Mortality risks in children aged 5–14 years in low-income and middle-income countries: a systematic empirical analysis

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Summary

Background Health priorities since the UN Millennium Declaration have focused strongly on children younger than 5 years. The health of older children (age 5–9 years) and younger adolescents (age 10–14 years) has been neglected until recently, especially in low-income and middle-income countries, and mortality measures for these age groups have often been derived from overly flexible models. We report global and regional empirical mortality estimates for children aged 5–14 years in low-income and middle-income countries, and compare them with ones from existing models.

Methods For this empirical analysis, we obtained birth-history data from surveys done over a 25-year period from 1986 by the Demographic and Health Surveys programme for 84 World Bank low-income and middle-income countries, and data about household deaths in China from their 1990 and 2010 censuses. We used these data to calculate mortality risks for children aged 5–14 years, and compare these risks to corresponding estimates of mortality in children younger than 5 years in the same countries. We used regression analysis to model these associations, generate estimates of the risks, and derive estimates of the numbers of deaths for 1990 and 2010 by applying those risks to population estimates from the UN World Population Prospects (WPP) 2012 Revision. We then compared the numbers of deaths with those given by the UN WPP itself and by the Institute for Health Metrics and Evaluation's Global Burden of Disease (GBD) 2010 study.

Findings The mean risk of a child dying at age 5–14 years in low-income and middle-income countries is about 19% of the risk of dying between birth and age 5 years (12% at age 5–9 plus 7% at age 10–14). According to our estimates, the total number of deaths at ages 5–14 years in low-income and middle-income regions fell from about 2·4 million (95% CI 1·9–2·7) in 1990 to about 1·5 million (1·2–1·8) in 2010. From our estimates we concluded there to have been 200 000 (16%) more deaths at ages 5–14 than in the UN report; however, our estimates exceeded GBD estimates by more than 700 000 (87%). The average annual rate of decline in mortality at age 5–9 years (about 3%) slightly exceeded that for ages 0–4 years (2·8%), but progress has been slower for age 10–14 years (about 2%).

Interpretation Our analysis suggests that mortality risks nowadays in the age range 5–14 years in low-income and middle-income countries are rather higher (relative to mortality in children younger than 5 years) than would be expected on the basis of historical evidence. Our findings broadly lend support for the UN WPP mortality estimates, but are almost double those underpinning GBD 2010. Global policy emphasis on reduction of mortality in children younger than 5 years should be broadened to include older children and adolescents.

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Introduction

The Millennium Declaration[1] established three explicit health goals: child health (Millennium Development Goal [MDG] 4), maternal health (MDG5), and control of malaria, tuberculosis, and AIDS (MDG6). Partly as a result of these goals, and partly because of increasing recognition of the importance of chronic diseases of adults,[2] health interventions and the associated efforts to improve measurements, particularly of mortality, in low-income and middle-income countries have largely focused on children younger than 5 years and adults aged 15 years and older. Until recently, the age range 5–14 years has been neglected, both with respect to health interventions and with respect to measurement. As noted by Viner and colleagues,[3] "global mortality data for children aged 5 years and older...are restricted to cross-sectional data or inclusion within studies of adult mortality". Part of the reason for the neglect of age 5–14 years might arise from the fact that this is the age range during which human mortality risks reach their minimum.[4] However, interest has now been renewed in the health of adolescents,[5,6] variously defined as people aged 10–19 years or 10–24 years, but this interest has not been accompanied by a substantial increase in measurement effort. The age range 5–9 years has continued to be largely ignored, in terms of both interventions and measurement. One exception is a report on 50-year mortality trends for children and young adults,[3] including explicit measures for children aged 5–9 years and young adolescents aged 10–14 years, in 50 low-income, middle-income, and high-income countries with accurate mortality data for at least half the period. However, the investigators noted that, because their study was restricted

Research in context

Evidence before this study

We searched the relevant scientific literature on methods and results antecedent to this study, using the tracking system from the UN Interagency Group for Child Mortality Estimation. High-quality vital registration systems provide the most definitive approach to ascertaining levels and trends in mortality. One study reviewed and extended the vital-registration literature for the age group 5–14 years covering high-income countries and selected (but non-representative) low-income and middle-income ones. Absence of vital-registration data in low-income and middle-income countries prompts use of two alternative estimation methods: use of model life tables (that to some extent assume past patterns of mortality in nowadays low-mortality vital-registration countries) which can guide estimation in countries where data are unavailable today, and data-based methods that rely on sample surveys, often Demographic and Health Surveys. Two more reports review and apply model life table approaches and describe results for the 5–14 years age group. The UN provides data-based assessments based on sample surveys, but only for children younger than 5 years.

Added value of this study

Our study extends the available literature in two ways. First, it extends estimations based on the widespread sample-survey database used to assess mortality in children younger than 5 years to include the age group 5–14 years, thereby enabling replacement of model-based results for this age group with data-based ones. Second, this study concludes that mortality in children aged 5–14 years is higher than stated in existing literature.

Implications of all the available evidence

Our conclusions point to several directions for policy and research. First, the unexpectedly large number of deaths in children aged 5–14 years suggests that the global policy emphasis on reducing mortality in children younger than 5 years should be broadened to include older children and adolescents. Second, country-specific analyses should be undertaken to complement this study's assessment by region. These analyses will enable monitoring of country performance over time. And, third, although detailed assessments of the distribution of deaths by cause for children younger than 5 years are available, assessments should be undertaken for the 5–9 and 10–14 years age groups.

to countries with at least 24 years of accurate mortality data, it could not include very low-income countries in Africa or Asia, and also excluded China and India.

In view of the scarcity of accurate data in most low-income and middle-income countries, which is attributable to the absence of adequate civil registration systems, mortality in the age range 5–14 years for low-income and middle-income countries is generally estimated from model age patterns of mortality, often called model life tables, fitted to measures of mortality for children younger than 5 years and adults.[7,8] Various model life table systems exist,[4,9,10] but most of them are based, in part, on the experience of countries with low mortality now when they had high mortality in the past. For several reasons, the model age patterns at higher levels of mortality might not resemble contemporary patterns closely. One such reason is the success of child-survival programmes, which can be expected to have reduced mortality in children younger than 5 years more sharply than in children aged 5–14 years; mortality in young adults is less responsive to the epidemiological transition than the mortality of young children.[3] Furthermore, the estimates of child and adult mortality to which the models are fitted are generally estimated from different data sources,[11] with potentially different biases, such that the modelled mortality estimates for ages 5–14 years might be seriously distorted.

Despite the fact that the age range 5–14 years has the lowest human mortality risks, from a developmental perspective it is a period of great importance. It is at these ages that the crucial early stages of education take place, and also the age of onset of adolescence, with

broad societal implications.[5,6] This report presents our generated empirical evidence on mortality in this age range in low-income and middle-income countries, and compares the estimates with historical age patterns of mortality and with estimates from the UN[8] and from the Institute for Health Metrics and Evaluation's Global Burden of Disease (GBD) 2010 study.[7]

Methods

Study design

All the data we used for this empirical analysis, except for China, come from the full birth histories obtained from surveys done over a 25-year period from 1986 by the Demographic and Health Surveys programme.[12] Demographic and Health Surveys entail interviews mainly with nationally representative samples of women of reproductive age; sample sizes range from about 3000 to 100 000 women. A full birth history obtains information from women (or only from ever-married women in some settings where childbearing outside marriage is very rare) about the sex and date of each of her livebirths, whether the child is still alive, and, if not, the age at which the child died. Demographic and Health Survey methods have not changed substantially with respect to full birth history over the life of the programme, and periodical assessments have not shown changes in the quality of these data. Full birth history data show the location of child deaths and child exposure to risk by age in calendar time, and thus enable the calculation of age-specific mortality rates (deaths per person-year of exposure) for specified periods.[13] These data have been used widely for studies of mortality in

children younger than 5 years; for example, the estimation of national and subnational levels and trends in mortality and its components in this age group,[14,15] and for exploring differentials in early child mortality.[16] However, the data also provide a basis (albeit with smaller sample numbers of deaths and thus larger sampling errors) for calculation of mortality risks for children aged between 5 and 14 years with the same methods. We used data from 194 Demographic and Health Surveys covering 84 countries from all six World Bank low-income and middle-income regions to estimate mortality in children younger than 5 years and between 5 and 14 years by sex.

Although Demographic and Health Surveys have been undertaken in all low-income and middle-income regions of the world, and in most countries that have substantial populations, no such surveys have been done in China. The 1990 and 2010 censuses of China, however, have obtained data about household deaths in the 12 months before the census.[17,18] We used these data to estimate the numbers of deaths in children aged 5–14 years in China.

Procedures

We used full birth history data from the Demographic and Health Surveys to calculate period occurrence-exposure mortality rates for single months (for children younger than 5 years) or years (for children aged 5–14 years) for the 10 complete calendar years before each survey. For mortality in children younger than 5 years (under-5 mortality rate [U5MR]), we used the routine sex-specific probabilities of dying between birth and age 5 years[19] to calculate mortality rates by sex for months of age from each survey, convert them into probabilities of dying from the beginning to the end of each month, and then chain together the corresponding probabilities of surviving to estimate sex-specific probabilities of dying between birth and age 5 years. For ages 5–14 years, we use the same method, but for single years rather than months of age, to estimate sex-specific probabilities of dying at age 5–9 years (ie, from the exact instant of a 5th birthday to an instant before a 10th birthday [$_5q_5$]) and age 10–14 years (ie, from the exact instant of a 10th birthday to an instant before a 15th birthday [$_5q_{10}$]).

To assess the general plausibility of our results, we compared the relations of $_5q_5$ and $_5q_{10}$ with U5MR with patterns seen in the Coale-Demeny[8] model life tables. These tables are less flexible than those used in the 2010 GBD study, because they do not fit separately to the age ranges of birth and 5 years, and 15 years and older, and are thus less likely to introduce distortion for ages 5–14 years. The tables are based on empirical data spanning a century of experience, largely in countries of Europe that now have low mortality but in the past had both high mortality and complete civil registration systems. They represent four distinct age patterns of mortality, called North, South, East, and West, referring
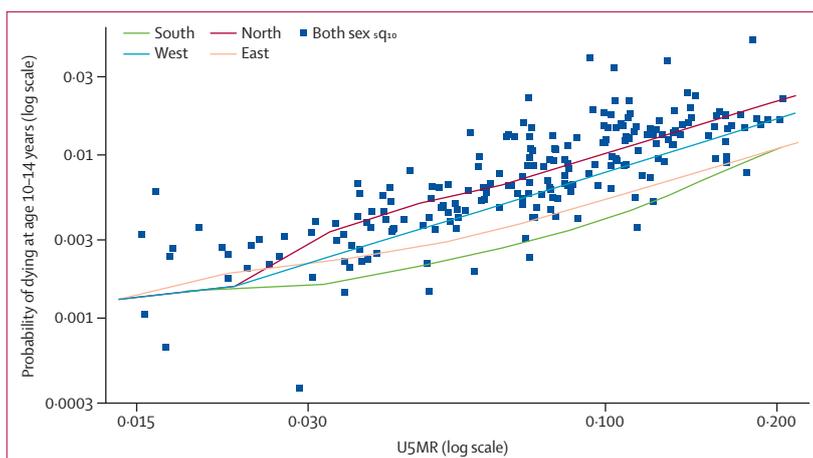

Figure 1: Probability of dying at age 10–14 years
Data are historical patterns. $_5q_{10}$=probabilities of dying at age 10–14 years. U5MR=sex-specific probabilities of dying between birth and age 5 years. North, South, East, and West represent four distinct age patterns of mortality, referring broadly to the area of Europe from which most of the Coale-Demeny[8] model lifetables were drawn.
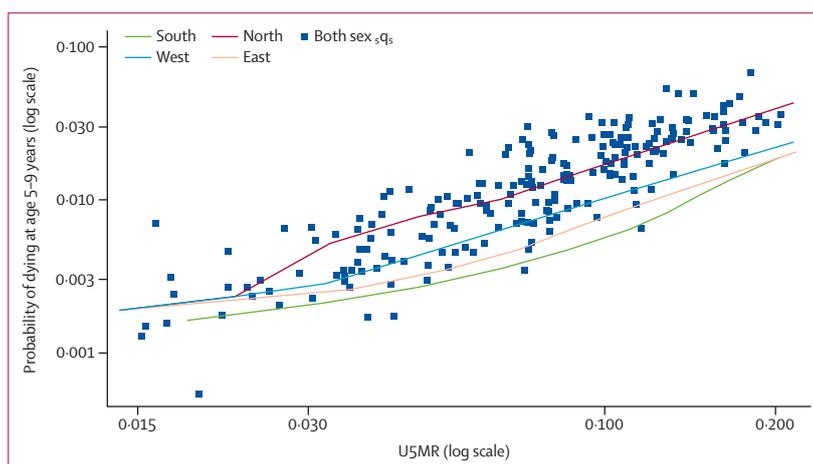

Figure 2: Probability of dying at age 5–9 years
Data are historical patterns. $_5q_5$ =probabilities of dying at age 5–9 years. U5MR=sex-specific probabilities of dying between birth and age 5 years. North, South, East, and West represent four distinct age patterns of mortality, referring broadly to the area of Europe from which most of the Coale-Demeny[8] model life tables were drawn.

broadly to the area of Europe from which most of their underlying empirical life tables were drawn. Thus for example the North tables are based mainly on the historical experience of Scandinavia. The West family is based on a much larger number of empirical life tables than the other regional models, and is generally regarded as the default pattern, to be used in the absence of previous knowledge about mortality patterns by age.

Statistical analysis

Our initial exploration of the data showed strong linear relations between the probabilities of dying between ages 5 and 9 years, 10 and 14 years, and under 5 years. To calculate the numbers of deaths at each age range in 1990 and 2010 by sex and World Bank low-income and middle-income region, we first developed regression models of $_nq_x$ on U5MR using country-level data from the
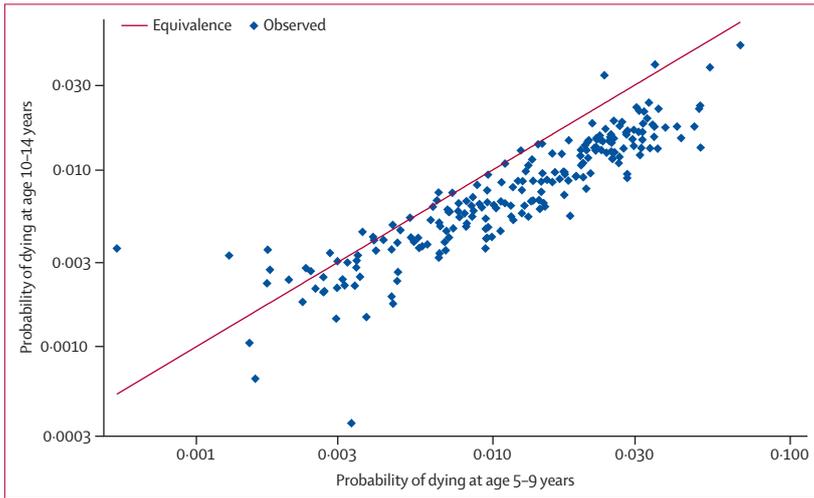
Figure 3: Comparison of probabilities of dying at age 5–9 years and 10–14 years
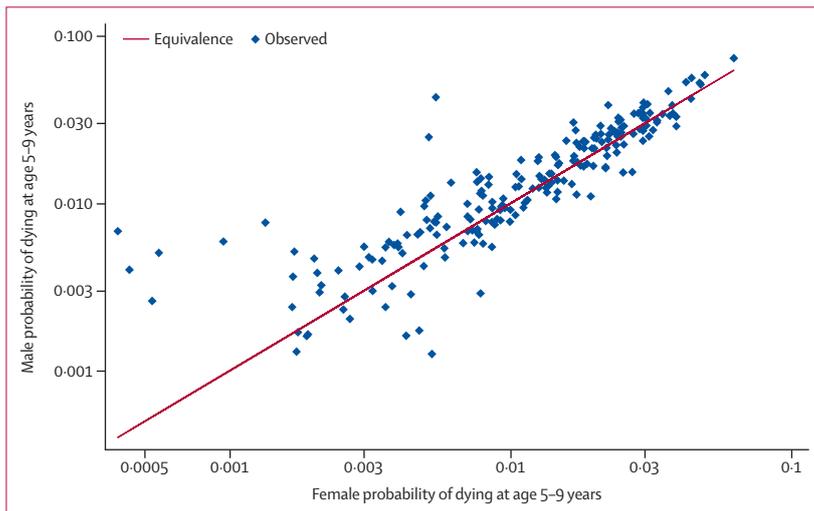Data are from both sexes.

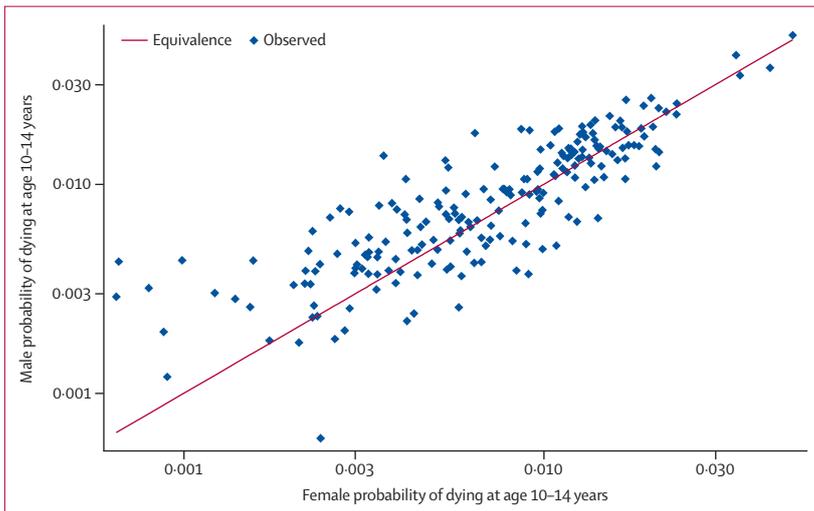**Figure 4:** Sex differences in probability of dying at age 5–9 years

Figure 5: Sex differences in probability of dying at age 10–14 years

Demographic and Health Surveys. The ordinary least-squares regression models were of the form:

$$\ln \left({}_5 q_x^{i,j,t}\right) = \alpha_x^{i,j} + \beta_x^{i,j}\ln U5MR^{i,j} + \gamma_x^{i,j}\left(\ln U5MR^{i,j} * t\right)$$

for which x=ages 5 or 10, i=World Bank region, j=sex, and t=a dummy variable showing whether the results came from a Demographic and Health Survey done before 2000 (t=0), or 2000 and later (t=1). Initial regressions suggested no significant difference in coefficients by region or sex, so the final model is based on all both-sex findings. However, we noted that the coefficient on the period-interaction term in the equation was significant at the 10% level for the age range 5–9 years, and highly significant for the age range 10–14 years. Regression results are reported in the appendix. We then combined region-specific and sex-specific estimates from the Interagency Group on Mortality Estimation of U5MR[20] for 1990 and 2010 with the models' estimated parameters to obtain regional estimates of ${}_5q_x$ for those years. We then converted ${}_5q_x$ to age-specific mortality rates ${}_5M_x$ using the standard expression ${}_5M_x={}_5q_x/(5-2\cdot5\times{}_5q_x)$; the ${}_5q_x$ probabilities and the ${}_5M_x$ rates share the same numerator (deaths in an age range) but different denominators, person-years of exposure in the case of rates, but an initial population age × for the probabilities. We then applied the ${}_5M_x$ estimates to age-specific and sex-specific population numbers by region for 1990 and 2010 from the UN World Population Prospects (WPP) 2012 revision[8] estimates of the regional populations by sex in 1990 and 2010, to obtain numbers of deaths by age group, sex, region, and year.

Two recent publications[8,21] have presented modelled estimates of mortality by age and sex for the world, regions, and countries from GBD 2010[21] and UN WPP (2012 revision).[8] Direct comparisons between the two sets of estimates are not possible because the two studies present information on deaths by age and sex for periods and regions defined in different ways: GBD 2010[21] presented estimates for 1970, 1990, and 2010, whereas the UN WPP estimates were for 1995–2000, 2000–05, and 2005–10. To make comparisons for 2010, we estimated the numbers of deaths by age group for the UN WPP series, first by calculating average annual numbers for 2000–05 and 2005–10, then calculating age-specific and sex-specific annual rates of change, and, finally, using those rates of change to extrapolate to 2010.

For China, we used census data. When using this format of data collection, the completeness of reporting of deaths of young children might differ from that of older children and adults.[8] The reporting of adult deaths in the first 6 months of 1990, as recorded by the census that year, is estimated to be about 91% for male deaths and 86% for female deaths,[22] by use of methods that compare age patterns of deaths with age patterns of population. Preliminary assessments show similar levels of completeness for deaths recorded in the 12 months

before the 2010 census. Accordingly, rather than relating probabilities of dying between the ages of 5 and 14 years to U5MR, we use reported numbers of deaths at ages 5–9 years and 10–14 years adjusted for completeness (and multiplied the 1990 deaths by two to correct for the half-year reporting period).

Role of the funding source

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

Results

There was substantial scatter in our results; even though each Demographic and Health Survey estimate is based on a 10-year reference period, substantial stochastic errors occurred in the estimates of $_5q_x$ and of U5MR, especially in countries with small surveys, low fertility, or low mortality. However, some general relations are clear. First, our empirical findings conform broadly to the historical Coale-Demeny patterns, which is reassuring with regard to data quality; second, they tended to cluster around the North pattern, particularly for $_5q_{10}$ (figure 1), but also for $_5q_5$ (figure 2) at higher levels of U5MR. This clustering around North in these datasets shows that mortality between ages 5 and 14 years for a specific U5MR tends to be rather high relative to historical standards.

Figure 3 compares results of $_5q_5$ and $_5q_{10}$ (for both sexes combined) from the same survey. With these data, the probability of dying at age 5–9 years, $_5q_5$, is systematically higher than $_5q_{10}$, the probability of dying at age 10–14 years. Across mortality levels, $_5q_{10}$ averages about 60% of $_5q_5$, a significant difference (p<0·0001).

We compared results of $_5q_5$ (figure 4) and $_5q_{10}$ (figure 5) by sex. Once again, substantial scatter was noted (the numbers of events are even smaller when divided by sex); but overall, male risks are slightly higher than female risks, by about 12% at ages 5–9 years (p<0·0001), and about 9% at ages 10–14 years (p=0·0035), both significant at a 1% level. At low levels of mortality, the male disadvantage might increase, though these findings came from surveys in countries of Europe or central Asia with very low fertility, and therefore high sampling errors.

Table 1 shows the region-specific and sex-specific estimates of $_5q_x$ obtained from the regression models summarised in the equation. The mean risk of dying at age 5–14 years in low-income and middle-income countries is about 19% of the risk of dying between birth and age 5 years (12% relative to U5MR at age 5–9 plus 7% relative to U5MR at age 10–14), a relative difference similar to that in developed countries. For both age ranges, risks declined from 1990 to 2010, but the declines were faster for the age range 5–9 years than for 10–14 years.

	Boys		Girls	
	Age 5–9 years	Age 10–14 years	Age 5–9 years	Age 10–14 years
East Asia and Pacific (excluding China)*				
1990	11·3 (9·4–13·6)	6·9 (5·7–8·3)	9·8 (8·1–11·8)	6·1 (5·1–7·4)
2010	4·8 (4·0–5·9)	3·9 (3·2–4·8)	3·8 (3·2–4·7)	3·3 (2·7–4·0)
Europe and central Asia				
1990	8·5 (7·1–10·3)	5·5 (4·5–6·6)	6·9 (5·7–8·3)	4·6 (3·8–5·6)
2010	3·7 (3·0–4·5)	3·2 (2·6–3·9)	2·8 (2·3–3·4)	2·0 (2·1–3·1)
Latin America and Caribbean				
1990	8·5 (7·0,10·2)	5·4 (4·5,6·6)	6·8 (5·6,8·2)	4·5 (3·8,5·5)
2010	3·1 (2·5–3·8)	2·8 (2·3–3·4)	2·4 (2·0–3·0)	2·3 (1·9–2·8)
Middle East and north Africa				
1990	10·3 (8·5–12·4)	6·4 (5·3–7·7)	9·4 (7·8–11·3)	5·9 (4·9–7·2)
2010	3·8 (3·1–4·7)	3·3 (2·7–4·0)	3·2 (2·6–3·9)	2·9 (2·3–3·5)
South Asia				
1990	22·2 (18·4–26·8)	11·9 (9·8–14·4)	23·2 (19·3–28·0)	12·3 (10·2–14·9)
2010	9·7 (8·1–11·7)	6·8 (5·6–8·2)	10·2 (8·5–12·3)	7·0 (5·8–8·5)
Sub-Saharan Africa				
1990	36·6 (30·2–44·4)	17·8 (14·7–21·7)	32·0 (26·5–38·7)	16·0 (13·2–19·4)
2010	19·5 (16·1–23·5)	11·6 (9·6–14·1)	16·7 (13·8–20·1)	10·3 (8·5–12·5)
Total from low-income and middle-income countries*				
1990	16·7 (13·9–20·1)	9·5 (7·8–11·4)	15·7 (13·0–18·9)	9·0 (7·4–10·8)
2010	8·8 (7·3–10·7)	6·3 (5·2–7·6)	8·1 (6·8–9·8)	5·9 (4·9–7·1)

Data are n (95% CIs), stratified by World Bank regions, age group, sex, and year. $_5q_5$=sex-specific probabilities of dying between exact ages 5 and 10 years. $_5q_{10}$=sex-specific probabilities of dying between exact ages 10 and 15 years. *The data on which our main analyses are based are not available for China, for which we estimated numbers of deaths (but not probabilities of dying) using different methods. Accordingly, in this table we present probabilities of dying for east Asia excluding China, which dominates the region. However, we also present estimated probabilities of dying for all low-income and middle-income countries, including China, using our model with estimates of under-5 mortality rates for all such countries.

Table 1: Estimated conditional probability of dying per 1000 children aged 5–14 years

Table 2 shows the estimated number of deaths at ages 5–14 years in 1990 and 2010 by age group, sex, and World Bank region. Three regions—east Asia and Pacific, south Asia, and sub-Saharan Africa—account for most of the total deaths in this age range (2·1 million [86%] of 2·4 million [95% CI 1·9–2·7] in 1990 and 1·4 million [91%] of 1·5 million [1·2–1·8] in 2010). South Asia had the largest number of deaths in 1990, but is overtaken by a substantial margin by sub-Saharan Africa in 2010. Male deaths exceeded female deaths in all regions and both years.

Table 3 compares our estimated numbers of deaths between ages 5 and 14 years in 2010 with the estimates available from GBD 2010 and UN WPP (2012 revision) by sex, age group, and region. The comparison between GBD, the UN, and our estimates is made for less-developed countries and sub-Saharan Africa, for which the GBD, UN, and World Bank regional classifications are almost identical; the GBD and UN estimates for global deaths, for which we have no estimates, are also shown.

At the global level, the GBD 2010 numbers of deaths at ages 5–14 years are about 40% less than the UN WPP estimates. Across the entire age range from birth to old age, the GBD number of deaths is only about 6% smaller

	Boys		Girls		Both sexes (95% CIs)	
	Age 5–9 years	Age 10–14 years	Age 5–9 years	Age 10–14 years	Age 5–9 years	Age 10–14 years
East Asia and Pacific (excluding China)						
1990	69	39	58	34	127 (105–152)	72 (60–88)
2010	30	24	23	19	53 (43–64)	43 (35–52)
China*						
1990	45	32	33	25	77 (64–94)	57 (48–70)
2010	15	17	9	9	24 (19–29)	26 (21–31)
Europe and central Asia						
1990	31	19	24	15	55 (46–67)	34 (28–41)
2010	10	8	7	6	16 (13–20)	15 (12–18)
Latin America and Caribbean						
1990	46	28	36	23	82 (68–100)	50 (42–61)
2010	18	16	13	13	31 (26–38)	29 (23–35)
Middle East and north Africa						
1990	35	19	31	17	66 (55–80)	35 (29–43)
2010	13	11	10	9	23 (19–28)	20 (16–24)
South Asia						
1990	338	162	331	157	669 (554–808)	319 (264–386)
2010	172	117	164	112	337 (279–406)	229 (189–277)
Sub-Saharan Africa						
1990	284	116	244	103	528 (434–641)	218 (180–266)
2010	246	126	206	109	451 (373–546)	235 (194–285)
Total from low-income and middle-income countries						
1990	848	414	756	372	1604 (1262–1848)	787 (602–884)
2010	503	319	432	277	935 (753–1102)	596 (470–691)

Data stratified by age group, sex, and World Bank region. Deaths (except for China) are for children age 5–14 years. Total from low-income and middle-income countries-specific mortality rates estimated from sex-specific probabilities of dying in table 1 applied to population estimates from UN Population Division 2012 World Population Prospects. *Numbers of deaths for China are based on numbers of deaths recorded in the 1990 and 2010 Population Censuses, adjusted as described in the main text.

Table 2: Estimated annual numbers of deaths (thousands) in 1990 and 2010 in children aged 5–14 years

	Global Burden of Disease*		World Population Prospects†		This study‡	
	Boys	Girls	Boys	Girls	Boys	Girls
World	450	367	698	644	..	..
Less-developed regions	441	361	686	637	822	709
Sub-Saharan Africa	151	127	377	381	372	315

Data are stratified by sex. *From Wang and colleagues, 2012 (Institute for Health Metrics and Evaluation's Global Burden of Disease 2010 study).[6] †Calculated from UN, 2013 (CIs not available).[7] ‡Based on data from table 2.

Table 3: Comparison of different estimates of numbers of deaths (thousands) of children aged 5–14 years in 2010

	Sex	Average annual rate of decline	
		Mortality risks	Deaths
Age 0–4 years	Male	2·8%	3·0%
Age 0–4 years	Female	2·9%	3·0%
Age 5–9 years	Male	3·0%	2·6%
Age 5–9 years	Female	3·1%	2·8%
Age 10–14 years	Male	2·1%	1·3%
Age 10–14 years	Female	2·1%	1·5%

Data (calculated from table 2) are stratified by 5-year age groups, and low-income and middle-income countries (including China), 1990–2010.

Table 4: The rate of decline in death rates and in deaths for children age 0–14 years from 1990–2010

(0·567–0·831 million for sub-Saharan Africa and 1·223–1·793 million for less-developed regions). Although broadly consistent with the UN, the 16% higher estimate from our study constitutes more than 200 000 deaths; ie, more than three-quarters of the total number of maternal deaths estimated for 2010. By contrast with the comparison with the UN, our estimates substantially exceed those of GBD 2010, by more than 87% (ie, 700 000 deaths).

Table 4 shows the rates of change in both probabilities of dying and numbers of deaths for our two age groups; our results suggest that probabilities of dying at age 5–9 years fell slightly faster than U5MR between 1990 and 2010, and those at age 10–14 years fell substantially more slowly. The numbers of deaths fell at about the same annual rate as the probabilities of dying, except for the age range 10–14 years, in which they fell more slowly because of continued population growth in that age group between 1990 and 2010.

Discussion

This report presents the first systematic empirical analysis of mortality between the ages of 5 and 14 years in low-income and middle-income countries. The key findings are: that mortality at age 5–14 relative to mortality in children younger than 5 years is rather higher than historical relations would suggest; that, in most of these populations, mortality reaches its minimum in the age range 10–14 years; and that generally, male risks are somewhat higher than female risks across all regions. On the basis of this analysis, in 2010, about 1·5 million deaths (95% CI 1·2–1·8) occurred in children between the ages of 5 and 14 years in what the UN defines as "less developed regions". By comparison, roughly 2·2 million children aged 1–4 years died in that year.[20]

One possible reason for the high (relative to mortality in children younger than 5 years and historical patterns) mortality between the ages of 5 and 14 years would be the success of public health interventions to reduce U5MR, which might therefore have declined faster than mortality from 5 to 14 years. Rates of change from 1990 to 2010, however, support this hypothesis only for the age range 10–14 years, in which rates of decline were slower. The

than the WPP number; a substantial proportion of the difference between the two totals is accounted for by the large discrepancy at ages 5–14 years. The estimates in our study (comparable only for less-developed regions and sub-Saharan Africa) are broadly consistent with the UN estimates, suggesting 16% more deaths for low-income and middle-income countries in general, but about 9% fewer deaths for sub-Saharan Africa; both UN numbers fall within the 95% CIs around our estimates

similarity of rates of decline for children aged 5–9 years to those for children younger than 5 years could be attributed to spillover from the success of interventions for children younger than 5 years. This success could also have improved the health of the surviving children as they get older, thus reducing their mortality risk.

The large differences between the numbers of deaths at age 5–14 years reported by GBD and UN WPP is surprising, because this age range has a substantial amount of empirical data available from Demographic and Health Surveys for low-income and middle-income countries. The differences result from different estimation approaches. The GBD estimates are derived from a model life table system that is fitted to the probability of dying by age 5 years and the probability of dying between the ages of 15 and 60 years, with a mortality standard selected on the basis of how much is known from reliable sources about the age pattern of mortality for the population being studied.[22] The approach of the UN population division is also country specific, and is difficult to summarise adequately, but in the absence of reliable country data uses a different system of model life tables.[8] The shortage of accurate civil registration data for low-income and middle-income countries (other than those of eastern Europe and central Asia, for which the Demographic and Health Surveys data have very high sampling errors because of low fertility and mortality) makes it impossible to definitively test which estimates are correct. However, the many empirical datasets compiled for this study, and the general perception that Demographic and Health Surveys data are of high quality, provide strong support for the UN WPP estimates.

Our analysis had some limitations. The results in this paper are based on birth histories obtained from women of reproductive age (15–49 years) at the time of each survey, and on events and exposure in the 10 years before each survey—these limitations have implications for the mortality measures. For example, children who were aged 14 years 10 years before a survey were born nearly 25 years before the survey, and must have been born to women early in their reproductive lives (before age 25 years) since Demographic and Health Surveys obtain birth histories only from women younger than 50 years. The births must also have been to women of low parity by comparison with a random sample of births at that time. Thus, potential selection issues are associated with use of birth-history data as a basis for mortality estimates for older children (one reason why we do not extend our analysis to the age group 15–19 years). If the children for whom data are provided have above-average mortality risks, we will tend to overestimate these risks and hence the number of deaths for older ages. However, these selection issues are unlikely to be of quantitative importance, whichever direction they might be in, because the mother's age or parity are unlikely to continue to be major factors in the mortality risks of their children after the age of 5 years.

Another issue is recall lapse. It has long been postulated[21] that women tend to omit births that occurred long before a survey, and such omissions might be more likely to occur for children who have died than for children who have survived. Such errors would probably lead to an underestimate of risk relative to children aged younger than 5 years. However, results from a study[23] for the Interagency Group on Mortality Estimation has shown that recall lapse has no detectable effect on estimates of mortality in children younger than 5 years up to 25 years before a survey, so any effect is likely to be very small.

All the results reported in this paper are derived from sample surveys, with the result that both the dependent and the independent variables used to fit the model have sampling errors associated with them. Thus potential for bias is present, although with no clear suggestion of which direction it might be in. Irrespective of bias, standard errors in individual estimates are often large, which is why we focused on regional, rather than country, estimates.

References
1 UN. UN Millennium Declaration. Resolution adopted by the General Assembly, 55th Session of the UN General Assembly, New York, Sept 18, 2000. http://www.un.org/ga/55/ (accessed July 26, 2015).
2 WHO. Global status report on non-communicable diseases 2010. Geneva: World Health Organization, 2011.
3 Viner RM, Coffey C, Matthews C, et al. 50-year mortality trends in children and young people: a study of 50 low-income, middle-income, and high-income countries. *Lancet* 2011; **377:** 1162–74.
4 Coale AJ, Demeny P. Regional model life tables and stable populations. Princeton: Princeton University Press, 1983.
5 Sawyer SM, Afifi RA, Bearinger LM, et al. Adolescence: a foundation for future health. *Lancet* 2012; **79:** 1630–40.
6 UNICEF. Progress for children: a report card on adolescents. New York: United Nations International Children's Emergency Fund, 2012
7 Wang H, Dwyer-Lindgren L, Lofgren KT, et al. Age-specific and sex-specific mortality in 187 countries, 1970–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380:** 2071–94.
8 UN. World Population Prospects: the 2012 Revision. Demographic profiles. http://esa.un.org/wpp/Documentation/pdf/WPP2012_Volume-II-Demographic-Profiles.pdf (accessed Jan 19, 2014).
9 UN. Model life tables for developing countries. Sales No E81XIII7. New York: United Nations, 1982.
10 Wilmoth JR, Zureick S, Canudas-Romo V, Inoue M, Sawyer C. A flexible two-dimensional mortality model for use in indirect estimation. *Popul Stud* **66:** 1–28.
11 Moultrie T, Dorrington R, Hill A, Hill K, Timæus I, Zaba B. Tools for Demographic Estimation. Paris: International Union for the Scientific Study of Population, 2013. http://demographicestimation.iussp.org (accessed July 26, 2015).

12   Rutstein SO, Rojas G. Guide to DHS statistics. Calverton: Demographic and Health Surveys, ORC-Macro, 2006.

13   Preston SH, Heuveline P, Guillot M. Demography: measuring and modelling population processes. Oxford: Blackwell, 2001.

14   Rutstein SO, Johnson K. The DHS wealth index. DHS Comparative Reports No 6. Calverton: Demographic and Health Surveys, 2004.

15   Murray CJM, Laakso T, Shibuya K, Hill K, Lopez AD. Can we achieve Millenium Development Goal 4? A new analysis of country trends and forecasts of under-5 mortality to 2015. *Lancet* 2007; **370:** 1040–54.

16   Rutstein SO. Factors associated with trends in infant and child mortality in developing countries during the 1990s. *Bull World Health Organ* 2000; **78:** 1256–70.

17   China's National Bureau of Statistics. Tabulation on the 1990 Population Census of the People's Republic of China. Beijing: China Statistics Press, 1993.

18   China's National Bureau of Statistics. Tabulation on the 2010 Population Census of the People's Republic of China. Beijing: China Statistics Press. 2012.

19   Hill K. Direct estimation of child mortality from birth histories. In: Moultrie T, Dorrington R, Hill A, Hill K, Timæus I, Zaba B. Tools for demographic estimation. Paris: International Union for the Scientific Study of Population, 2013: 165–77. demographicestimation.iussp.org (accessed July 26, 2015).

20   UN Interagency Group for Mortality Estimation. Levels and trends in child mortality: 2014 report. New York: United Nations International Children's Emergency Fund, 2014.

21   Som RK. Recall lapse in demographic enquiries. New York: Asia Publishing House, 1973.

22   Banister J, Hill K. Mortality in China 1964–2000. *Popul Stud* 2004; **58:** 55–75.

23   Alkema L, New JR. Global estimation of child mortality using a Bayesian B-spline regression model, 2013. http://Arxiv.org (accessed July 26, 2015).