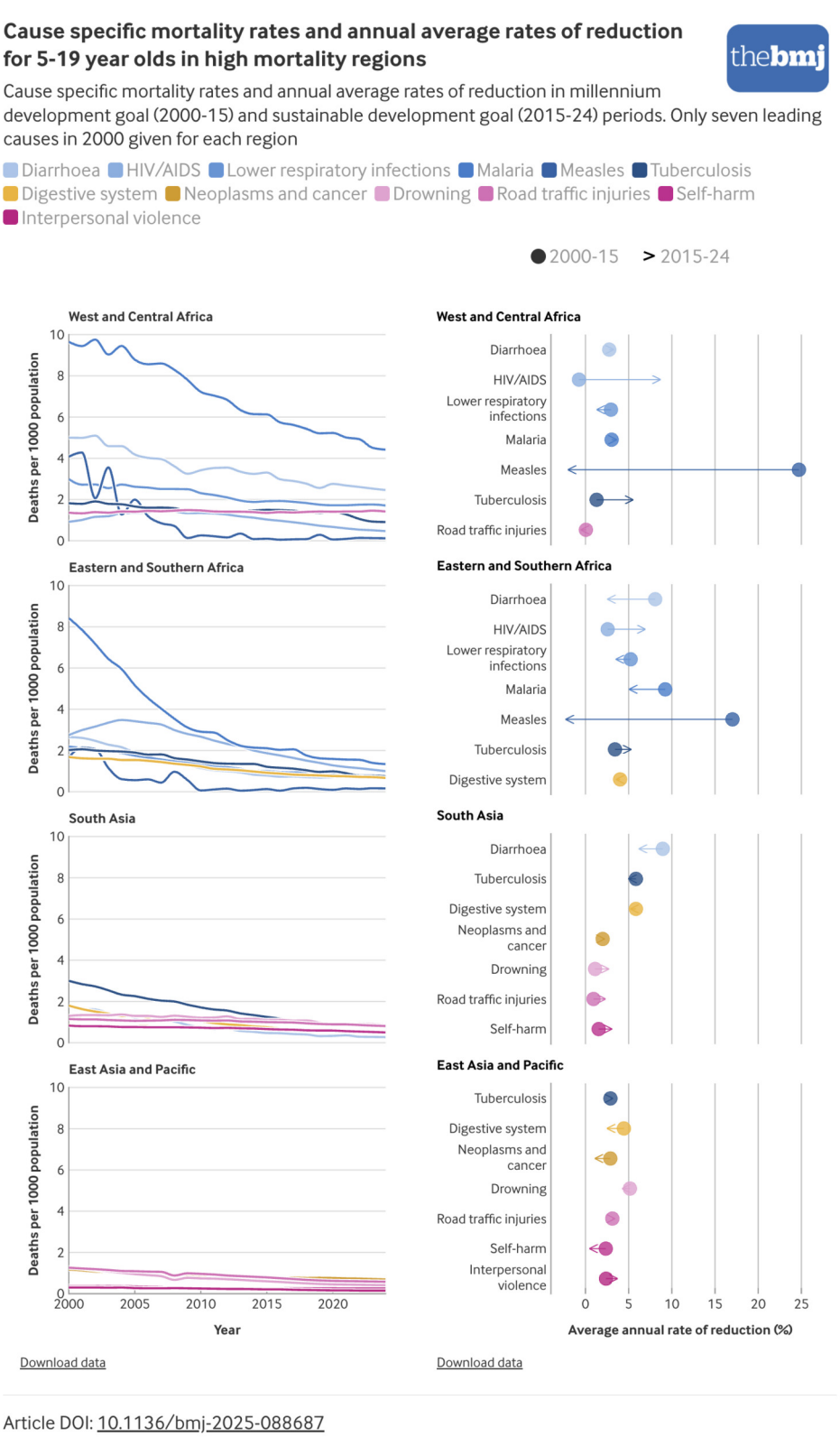

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Fig 4 | Cause specific mortality rates and average annual rates of reduction for 5-19 year olds in high mortality regions. An interactive version of this graphic and downloadable data are available at https://public.flourish.studio/visualisation/29052864/

Figure 5 presents causes of death in 2024 by age-sex group and region, with leading causes highlighted in supplementary table S8. Globally, in 2024 malaria was the cause with the highest rates among 5-9 and 10-14 year olds, with 0.42 (90% UI 0.36 to 0.48) and 0.31 (0.22 to 0.39) deaths per 1000 population, respectively. Among 15-19 year olds, self-harm is most prevalent in female adolescents (0.43,

0.38 to 0.48) while road traffic injuries caused the highest mortality rates in male adolescents (0.72, 0.66 to 0.78). We observe a remarkable regional heterogeneity in age and cause specific mortality patterns. CMPN conditions comprised a larger proportion of total deaths in West and Central Africa and Eastern and Southern Africa than other regions, especially in younger ages. In West and Central Africa, CMPN conditions made up more than three quarters of total deaths in 5-14 year olds, with leading causes of malaria, diarrhoea, and lower respiratory infections.

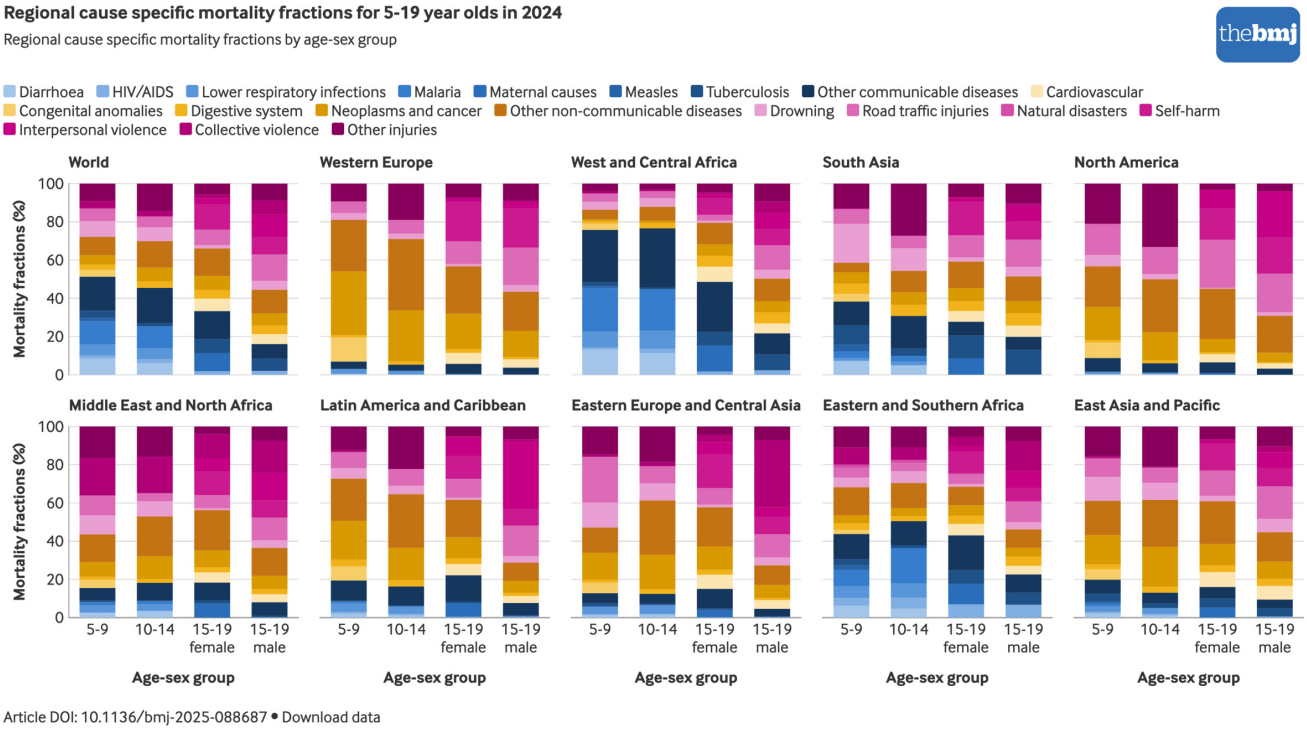

Fig 5 | Regional cause specific mortality fractions in 2024 by age-sex group. Leading causes within each group and region are highlighted in supplementary table S8. An interactive version of this graphic and downloadable data are available at https://public.flourish.studio/visualisation/29054343/

In 2024, deaths because of maternal causes among 15-19 year old female adolescents were highest in West and Central Africa (7215 deaths, 90% UI 4881 to 9548; 13.54%, 10.10% to 16.97%), Eastern and Southern Africa (4421, 3213 to 5628; 10.65%, 8.46% to 12.85%), South Asia (5077, 3829 to 6325; 8.52%, 7.09% to 9.95%), and East Asia and Pacific (1055, 564 to 1546; 5.07%, 3.16% to 6.99%). Deaths caused by tuberculosis were highest in South Asia, especially among 5-9 year olds (7913 deaths, 5062 to 10 764; 10.18%, 6.50% to 13.87%), 15-19 year old female adolescents (7151, 5881 to 8421; 12.00%, 10.14% to 13.86%) and 15-19 year old male adolescents (10 283, 7401 to 13 165; 12.95%, 9.34% to 16.56%). HIV/AIDS had the highest share in Eastern and Southern Africa, comprising 4.07-6.98% of total deaths across all age-sex groups. Mozambique had the highest number of HIV/AIDS deaths among 5-19 year olds (3503, 2387 to 3718; 22.48%, 17.05% to 27.91%), followed by Nigeria (2092, 1774 to 2410; 1.19%, 0.88% to 1.51%) and Uganda (1878, 1575 to 2182; 7.95%, 6.10% to 9.79%).

Injury related causes were more prominent among 15-19 year olds compared with younger ages. Road traffic injuries ranked among the top three leading causes for 15-19 year old male adolescents across all regions. However, intentional injuries, such as self-harm and interpersonal violence—which were not modelled for younger ages—emerge as critical factors. Self-harm was a top three leading cause of death for 15-19 year old female adolescents in all regions. In Latin America and Caribbean, 12 090 deaths (90% UI 10 996 to 13 183; 35.60%, 33.56% to 37.64%) among 15-19 year old male adolescents are attributed to interpersonal violence. In North America, the figure drops to 2177 deaths (2042 to 2312), still representing a substantial 24.15% (23.39% to 24.91%). Mortality from collective violence is high among 15-19 year old male adolescents in Eastern and Southern Africa (10 979 deaths, 8545 to 13 413; 15.61%, 12.47% to 18.74%) because of the Sudanese civil war. A similar picture is observed in Eastern Europe and Central Asia (4624 deaths, 4235 to 5013), mostly driven by the Russian invasion of Ukraine, but representing the largest regional share of 35.12% (33.36% to 36.88%). In the Middle East and North Africa, the killings and destruction perpetuated in Gaza had a devastating impact on all age-sex groups, leading to 12 098 deaths (6245 to 17 951) among 5-19 year olds in occupied Palestine in 2024.

Discussion

We provide annual cause specific mortality estimates for children and adolescents aged 5-19 years across geographical and age-sex groups from 2000 to 2024. The estimates have been reviewed and endorsed by representatives of WHO member states through country consultation and are publicly available on an open data portal managed by Unicef.[14] Globally, the leading causes of death in 2024 were road traffic injuries, malaria, and neoplasms. At the regional and national levels, cause specific mortality patterns varied markedly by age and geography, reflecting the wide epidemiological diversity of this age group. However, these leading global causes can serve as entry points for examining regional variations, age specific patterns, and the changing drivers of mortality over time.

Principal findings

Deaths caused by road traffic injuries among 5-19 year olds ranged from 5% to 19% of the total across all regions in 2024. Although certain communicable diseases show much higher age and cause specific rates in high mortality settings and among younger children, road traffic injuries represent a shared vulnerability across contexts and throughout adolescence, especially in low mortality regions and among 15-19 year old male adolescents. After substantial reductions in road traffic injury deaths during the millennium development goal period, subsequent gains have been reduced in Europe and North America. In low and middle income countries, deaths from road traffic injuries may decline more slowly—or even start to rise—in the coming years owing to increasing urbanisation and motorisation.[42] In general, injury related causes were more important at older ages. Self-harm was the leading cause of death among 15-19 year old female adolescents and the third leading cause among male adolescents of the same age. Increases in self-harm and other injuries after 2020, as observed most notably in North America, could suggest the vulnerability of children and adolescents to disruptions and behaviour changes caused by the covid-19 pandemic. Although deaths because of the covid-19 virus among children and adolescents were low, secondary impacts from pandemic related disruptions may have produced an increase in risky behaviours and substance abuse.[43] Ongoing conflicts in Palestine, Ukraine, and Sudan have significantly contributed to the estimated number of deaths from collective violence in recent years.

Malaria remained the second leading cause of death globally in 2024, despite its comparatively limited age range and geographical distribution. The burden of malaria falls primarily on countries in West and Central Africa, followed by Eastern and Southern Africa. Rates of malaria mortality reduction achieved after the turn of the millennium have decelerated in more recent years, perhaps partially because of the new malaria vaccine being scaled up. Future progress remains uncertain as rising temperatures, increased humidity, and shifting precipitation patterns may alter malaria transmission dynamics, potentially expanding endemic zones into new areas and exposing previously unaffected populations.[44] Although the association between malaria and climate change is complex, the risk in general seems to be increasing.[45] Resistance to malaria treatment[46] and reduced efficacy of insecticides because of changes in mosquito vector species contribute to the risk.[47]

Other communicable conditions such as diarrhoea exert a considerable toll as the second and fourth leading cause of death among 5-9 and 10-14 year olds, respectively. While the burden falls much more on children under 5,[7] research indicates that the risk from common bacterial (eg, *Escherichia coli*) and viral (eg, rotavirus) pathogens continues in children at later ages.[48] Diarrhoea can usually be effectively managed through a combination of rotavirus immunisation for infants, oral rehydration solutions and zinc supplements, and preventative measures aimed at improving water quality, sanitation, food safety, and hygiene; though coverage and uptake of interventions is uneven.[48] Using cholera and rotavirus vaccines may also interrupt outbreaks,[49] which are more likely with extreme weather, humanitarian crises, and in fragile settings with strained public health infrastructure.[50]

Substantial progress has been achieved in reducing HIV/AIDS related deaths since the peak of the epidemic in the mid-2000s, particularly in Eastern and Southern Africa. Substantial financial and technical support from the United States and Europe—channelled through international aid agencies and bilateral initiatives such as PEPFAR (US President's Emergency Plan for AIDS Relief)—has been instrumental in expanding access to HIV/AIDS treatment and prevention.[51] However, recent funding cuts, particularly from the US,[52] have created critical gaps in programme coverage and sustainability. These disruptions are especially concerning for children and adolescents, who already face structural and social barriers in accessing and adhering to HIV treatment and prevention services.[53] Without renewed commitment and investment, these setbacks threaten to reverse gains, leading to a potential resurgence in new infections and HIV/AIDS related mortality.[54]

Maternal mortality is another area of concern where progress has stalled since 2015 and more than 80% of countries risk missing the sustainable development goal target 3.1 of fewer than 70 deaths per 100 000 live births by 2030.[55] Although the interventions to prevent or manage maternal complications are well established, quality assured timely delivery remains a challenge in settings where healthcare systems are weak and access is uneven.[56] Among adolescent girls in particular, key health interventions include comprehensive sexual and reproductive health education, improving access to modern contraception to prevent unwanted pregnancies, prevention and management of anaemias, and psychosocial support and related services for mental health and wellbeing.[57]

Policy implications

As mortality rates from leading causes have declined over the years, maintaining the same pace of reduction becomes more challenging, making it necessary to focus on causes that have not previously been prioritised for children and adolescents. These causes may include child cancer and other non-communicable diseases, which represent a larger share in high income countries and regions, and are becoming more relevant in low and middle income countries. In Eastern and Southern Africa, for instance, the share of neoplasm and cancer deaths among 5-9 year olds rose from 0.76% (90% UI 0.59% to 0.93%) in 2000 to 4.05% (3.36% to 4.74%) in 2024, and a similar increase has been observed in South Asia.

Neoplasms in children and adolescents remain difficult to diagnose in low and middle income countries because of health system limitations, including shortages in paediatric oncology workforces, limited diagnostic infrastructure, and low awareness of early cancer symptoms and screening access. These constraints often lead to misdiagnosis or delayed diagnosis and advanced presentation associated with suboptimal survival.[58 59] Despite these barriers, the share increase could be explained by population growth, increasing neoplasm incidence,[60] and gradual improvements in diagnostic capacity and reporting systems.[61 62] In this evolving landscape, a need exists for feasible, cost effective treatments to broaden intervention priorities aimed at reducing mortality and disability. Previous research has shown the positive impact of cancer treatments for 0-19 year olds in low and middle income countries,[63] with a cost effectiveness that may be comparable to that of certain communicable diseases.[64]

Late childhood and adolescence constitutes a sensitive developmental period, during which people navigate evolving physical and mental health needs, and increased vulnerability to behavioural and societal risks. This is also a critical window when interventions and the maintenance of good health can have enduring benefits for people and societies alike.[6] With five years left in the sustainable development goal period, improving survival in children and adolescents requires multisectoral action beyond health, including education, infrastructure, sanitation, and law enforcement. Building on past gains in reducing under 5 mortality,[7] resources should extend to prevent and treat injuries and non-communicable diseases in 5-19 year olds. The global health

community is increasingly focused on this age group,[57] but to make progress, investments are needed in strengthening data systems, including birth and death registration, to ensure life saving interventions reach those in greatest need.

Strengths

Our study has several notable strengths. Firstly, it draws on a systematic review of cause of death studies for children and adolescents.[25] Secondly, we generated a large covariate database encompassing a wide range of domains and data sources, which were incorporated into the models in a systematic and consistent manner. Together with the inclusion of single cause data from disease specific estimation groups, this approach enhances the precision and internal consistency of the results. Thirdly, the estimation process includes a formal country consultation step allowing national experts to review, validate, and contribute contextual information to the findings. WHO coordinated this process through an organisational memo to member states, who nominated focal points from national statistical agencies and ministries of health to review the data sources and preliminary cause of death estimates. Finally, the analysis underscores the importance of transparency at every stage—from data inputs and model assumptions to communicating uncertainty—enhancing the reproducibility and credibility of the estimates while ensuring broader access to the data.

Challenges

This work is also subject to a few limitations. The primary challenge is one of data scarcity. High quality data remain limited in quantity and geographical coverage, particularly for older age groups, where causes of death become more diverse. This scarcity is most acute for 15-19 year old male adolescents, for whom we have 34% fewer data points than the 5-9 year age group. High quality vital registration data are largely confined to high income countries where deaths are least frequent, while for high mortality settings, our models depend predominantly on verbal autopsy studies, few of which are nationally representative. We are lacking cause of death data for the age groups under study for most high mortality model countries. Therefore, we rely on our models to identify patterns of cause of death distributions from the available data that can be used to predict patterns elsewhere.

We acknowledge the fundamental difference in reliability between cause of death from high quality vital registration systems and verbal autopsy. Although verbal autopsy can identify certain causes with clear symptom patterns, accuracy is limited for many other causes, particularly those that are less clinically distinct[65] or subject to reporting biases.[66] This limitation has implications for the reliability of model based estimates for high mortality model countries, which rely on verbal autopsy data for model training. We attempt to reflect this through the uncertainty intervals, which tend to be wider for high mortality model countries. However, these intervals may not fully capture differences in the underlying quality of input data or the additional uncertainty inherent in verbal autopsy derived causes of death. Furthermore, we strive to account for many sources of uncertainty, but we did not account for uncertainty in covariates.

Improving the quantity and quality of cause of death data in high burden settings should be a priority. Putting in place data collection systems, such as sample registration systems, is a promising avenue for generating high quality population data with lower administrative and financial demands than civil and vital registration systems. Additionally, improving verbal autopsies with AI presents new opportunities for research. Within the CA CODE group, we have used data from the CHAMPS (Child Health and Mortality Prevention Surveillance) study[67] to assess systematic misclassification of cause of death by verbal autopsy algorithms and calibrate cause of death estimation models for children under 5.[15 68] Unfortunately, similar data for older age groups are lacking. Expanding this work to include 5-19 year olds would enable more accurate estimates based on verbal autopsy data.

What is already known on this topic

- Although nearly all deaths among children and adolescents aged 5-19 years are attributable to preventable causes, this age group receives comparatively less attention in global health policy and research than younger children and adults
- Cause of death data for children and adolescents are most limited in regions with the highest mortality burden where vital registration is incomplete or non-existent
- Other global estimation exercises have combined data from vital registration and verbal autopsy studies, and general and special populations—a limitation that previous work began to address and this study extends further

What this study adds

- This study provides updated global, regional, and national cause specific mortality estimates for children and adolescents aged 5-19 years from 2000 to 2024
- Road traffic injuries, malaria, and neoplasms were found to be the three leading causes of death in 5-19 year olds globally in 2024, with large variations by age, sex, and geography
- Progress in reducing deaths caused by communicable conditions has slowed since 2015, with these causes still exerting a considerable toll in high mortality settings and among younger children

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Dissemination to participants and related patient and public communities: The estimates presented here have been reviewed and endorsed by representatives of WHO member states through country consultation and are publicly available on an open data portal managed by Unicef (https://childmortality.org/). Additionally, estimates have been disseminated as part of the 2025 UN IGME report.[3]

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estimates on causes of death in people younger than 20 years produced by the CA CODE group are publicly available at https://childmortality.org/.

1 United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects 2024. https://population.un.org/wpp/.

2 Baird S, Choonara S, Azzopardi PS, etal. A call to action: the second *Lancet* Commission on adolescent health and wellbeing. *Lancet* 2025;405:-2022. doi: 10.1016/S0140-6736(25)00503-3. pmid: 40409329

3 United Nations Inter-agency Group for Child Mortality Estimation (UN IGME). Levels & trends in child mortality: Report 2025 — Estimates developed by the United Nations Inter-agency Group for Child Mortality Estimation. New York: United Nations Children's Fund, 2026. https://childmortality.org/wp-content/uploads/2026/05/UNIGME-Child-Mortality-Report-2025.pdf.

4 Fadel SA, Boschi-Pinto C, Yu S, etal. Trends in cause-specific mortality among children aged 5-14 years from 2005 to 2016 in India, China, Brazil, and Mexico: an analysis of nationally representative mortality studies. *Lancet* 2019;393:-27. doi: 10.1016/S0140-6736(19)30220-X. pmid: 30876707

5 Strong KL, Pedersen J, White Johansson E, etal. Patterns and trends in causes of child and adolescent mortality 2000-2016: setting the scene for child health redesign. *BMJ Glob Health* 2021;6:e004760. doi: 10.1136/bmjgh-2020-004760. pmid: 33731440

6 Black RE, Liu L, Hartwig FP, etal. Health and development from preconception to 20 years of age and human capital. *Lancet* 2022;399:-40. doi: 10.1016/S0140-6736(21)02533-2. pmid: 35489357

7 Perin J, Mulick A, Yeung D, etal. Global, regional, and national causes of under-5 mortality in 2000-19: an updated systematic analysis with implications for the Sustainable Development Goals. *Lancet Child Adolesc Health* 2022;6:-15. doi: 10.1016/S2352-4642(21)00311-4. pmid: 34800370

8 Amouzou A, Barros AJD, Requejo J, etal. The 2025 report of the *Lancet* Countdown to 2030 for women's, children's, and adolescents' health: tracking progress on health and nutrition. *Lancet* 2025;405:-54. doi: 10.1016/S0140-6736(25)00151-5. pmid: 40222381

9 UN General Assembly. Transforming our world: the 2030 Agenda for Sustainable Development. 2015. https://sdgs.un.org/2030agenda.

10 Black RE, Cousens S, Johnson HL, etalChild Health Epidemiology Reference Group of WHO and UNICEF. Global, regional, and national causes of child mortality in 2008: a systematic analysis. *Lancet* 2010;375:-87. doi: 10.1016/S0140-6736(10)60549-1. pmid: 20466419

11 Liu L, Johnson HL, Cousens S, etalChild Health Epidemiology Reference Group of WHO and UNICEF. Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000. *Lancet* 2012;379:-61. doi: 10.1016/S0140-6736(12)60560-1. pmid: 22579125

12 Liu L, Oza S, Hogan D, etal. Global, regional, and national causes of under-5 mortality in 2000-15: an updated systematic analysis with implications for the Sustainable Development Goals. *Lancet* 2016;388:-35. doi: 10.1016/S0140-6736(16)31593-8. pmid: 27839855

13 Liu L, Villavicencio F, Yeung D, etal. National, regional, and global causes of mortality in 5-19-year-olds from 2000 to 2019: a systematic analysis. *Lancet Glob Health* 2022;10:-47. doi: 10.1016/S2214-109X(21)00566-0. pmid: 35180417

14 Villavicencio F, Perin J, Eilerts-Spinelli H, etal. Global, regional, and national causes of death in children and adolescents younger than 20 years: an open data portal with estimates for 2000-21. *Lancet Glob Health* 2024;12:-7. doi: 10.1016/S2214-109X(23)00496-5. pmid: 37898143

15 Perin J, Prieto-Merino D, Wahi A, etal. Systematic estimates of global causes of neonatal and under 5 mortality in 2000-24: secondary data analysis using bayesian multinomial logistic regression. *BMJ* 2026;393:e088686.

16 World Health Organization, Department of Data and Analytics (DNA), Division of Data, Analytics and Delivery for Impact (DNI). WHO methods and data sources for country-level causes of death 2000-2021. Global Health Estimates Technical Paper WHO/DDI/DNA/GHE/2024.2. Geneva: World Health Organization, 2024.

17 Kalter HD, Gray RH, Black RE, Gultiano SA. Validation of postmortem interviews to ascertain selected causes of death in children. *Int J Epidemiol* 1990;19:-6. doi: 10.1093/ije/19.2.380. pmid: 2376451

18 National Institute of Population Research and Training (NIPORT). *Bangladesh maternal health services and maternal mortality survey 2001.* Dhaka (Bangladesh): NIPORT, 2003. https://dhsprogram.com/pubs/pdf/FR142/FR142.pdf.

19 National Institute of Population Research and Training (NIPORT). *Bangladesh maternal mortality survey 2010.* Dhaka (Bangladesh): NIPORT, 2011. https://www.measureevaluation.org/resources/publications/tr-12-87.html.

20 National Institute of Population Research and Training, International Centre for Diarrhoeal Disease Research, Bangladesh, MEASURE Evaluation. *Bangladesh maternal mortality and health care survey 2016.* Dhaka (Bangladesh); Chapel Hill (NC): NIPORT, icddr,b, and MEASURE Evaluation, 2019. https://www.measureevaluation.org/resources/publications/tr-18-297.html.

21 Macicame I, Kante AM, Wilson E, etalCOMSA-Mozambique study team. Countrywide mortality surveillance for action in Mozambique: results from a national sample-based vital statistics system for mortality and cause of death. *Am J Trop Med Hyg* 2023;108(5 Suppl):-16. doi: 10.4269/ajtmh.22-0367. pmid: 37037442

22 Carshon-Marsh R, Aimone A, Ansumana R, etal. Child, maternal, and adult mortality in Sierra Leone: nationally representative mortality survey 2018-20. *Lancet Glob Health* 2022;10:-23. doi: 10.1016/S2214-109X(21)00459-9. pmid: 34838202

23 Ghana Statistical Service, Ghana Health Service, ICF. *Ghana maternal health survey 2007.* Accra (Ghana); Calverton (MD): GSS, GHS, and ICF, 2009. https://dhsprogram.com/pubs/pdf/FR227/FR227.pdf.

24 Ghana Statistical Service, Ghana Health Service, ICF. *Ghana maternal health survey 2017.* Accra (Ghana); Rockville, MD: GSS, GHS, and ICF, 2018. https://dhsprogram.com/pubs/pdf/FR340/FR340.pdf.

25 Wahi A, Perin J, Eilerts-Spinelli H, etal. Consolidating cause-of-death evidence for children and adolescents through an updated systematic review and known investigator-tracing.*SSRN* 2026. doi: 10.2139/ssrn.6339658.

26 Liu S, Wu X, Lopez AD, etal. An integrated national mortality surveillance system for death registration and mortality surveillance, China. *Bull World Health Organ* 2016;94:-57. doi: 10.2471/BLT.15.153148. pmid: 26769996

27 Liu Y, Chu Y, Yeung D, etal. National and sub-national levels and causes of mortality among 5-19-year-olds in China in 2004-2019: a systematic analysis of evidence from the Disease Surveillance Points System. *J Glob Health* 2022;12:. doi: 10.7189/jogh.12.11008. pmid: 36181508

28 Mulick AR, Oza S, Prieto-Merino D, Villavicencio F, Cousens S, Perin J. A Bayesian hierarchical model with integrated covariate selection and misclassification matrices to estimate neonatal and child causes of death. *J R Stat Soc Ser A Stat Soc* 2022;185:-120. doi: 10.1111/rssa.12853.

29 Park T, Casella G. The Bayesian Lasso. *J Am Stat Assoc* 2008;103:-6. doi: 10.1198/016214508000000337.

30 R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. 2025. https://www.r-project.org/.

31 Carpenter B, Gelman A, Hoffman MD, etal. Stan: A probabilistic programming language. *J Stat Softw* 2017;76:-32. doi: 10.18637/jss.v076.i01. pmid: 36568334

32 Guo J, Gabry J, Goodrich B, et al. rstan: R interface to Stan (version 2.32.7). 2025. https://CRAN.R-project.org/package=rstan.

33 UNAIDS. AIDS, crisis and the power to transform: UNAIDS Global AIDS Update 2025. Geneva: Joint United Nations Programme on HIV/AIDS, 2025. https://www.unaids.org/sites/default/files/2025-07/2025-global-aids-update-JC3153_en.pdf.

34 World Health Organization. Global tuberculosis report 2024. Geneva: World Health Organization, 2024. https://iris.who.int/server/api/core/bitstreams/7292c91e-ffb0-4cef-ac39-0200f06961ea/content.

35 Minta AA, Ferrari M, Antoni S, etal. Progress toward measles elimination — worldwide, 2000-2023. *MMWR Morb Mortal Wkly Rep* 2024;73:-42. doi: 10.15585/mmwr.mm7345a4. pmid: 39541251

36 Abdullah S, Adazu K, Masanja H, etal. Patterns of age-specific mortality in children in endemic areas of sub-Saharan Africa. *Am J Trop Med Hyg* 2007;77(Suppl 6):-105. doi: 10.4269/ajtmh.77.6.suppl.99. pmid: 18165480

37 Brooker SJ, Clarke S, Fernando D, etal. Malaria in middle childhood and adolescence. In: Bundy DAP, de Silva N, Horton S, Jamison DT, Patton GC, eds. *Child and adolescent health and development.* 3rd ed. The World Bank, 2017doi: 10.1596/978-1-4648-0423-6_ch14.

38 World Health Organization. World malaria report 2024: addressing inequity in the global malaria response. Geneva: World Health Organization, 2024. https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2024.

39 Delforge D, Wathelet V, Below R, etal. EM-DAT: the Emergency Events Database. *Int J Disaster Risk Reduct* 2025;124:105509. doi: 10.1016/j.ijdrr.2025.105509.

40 World Health Organization. The Global Health Observatory. 2025. https://www.who.int/data/gho.

41 Page MJ, McKenzie JE, Bossuyt PM, etal. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:. doi: 10.1136/bmj.n71. pmid: 33782057

42 Staton C, Vissoci J, Gong E, etal. Road traffic injury prevention initiatives: a systematic review and metasummary of effectiveness in low and middle income countries. *PLoS One* 2016;11:e0144971. doi: 10.1371/journal.pone.0144971. pmid: 26735918

43 Richter L. The effects of the COVID-19 pandemic on the risk of youth substance use. *J Adolesc Health* 2020;67:-8. doi: 10.1016/j.jadohealth.2020.07.014. pmid: 32773298

44 Leal Filho W, May J, May M, Nagy GJ. Climate change and malaria: some recent trends of malaria incidence rates and average annual temperature in selected sub-Saharan African countries from 2000 to 2018. *Malar J* 2023;22:. doi: 10.1186/s12936-023-04682-4. pmid: 37641080

45 Leal Filho W, Gbaguidi GJ, Zuñiga RAA, Ibrahim U. Climate change and malaria: an old enemy of Africa is back. *BMC Public Health* 2025;25:. doi: 10.1186/s12889-025-24555-6. pmid: 41188781

46 Rosenthal PJ, Asua V, Bailey JA, etal. The emergence of artemisinin partial resistance in Africa: how do we respond?*Lancet Infect Dis* 2024;24:-600. doi: 10.1016/S1473-3099(24)00141-5. pmid: 38552654

47 Chapoterera B, Naidoo K, Marume A. Impact of climate change on malaria transmission in Africa: A scoping review of literature. *J Public Health Afr* 2025;16:. doi: 10.4102/jphia.v16i1.1346. pmid: 40937113

48 Das S, Neupane R, Beard J, etal. Aetiology of diarrhoea in children aged zero to nine years in low- and middle-income countries: a systematic review. *J Glob Health* 2024;14:. doi: 10.7189/jogh.14.04168. pmid: 39485019

49 Black RE, Perin J, Yeung D, etal. Estimated global and regional causes of deaths from diarrhoea in children younger than 5 years during 2000-21: a systematic review and Bayesian multinomial analysis. *Lancet Glob Health* 2024;12:-28. doi: 10.1016/S2214-109X(24)00078-0. pmid: 38648812

50 Zheng Q, Luquero FJ, Ciglenecki I, etal. Cholera outbreaks in sub-Saharan Africa during 2010-2019: a descriptive analysis. *Int J Infect Dis* 2022;122:-21. doi: 10.1016/j.ijid.2022.05.039. pmid: 35605949

51 El-Sadr WM, Holmes CB, Mugyenyi P, etal. Scale-up of HIV treatment through PEPFAR: a historic public health achievement. *J Acquir Immune Defic Syndr* 2012;60(Suppl 3):-104. doi: 10.1097/QAI.0b013e31825eb27b. pmid: 22797746

52 United States of America, Department of State. America first global health strategy. Washington, DC: Department of State, 2025. https://www.state.gov/america-first-global-health-strategy.

53 Hlophe LD, Tamuzi JL, Shumba CS, Nyasulu PS. Barriers and facilitators to anti-retroviral therapy adherence among adolescents aged 10 to 19 years living with HIV in sub-Saharan Africa: a mixed-methods systematic review and meta-analysis. *PLoS One* 2023;18:e0276411. doi: 10.1371/journal.pone.0276411. pmid: 37200399

54 Ratevosian J, Ngangula P, Tram KH. Modeling the fallout: projecting the global impact of donor funding cuts on HIV prevention, treatment, and care. *Curr Opin HIV AIDS* 2025;20:-31. doi: 10.1097/COH.0000000000000977. pmid: 40891590

55 World Health Organization. Trends in maternal mortality estimates 2000 to 2023: estimates by WHO, UNICEF, UNFPA, World Bank Group and UNDESA/Population Division. Geneva: World Health Organization, 2025. https://www.who.int/publications/i/item/9789240108462.

56 Souza JP, Day LT, Rezende-Gomes AC, etal. A global analysis of the determinants of maternal health and transitions in maternal mortality. *Lancet Glob Health* 2024;12:-16. doi: 10.1016/S2214-109X(23)00468-0. pmid: 38070536

57 World Health Organization. The global strategy for women's, children's and adolescents' health (2016-2030). New York: Every Woman Every Child, 2015. https://www.who.int/docs/default-source/child-health/the-global-strategy-for-women-s-children-s-and-adolescents-health-2016-2030.pdf.

58 Parikh NS, Howard SC, Chantada G, etalInternational Society of Pediatric Oncology. SIOP-PODC adapted risk stratification and treatment guidelines: Recommendations for neuroblastoma in low- and middle-income settings. *Pediatr Blood Cancer* 2015;62:-16. doi: 10.1002/pbc.25501. pmid: 25810263

59 Lam CG, Howard SC, Bouffet E, Pritchard-Jones K. Science and health for all children with cancer. *Science* 2019;363:-6. doi: 10.1126/science.aaw4892. pmid: 30872518

60 Steliarova-Foucher E, Colombet M, Ries LAG, etalICC-3 contributors. International incidence of childhood cancer, 2001-10: a population-based registry study. *Lancet Oncol* 2017;18:-31. doi: 10.1016/S1470-2045(17)30186-9. pmid: 28410997

61 Gupta S, Howard SC, Hunger SP, etal. Treating childhood cancer in low- and middle-income countries. In: Gelband H, Jha P, Sankaranarayanan R, etal, eds. *Cancer: Disease control priorities.* 3rd ed. The World Bank, 2015, doi: 10.1596/978-1-4648-0349-9_ch7.

62 Santero M, Ortiz Sequeira R, Cruz Paixao M, etal. Childhood cancer survival in low- and middle-income countries and the Global South: emerging evidence and critical gaps from a scoping review of observational studies. *EJC Paediatr Oncol* 2025;6. doi: 10.1016/j.ejcped.2025.100422. pmid: 41368027

63 CureAll framework: WHO Global Initiative for Childhood Cancer. Increasing access, advancing quality, saving lives. Geneva: World Health Organization, 2021. https://creativecommons.org/licenses/by-nc-sa/3.0/igo/.

64 Fung A, Horton S, Zabih V, Denburg A, Gupta S. Cost and cost-effectiveness of childhood cancer treatment in low-income and middle-income countries: a systematic review. *BMJ Glob Health* 2019;4:e001825. doi: 10.1136/bmjgh-2019-001825. pmid: 31749998

65 Rakislova N, Jordao D, Ismail MR, etal. Accuracy of verbal autopsy, clinical data and minimally invasive autopsy in the evaluation of malaria-specific mortality: an observational study. *BMJ Glob Health* 2021;6:e005218. doi: 10.1136/bmjgh-2021-005218. pmid: 34083241

66 Ray-Bennett NS, Dissanayake L, Ekezie W, etal. Verbal autopsy instruments for 'causes and circumstances' surrounding drowning deaths in low- and middle-income countries: a scoping review. *Inj Prev* 2025;ip-2025-045685. doi: 10.1136/ip-2025-045685. pmid: 40764022

67 Blau DM, Baillie VL, Els T, etalCHAMPS Consortium. Deaths attributed to respiratory syncytial virus in young children in high-mortality rate settings: report from Child Health And Mortality Prevention Surveillance (CHAMPS). *Clin Infect Dis* 2021;73(Suppl 3):-28. doi: 10.1093/cid/ciab509. pmid: 34472577

68 Pramanik S, Zeger S, Blau D, Datta A. Modeling structure and country-specific heterogeneity in misclassification matrices of verbal autopsy-based cause of death classifiers. *Ann Appl Stat* 2025;19:-39. doi: 10.1214/24-AOAS2006.

Web appendix: Supplementary information