Neonatal, postneonatal, childhood, and under-5 mortality for 187 countries, 1970–2010: a systematic analysis of progress towards Millennium Development Goal 4

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Summary

Background **Previous assessments have highlighted that less than a quarter of countries are on track to achieve Millennium Development Goal 4 (MDG 4), which calls for a two-thirds reduction in mortality in children younger than 5 years between 1990 and 2015. In view of policy initiatives and investments made since 2000, it is important to see if there is acceleration towards the MDG 4 target. We assessed levels and trends in child mortality for 187 countries from 1970 to 2010.**

Methods **We compiled a database of 16 174 measurements of mortality in children younger than 5 years for 187 countries from 1970 to 2009, by use of data from all available sources, including vital registration systems, summary birth histories in censuses and surveys, and complete birth histories. We used Gaussian process regression to generate estimates of the probability of death between birth and age 5 years. This is the first study that uses Gaussian process regression to estimate child mortality, and this technique has better out-of-sample predictive validity than do previous methods and captures uncertainty caused by sampling and non-sampling error across data types. Neonatal, postneonatal, and childhood mortality was estimated from mortality in children younger than 5 years by use of the 1760 measurements from vital registration systems and complete birth histories that contained specific information about neonatal and postneonatal mortality.**

Findings **Worldwide mortality in children younger than 5 years has dropped from 11·9 million deaths in 1990 to 7·7 million deaths in 2010, consisting of 3·1 million neonatal deaths, 2·3 million postneonatal deaths, and 2·3 million childhood deaths (deaths in children aged 1–4 years). 33·0% of deaths in children younger than 5 years occur in south Asia and 49·6% occur in sub-Saharan Africa, with less than 1% of deaths occurring in high-income countries. Across 21 regions of the world, rates of neonatal, postneonatal, and childhood mortality are declining. The global decline from 1990 to 2010 is 2·1% per year for neonatal mortality, 2·3% for postneonatal mortality, and 2·2% for childhood mortality. In 13 regions of the world, including all regions in sub-Saharan Africa, there is evidence of accelerating declines from 2000 to 2010 compared with 1990 to 2000. Within sub-Saharan Africa, rates of decline have increased by more than 1% in Angola, Botswana, Cameroon, Congo, Democratic Republic of the Congo, Kenya, Lesotho, Liberia, Rwanda, Senegal, Sierra Leone, Swaziland, and The Gambia.**

Interpretation **Robust measurement of mortality in children younger than 5 years shows that accelerating declines are occurring in several low-income countries. These positive developments deserve attention and might need enhanced policy attention and resources.**

Funding **Bill & Melinda Gates Foundation.**

Introduction

There are only 5 years left to achieve Millennium Development Goal 4 (MDG 4), which calls for a two-thirds reduction in mortality in children younger than 5 years between 1990 and 2015. Regular assessment of levels and trends in child mortality is essential for countries to ascertain their progress towards this goal and to take action to meet it. Previous appraisals of mortality in children younger than 5 years suggest that few countries are on track to meet MDG 4.[1–3] In each of these studies,[1–3] no more than 26% of low-income and middle-income countries examined were deemed to be on track to reach this target. Groups such as the Countdown to 2015 Initiative[3] have therefore tried to rally support to accelerate progress in child mortality.[4–7]

The MDG 4 target has shifted the focus from tracking levels of child mortality to assessing whether countries are reducing child mortality at the 4·4% rate per year needed to achieve the two-thirds reduction in 25 years. Accurate assessments of rates of change need more robust measurement with narrower uncertainty intervals than do assessments of levels. Although there have been substantial investments in the collection of data such as summary and complete birth histories to measure child mortality, assessments of trends have varied substantially from year to year and from source to source. For example, the list of the ten countries with the fastest rates of decline in child mortality between 1990 and 2007, as reported by UNICEF in 2008,[8] UNICEF in 2009,[9] and the UN

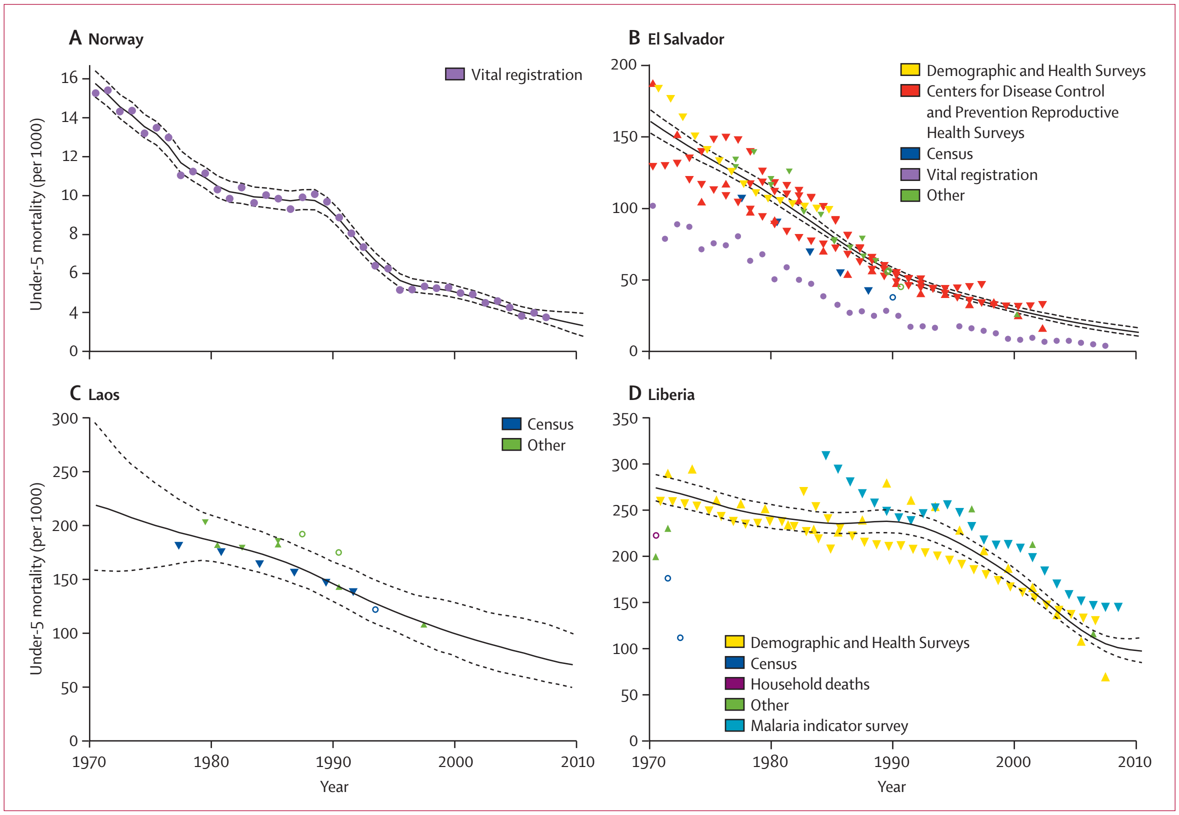

Figure 1: **Empirical data sources and estimated under-5 mortality from 1970 to 2010 for selected countries**
Dashed lines indicate uncertainty intervals. Hollow circles represent outliers. Under-5 mortality is defined as the probability of death between birth and age 5 years. Upward-pointing triangles are direct estimates from complete birth histories. Downward-pointing triangles are indirect estimates from summary birth histories.

Population Division (UNPD) in 2009,[10] have only three countries in common: Portugal, Vietnam, and the Maldives. In 2008, UNICEF reported that Thailand had the fastest rate of decline in the world, leading researchers to undertake a case study of this success.[11] But in 2009, UNICEF reported that Thailand had only the 47th fastest rate of decline;[9] in a UNPD report, the country had the fourth fastest rate of decline.[10] Such confusion about the true extent of progress can foster policy inaction in countries, precisely at a time when targeted, effective programmes are needed most. Variation in the assessments of rates of decline indicates the availability and use of different datasets, different analytical methods, and different decisions about data quality by the analysts.

Evidence from several low-income countries suggests that in some countries, declines in mortality in children younger than 5 years might have accelerated since 2000,[12–14] whereas in others, the rate of decline might be slowing. During the 25 years of the MDG 4 target, countries are likely to experience accelerations and decelerations in rates of decline. Acceleration matters because it could be an early indication of policy or programme success. The need to use the best datasets and the most valid methods for assessing child mortality over time is only intensified when trying to detect such accelerations and decelerations. In view of the scale-up in development assistance for health,[15] the expansion of insecticide-treated net coverage,[16] activity of the GAVI Alliance,[17] and rollout of antiretroviral drugs,[18] there are many reasons to hope that accelerations might be occurring in some countries.

In this study, we examined levels, rates of decline, and accelerations and decelerations in rates of decline in neonatal, postneonatal, childhood, and under-5 mortality from 1970 to 2010 in 187 countries. This study was aided by four important developments since the previous studies were done. First, we made use of data that have been newly released or acquired during an intensive 3-year effort to obtain access to microdata (individual-level data) and tabulated data sources. Second, we used new methods to analyse data from summary birth histories with reduced bias and measurement error.[19] Third, we applied new data synthesis methods with enhanced predictive validity to combine data from several sources and capture both sampling and non-sampling error patterns. This new method requires many fewer subjective inputs to estimation, ensuring that the output is strongly grounded in empirical data and is as reproducible as possible. Finally, we took advantage of more data and better models with improved predictive validity to analyse country patterns of neonatal, postneonatal, and childhood mortality.

Methods

Data sources

By use of improved methods, we substantially updated the database of measurements for under-5 mortality (defined as the probability of death between birth and age 5 years) used by Murray and colleagues[1] in 2007 to include newly released or obtained data, as well as reanalysed microdata from many of the sources included in the 2007 database. We retained measurements from the original database if we were not able to reanalyse the source data. The database now contains 7933 more measurements than did the 2007 analysis. Data for mortality in children younger than 5 years were derived from a range of sources, including vital registration systems, sample registration systems, surveys, and censuses. A full list of data types and sources is provided in webappendix pp 211–15.

See Online for webappendix

Survey measurements of under-5 mortality in the database consist of data from complete and summary birth histories. Under-5 mortality from complete birth histories in continuing survey programmes such as the Demographic and Health Surveys (DHS) were computed from pooled data across all such surveys in a given country (World Fertility Surveys, as the precursor to DHS, were included with DHS). The pooling approach mitigates some of the concerns of bias in the complete birth histories, such as selection bias for surveys in countries with high prevalence of HIV.[20] If microdata were available from summary birth histories, we estimated under-5 mortality by use of the combined method developed by Rajaratnam and colleagues.[19] If microdata were not available, but we were able to obtain tabulated data for children who died and children ever-born by mother's age, we applied the maternal age cohort-derived method.[19] We analysed 545 surveys with summary birth history microdata or tabulated data and 256 surveys with complete birth history microdata. If microdata or tabulated data were not available, we included estimated values of under-5 mortality from reports, such as preliminary DHS reports.

We also analysed survey and census data for deaths in the household. We adjusted estimates on the basis of household deaths from single surveys by use of the growth balance method.[21] When completeness of death reporting was estimated to be more than 100%, we adjusted the death rates downwards, with the logic that respondents might be telescoping deaths—ie, including deaths that occurred outside the recall period in the period of recall.[22,23] Child death registration is usually lower than is adult death registration, so estimates corrected upward (24 in total) must be viewed as lower bound estimates of child mortality. Sensitivity of our results to inclusion of these sources is presented in webappendix pp 10–11.

Our final database contained 17 208 measurements, consisting of 10 555 reanalysed measurements from summary birth histories, 1455 from complete birth histories, 79 from household deaths, 3626 from vital registration systems, and 1493 from various other sources. 1034 of the total measurements were classified as outliers on the basis of examination of country plots and in some cases because of known biases in the data. We used two criteria for identifying outliers: rates of child mortality that were far beyond the plausible range in view of a country's level of development, and rates of child mortality that were substantially inconsistent with other sources of information for the same country that cannot be explained by a known mortality shock. Generally, we favoured the inclusion of data points rather than their exclusion. We also excluded countries with populations of less than 50 000 from the analysis. Overall, we produced yearly estimates of under-5 mortality from 16 174 empirical measurements for 187 countries.

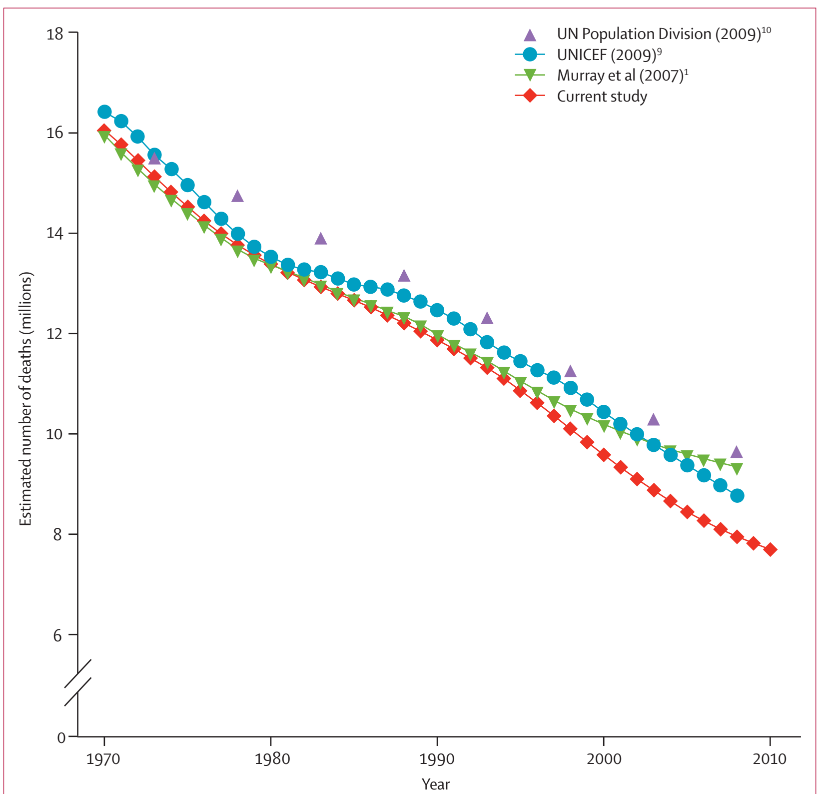

Figure 2: **Worldwide number of deaths in children younger than 5 years from 1970 to 2010**

Estimation of under-5 mortality

For each country, we generated a time series of estimates of under-5 mortality by synthesising the empirical data estimates with an analytical technique called Gaussian process regression (GPR).[24–27] Details of the implementation of this technique are shown in webappendix pp 1–8. Briefly, we applied Loess regression of the log of under-5 mortality in a country as a function of time and an indicator variable for measurements from vital registration data to allow for under-registration of child deaths. This predicted series was then updated by the data within each country by use of GPR. Our GPR model improves on previous approaches to synthesising measurements for under-5 mortality by providing the flexibility to track observed trends in the data and a coherent, empirical framework for distinguishing these real trends from fluctuations caused by sampling and non-sampling errors. Uncertainty in the measurements because of non-sampling error was captured in the model by a set of variance parameters, one for each type of data source. These parameters were estimated on the basis of the degree to which a source tends to disagree with the other sources. The more that a particular source conflicted with other sources, the higher the variance parameter will be and thus the more uncertain the measurements. The model takes this uncertainty into account as well as the sampling uncertainty and accordingly smooths data that are noisy (ie, with large variation because of sampling or small numbers) and uncertain. For countries with reliable data, the GPR estimates closely track the observed data.

As described in webappendix pp 8–10, we assessed the validity of this strategy to synthesise data sources by undertaking two types of out-of-sample predictive validity tests. When 20% of surveys and 20% of vital registration country-years were excluded from the analysis, the GPR predictions for these withheld data had a median relative error of 7·3%. When the last 10 years of data for every country with at least 20 years of data were excluded, GPR predictions had a median relative error of 10·9%. Webappendix p 212 shows the predictive validity of GPR compared with four other methods on performance in the two types of out-of-sample predictive validity tests. The four methods consist of a Loess-based approach and spline-based approaches with varying numbers of knots. GPR outperforms all four of these approaches.

One benefit of GPR is that it improves on previous attempts to estimate uncertainty in under-5 mortality that have ignored the many sources of uncertainty beyond model specification for an ad-hoc choice of model.[1] The uncertainty in this application depends on the sample sizes of the measurement instruments, non-sampling error for a given data source, and aspects of the Gaussian process. Details are provided in webappendix pp 1–17.

Wars, earthquakes, and other mortality shocks

Periods that were affected by mortality shocks were identified by data from the Uppsala Conflict Data Program and the Centre for Research on the Epidemiology of Disasters.[28–31] Deaths caused by conflict or natural disaster from each database, in addition to population estimates from the UN,[10] were used to generate a variable of war/disaster deaths per head. Any year with a value higher than a threshold of one death per 10 000 population was coded as a mortality shock year. We also examined the data from each country to identify aberrations in observed mortality that were consistent with a historical record of conflict or disaster. Empirical data points from years classified as mortality shocks were not included in the GPR estimation. We added the shocks back in by replacing the GPR estimate with the mean of the empirical measurements in the year of the shock. For countries in which shocks were expected but not present in the data (surveys are often unable to include regions heavily affected by conflict), such as the Democratic Republic of the Congo, Ethiopia, and Sudan, we used province-level data from the Complex Emergency Database (CE-DAT) to generate national estimates that were more indicative of mortality shocks.[32] Unfortunately, because of the wide variation in the CE-DAT data, this effort did not substantially alter the GPR estimates for these countries; therefore, we did not include these data points. Because of the difficulties inherent in obtaining reliable data that cover periods of mortality shocks, the systematic process we applied in these scenarios is imperfect and remains a limitation to our analysis. The effect of the Haiti 2010 earthquake was estimated by applying the same percentage increase in mortality, compared with the previous year, recorded in the Armenia 1988 earthquake.

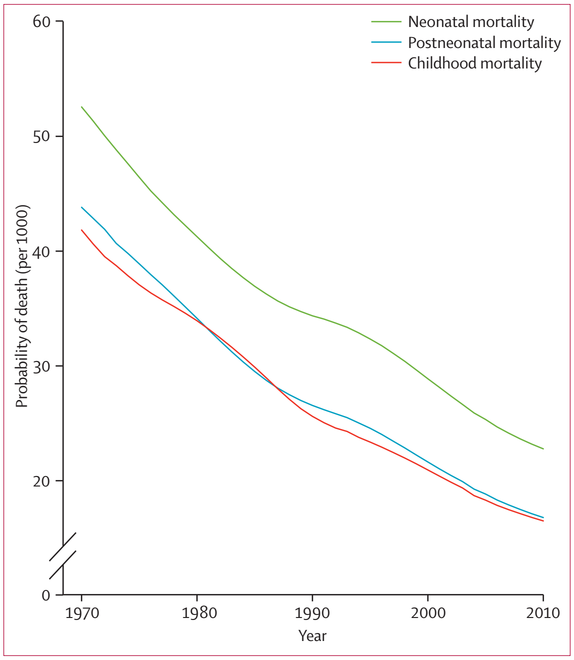

Figure 3: **Worldwide neonatal, postneonatal, and childhood mortality from 1970 to 2010**
See text for definitions of neonatal, postneonatal, and childhood mortality.

Analysis of trends

We computed yearly rates of change in under-5 mortality and examined rates over time for each country. The average rate of decline needed to meet MDG 4 is 4·4% per year, and across different periods between 1990 and 2010, we looked at how many countries were experiencing declines at that rate or greater.

Concerns have also been raised that mortality from HIV might be differentially affecting mothers whose

	1970	1980	1990	2000	2010
Asia Pacific, high income					
Brunei	53·4 (48·2–60·0)	21·4 (18·5–24·7)	11·4 (10·0–13·1)	9·2 (8·0–10·9)	7·5 (5·6–10·3)
Japan	17·8 (17·7–18·0)	11·6 (11·4–11·7)	6·6 (6·5–6·8)	4·4 (4·3–4·5)	3·3 (2·8–3·9)
Singapore	29·2 (27·9–30·5)	15·3 (14·4–16·3)	7·7 (7·2–8·3)	4·1 (3·7–4·4)	2·5 (1·9–3·3)
South Korea	56·5 (52·1–61·0)	18·7 (14·2–24·2)	11·3 (8·4–14·7)	9·3 (6·8–12·2)	5·1 (3·4–7·6)
Asia, central					
Armenia	103·1 (88·6–122·8)	68·9 (65·7–72·1)	50·9 (48·7–53·2)	32·2 (30·7–33·8)	19·3 (15·7–23·8)
Azerbaijan	149·8 (109·1–206·8)	109·8 (99·7–121·9)	78·6 (73·3–83·2)	56·2 (52·5–59·6)	33·8 (26·6–42·7)
Georgia	94·0 (77·9–113·0)	58·9 (55·7–62·3)	44·8 (42·6–47·0)	35·2 (33·2–37·2)	23·9 (19·0–29·3)
Kazakhstan	69·8 (60·9–78·5)	65·3 (61·8–68·9)	53·3 (50·3–56·0)	44·1 (40·8–47·5)	31·3 (25·4–40·0)
Kyrgyzstan	139·3 (126·5–152·6)	98·2 (94·1–102·8)	69·5 (66·8–72·6)	50·9 (46·7–54·5)	42·5 (36·0–52·4)
Mongolia	157·4 (147·0–169·4)	126·3 (121·2–131·5)	94·5 (90·9–98·5)	58·5 (55·7–61·4)	33·8 (29·4–38·7)
Tajikistan	177·5 (142·2–210·6)	143·5 (135·2–152·6)	108·4 (102·2–114·3)	81·4 (76·8–86·1)	49·7 (39·7–60·4)
Turkmenistan	184·7 (137·2–239·7)	124·8 (111·7–139·9)	98·4 (89·4–108·5)	74·7 (64·4–86·3)	26·0 (18·9–34·8)
Uzbekistan	81·6 (70·5–92·2)	77·4 (74·1–81·4)	65·9 (62·6–68·5)	57·3 (54·8–60·4)	43·5 (36·7–51·6)
Asia, east					
China	85·7 (73·3–99·8)	48·5 (43·0–54·3)	39·6 (35·8–43·3)	32·0 (28·5–36·5)	15·4 (11·8–20·1)
North Korea	114·4 (62·1–210·7)	70·5 (38·3–129·7)	50·9 (27·7–93·8)	45·9 (24·9–84·5)	33·4 (18·1–61·5)
Taiwan	27·4 (26·9–27·9)	15·3 (15·0–15·6)	8·9 (8·7–9·2)	8·6 (8·3–8·9)	6·2 (5·2–7·4)
Asia, south					
Afghanistan	286·9 (260·0–314·9)	212·0 (196·9–230·1)	163·5 (154·2–173·5)	141·0 (131·6–150·4)	121·3 (109·0–134·7)
Bangladesh	234·4 (227·4–242·7)	191·0 (186·5–195·2)	139·5 (136·7–142·5)	87·9 (85·5–90·1)	55·9 (51·6–60·1)
Bhutan	278·1 (246·8–310·7)	207·7 (190·3–229·4)	144·8 (134·9–156·7)	88·1 (81·4–95·7)	54·1 (47·4–61·8)
India	197·8 (191·9–203·4)	150·9 (147·8–154·0)	114·3 (112·0–116·7)	84·6 (82·5–86·8)	62·6 (58·2–67·3)
Nepal	261·7 (252·3–271·7)	210·2 (204·7–215·8)	137·3 (133·6–141·0)	77·9 (75·3–80·9)	47·3 (42·6–52·3)
Pakistan	169·2 (162·6–176·5)	134·9 (129·0–141·0)	113·3 (109·0–117·7)	94·6 (89·9–98·8)	80·3 (70·5–92·3)
Asia, southeast					
Cambodia	169·2 (140·7–203·6)	173·4 (164·8–183·6)	121·2 (115·5–127·3)	105·4 (99·8–111·7)	59·7 (42·4–84·8)
Burma	162·6 (139·0–190·4)	125·6 (106·5–144·1)	120·2 (103·5–142·9)	79·6 (68·3–92·4)	55·0 (39·7–76·0)
Indonesia	156·8 (152·5–161·0)	104·1 (101·7–106·8)	71·5 (69·8–73·3)	48·8 (47·4–50·4)	36·6 (32·4–41·1)
Laos	218·8 (158·4–296·1)	184·7 (165·4–207·9)	144·5 (126·9–164·7)	98·3 (76·3–127·0)	68·3 (47·1–97·9)
Malaysia	49·6 (47·0–52·3)	28·0 (25·6–30·6)	16·4 (15·1–17·9)	9·6 (8·7–10·6)	5·1 (4·1–6·3)
Maldives	247·1 (226·3–272·5)	172·7 (160·7–187·0)	88·5 (80·8–96·7)	34·0 (29·7–39·0)	14·0 (11·1–17·9)
Mauritius	84·0 (81·7–86·4)	43·8 (42·2–45·3)	24·4 (23·3–25·5)	19·0 (18·1–20·1)	13·0 (10·7–15·7)
Philippines	87·5 (83·8–90·9)	78·8 (76·3–81·3)	54·1 (52·4–55·9)	38·3 (36·5–40·7)	28·6 (23·6–33·9)
Seychelles	116·0 (95·1–142·6)	46·5 (40·2–54·6)	26·6 (22·9–30·8)	22·8 (18·2–28·5)	15·9 (10·7–23·9)
Sri Lanka	66·8 (63·0–70·7)	43·7 (41·2–46·5)	35·4 (32·1–39·2)	17·6 (15·8–19·4)	10·1 (7·2–14·0)
Thailand	87·9 (84·5–91·3)	49·2 (47·3–51·5)	23·3 (22·1–24·7)	13·8 (13·1–14·7)	8·9 (7·6–10·5)
Timor-Leste	202·1 (177·4–229·7)	153·2 (142·0–167·5)	101·4 (92·7–110·3)	82·6 (74·0–92·5)	63·2 (46·7–83·7)
Vietnam	87·3 (77·0–99·2)	67·9 (64·4–71·6)	46·3 (43·8–48·8)	21·8 (19·9–24·0)	12·9 (9·1–18·6)
Australasia					
Australia	23·1 (22·6–23·6)	14·6 (14·1–15·0)	9·9 (9·6–10·3)	6·4 (6·2–6·7)	4·7 (3·9–5·6)
New Zealand	21·5 (20·7–22·3)	16·5 (15·8–17·3)	11·1 (10·6–11·7)	7·9 (7·5–8·3)	5·8 (5·0–6·9)

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children have high mortality, resulting in selection bias.[14] This bias is expected to have a larger effect farther back in time before the survey,[33–35] which would tend to reduce the estimated trend in child mortality. Our use, in nearly all countries, of overlapping surveys to estimate the levels and trends in child mortality should substantially attenuate this effect. As described in more detail in the webappendix, we have further examined the under-5 mortality rate in HIV-positive women and HIV-negative women in the 10 years before the survey in 21 DHS with HIV testing that can be linked to the complete birth histories. The difference in the under-5 mortality rate ranges from 135 (uncertainty interval 72–200) per 1000 higher in HIV-positive women than in HIV-negative women to 73 (4–141) per 1000 lower in HIV-positive women than in HIV-negative women. This variation is related to the correlated socioeconomic status and location of HIV-positive women relative to

	1970	1980	1990	2000	2010
(Continued from previous page)					
Caribbean					
Antigua and Barbuda	65·4 (58·9–73·3)	68·5 (58·9–79·1)	64·6 (57·7–72·6)	86·5 (76·8–97·4)	74·3 (55·4–98·4)
Barbados	71·5 (65·9–77·7)	40·4 (36·9–44·7)	26·4 (23·6–29·4)	21·7 (18·9–25·1)	10·6 (8·1–13·7)
Belize	127·6 (109·6–145·0)	78·0 (71·0–85·9)	43·6 (40·0–46·9)	31·0 (28·7–34·1)	22·7 (19·2–27·8)
Cuba	38·9 (35·8–43·0)	23·3 (21·6–25·3)	13·9 (12·8–15·1)	8·6 (7·9–9·4)	5·2 (4·5–6·1)
Dominica	218·1 (208·1–228·9)	39·7 (36·1–43·5)	63·5 (58·4–69·3)	59·8 (53·7–66·1)	49·0 (36·9–64·8)
Dominican Republic	118·7 (115·5–121·9)	84·4 (82·4–86·5)	57·0 (55·7–58·5)	38·3 (37·1–39·4)	27·5 (24·6–30·7)
Grenada	80·0 (71·5–89·6)	45·0 (39·1–52·0)	26·7 (23·8–30·0)	21·6 (18·3–24·9)	11·6 (9·1–14·7)
Guyana	72·0 (67·4–76·6)	69·2 (63·8–75·2)	61·0 (57·2–64·6)	46·8 (43·9–49·9)	38·0 (32·9–44·7)
Haiti	229·6 (220·0–240·9)	198·6 (192·8–204·8)	149·2 (145·1–154·0)	99·8 (95·9–103·3)	102·6 (90·0–119·6)
Jamaica	57·0 (53·2–60·9)	45·0 (42·4–48·1)	33·9 (32·0–35·9)	25·4 (23·5–27·2)	18·4 (15·4–22·0)
Saint Lucia	77·0 (71·3–84·0)	39·1 (36·4–41·7)	23·2 (21·2–25·1)	16·4 (14·9–18·4)	11·4 (8·8–14·6)
Saint Vincent and the Grenadines	80·1 (74·6–85·9)	60·1 (55·8–65·1)	24·8 (22·2–27·9)	24·0 (21·6–26·8)	23·2 (18·9–28·8)
Suriname	71·8 (62·3–83·1)	60·5 (56·5–65·0)	46·4 (43·1–49·6)	43·7 (39·6–48·4)	35·5 (28·5–43·7)
The Bahamas	68·8 (61·5–76·3)	49·9 (45·7–54·4)	36·0 (32·8–39·6)	18·3 (16·3–21·0)	15·8 (12·8–19·5)
Trinidad and Tobago	51·6 (48·8–54·4)	37·2 (35·2–39·3)	30·2 (28·1–32·4)	31·9 (29·5–34·6)	25·4 (20·4–31·4)
Europe, central					
Albania	65·3 (50·1–84·7)	42·5 (38·3–47·3)	40·1 (37·6–42·7)	22·3 (20·5–24·1)	15·1 (12·1–19·0)
Bosnia and Herzegovina	58·6 (40·2–84·7)	34·3 (26·2–44·3)	17·7 (16·9–18·7)	10·4 (9·7–11·1)	7·9 (6·2–9·8)
Bulgaria	32·2 (29·4–35·5)	23·9 (21·9–26·0)	18·3 (16·6–20·0)	17·4 (15·9–19·0)	10·7 (8·7–13·3)
Croatia	40·8 (29·7–56·2)	24·5 (20·6–30·1)	13·4 (12·8–14·0)	8·5 (8·1–9·0)	5·4 (4·7–6·2)
Czech Republic	29·3 (26·3–32·5)	21·1 (19·5–22·9)	14·2 (13·0–15·5)	7·4 (6·7–8·3)	4·1 (3·5–5·0)
Hungary	38·0 (34·3–41·5)	25·1 (22·1–27·7)	16·7 (15·0–18·1)	10·2 (9·3–11·3)	5·5 (4·4–6·7)
Macedonia	59·6 (41·3–86·4)	40·7 (31·5–52·1)	26·2 (23·6–28·9)	18·5 (16·8–20·4)	11·8 (9·3–15·0)
Montenegro	82·6 (56·2–119·0)	45·6 (31·8–64·8)	25·1 (18·5–34·1)	13·9 (12·5–15·6)	9·4 (7·7–11·8)
Poland	36·5 (36·0–36·9)	24·9 (24·5–25·3)	19·0 (18·6–19·3)	9·6 (9·3–9·9)	6·4 (5·1–8·2)
Romania	50·4 (45·7–55·6)	36·3 (32·5–40·8)	30·4 (27·2–33·9)	22·2 (20·0–24·8)	15·2 (12·4–18·8)
Serbia	37·7 (26·0–54·6)	21·7 (15·7–30·8)	12·7 (9·6–16·6)	7·8 (7·5–8·1)	4·0 (3·5–4·6)
Slovakia	31·9 (30·8–33·0)	23·4 (22·6–24·3)	14·2 (13·5–14·9)	10·2 (9·5–10·9)	6·6 (5·1–8·6)
Slovenia	42·6 (31·5–57·9)	21·3 (18·0–25·4)	10·6 (9·9–11·3)	5·4 (4·9–5·9)	3·2 (2·6–3·8)
Europe, eastern					
Belarus	32·0 (29·4–34·9)	27·5 (25·5–29·7)	21·5 (19·9–23·1)	16·9 (15·7–18·1)	10·4 (8·8–12·4)
Estonia	23·6 (21·8–25·8)	21·8 (20·0–23·8)	18·0 (16·4–19·8)	11·0 (9·9–12·1)	6·3 (5·3–7·4)
Latvia	23·2 (21·3–25·3)	21·7 (19·8–23·7)	17·3 (15·7–19·0)	14·8 (13·5–16·3)	9·5 (7·7–11·3)
Lithuania	24·9 (23·8–26·0)	20·3 (19·4–21·2)	14·4 (13·7–15·2)	10·9 (10·2–11·6)	6·8 (5·7–7·9)
Moldova	65·0 (54·7–77·1)	56·2 (51·6–61·5)	35·1 (33·0–37·6)	23·0 (21·6–24·6)	13·7 (11·7–16·1)
Russia	35·4 (32·0–39·1)	32·8 (29·7–36·4)	26·7 (23·7–29·7)	21·6 (19·3–24·2)	14·5 (12·0–17·3)
Ukraine	30·5 (28·0–33·3)	29·2 (27·2–31·3)	21·6 (20·3–23·0)	19·7 (18·6–20·9)	15·5 (13·0–18·5)

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HIV-negative women. We have simulated the effect of this range on our estimates in view of the types of analytical methods we apply, and find that biases even in the presence of HIV seroprevalence of 20% range from underestimation of ten per 1000 to overestimation of six per 1000. Trends in the past 10–15 years are largely unaffected. Because of the enormous variation in the potential bias and, the further confounding of this association by scale-up of prevention of mother-to-child transmission and antiretroviral drugs, we have opted to not apply any standard correction to the estimated rates of child mortality.

Neonatal, postneonatal, and childhood death rates

We divided the estimates of under-5 mortality generated by GPR into estimates of neonatal (the probability of death before age 1 month), postneonatal (the probability of death before age 1 year conditional on surviving to age 1 month), and childhood (the probability of death from age 1 year to age 5 years) risks of death by use of a two-step modelling process in which we first predicted sex-specific under-5 mortality and then predicted the sex-specific neonatal, postneonatal, and childhood risks of death. We modelled the age breakdown by use of separate models for boys and girls because different levels of

	1970	1980	1990	2000	2010
(Continued from previous page)					
Europe, western					
Andorra	16·3 (11·5–23·1)	11·7 (8·3–16·6)	9·4 (6·6–13·3)	7·1 (5·0–10·1)	4·9 (3·4–6·9)
Austria	29·4 (28·5–30·2)	17·2 (16·5–17·8)	10·8 (10·3–11·3)	6·1 (5·7–6·5)	3·9 (3·3–4·6)
Belgium	25·5 (24·8–26·2)	15·3 (14·7–15·8)	10·2 (9·8–10·7)	6·2 (5·9–6·5)	4·3 (3·6–5·3)
Cyprus	26·6 (22·5–31·1)	20·0 (17·9–22·1)	12·8 (11·7–14·0)	6·6 (5·9–7·3)	2·8 (2·3–3·4)
Denmark	16·4 (15·8–17·1)	10·1 (9·6–10·7)	8·7 (8·2–9·2)	5·8 (5·5–6·2)	4·1 (3·4–4·9)
Finland	15·9 (15·1–16·8)	8·0 (7·5–8·5)	7·1 (6·6–7·5)	4·5 (4·1–4·8)	3·0 (2·5–3·7)
France	19·2 (19·0–19·5)	14·7 (14·4–14·9)	9·5 (9·3–9·7)	5·4 (5·3–5·6)	3·9 (3·2–4·8)
Germany	25·8 (25·5–26·1)	14·0 (13·8–14·3)	8·9 (8·7–9·1)	5·2 (5·0–5·3)	4·1 (3·5–4·8)
Greece	28·7 (27·8–29·4)	19·0 (18·3–19·7)	11·2 (10·6–11·6)	6·9 (6·6–7·3)	3·7 (3·0–4·5)
Iceland	16·4 (14·9–18·0)	9·7 (8·6–10·9)	6·7 (5·9–7·7)	4·1 (3·5–4·8)	2·6 (2·1–3·3)
Ireland	23·4 (22·5–24·3)	14·9 (14·3–15·6)	9·9 (9·2–10·5)	7·4 (7·0–7·8)	4·2 (3·5–5·1)
Israel	27·2 (26·3–28·2)	19·0 (18·3–19·7)	12·1 (11·6–12·6)	6·9 (6·6–7·3)	4·7 (3·9–5·7)
Italy	34·3 (34·0–34·7)	17·0 (16·7–17·3)	10·0 (9·8–10·2)	6·4 (6·2–6·6)	3·3 (2·8–4·0)
Luxembourg	23·3 (21·5–25·7)	13·9 (12·5–15·4)	9·1 (8·2–10·2)	5·1 (4·6–5·8)	2·9 (2·3–3·7)
Malta	31·5 (28·8–34·5)	16·9 (15·2–18·7)	11·3 (10·0–12·8)	7·2 (6·1–8·4)	5·2 (4·0–6·9)
Netherlands	16·4 (16·0–16·9)	11·4 (11·0–11·9)	8·9 (8·6–9·2)	6·5 (6·3–6·8)	4·3 (3·7–4·9)
Norway	15·8 (15·1–16·4)	10·5 (9·9–11·0)	8·8 (8·4–9·3)	5·0 (4·7–5·3)	3·4 (2·8–4·0)
Portugal	74·4 (73·2–75·6)	29·4 (28·6–30·2)	15·0 (14·4–15·6)	8·0 (7·6–8·5)	3·3 (2·6–4·3)
Spain	32·8 (32·4–33·2)	14·3 (14·1–14·6)	9·2 (9·0–9·5)	5·7 (5·5–5·9)	3·8 (3·1–4·6)
Sweden	12·7 (12·2–13·3)	8·9 (8·5–9·3)	7·2 (6·9–7·6)	4·9 (4·6–5·2)	2·7 (2·2–3·3)
Switzerland	18·7 (18·1–19·4)	10·6 (10·1–11·1)	8·8 (8·4–9·2)	6·0 (5·7–6·3)	4·2 (3·5–5·0)
UK	21·8 (21·5–22·1)	15·2 (15·0–15·5)	9·7 (9·5–9·9)	6·8 (6·6–6·9)	5·3 (4·5–6·2)
Latin America, Andean					
Bolivia	220·7 (212·7–229·9)	153·0 (148·1–158·0)	103·9 (100·3–107·5)	62·2 (58·6–65·6)	46·7 (39·9–57·0)
Ecuador	129·1 (125·8–132·7)	82·5 (80·4–84·6)	50·1 (48·7–51·8)	34·0 (32·1–35·7)	21·0 (18·0–24·3)
Peru	159·0 (154·8–163·2)	114·1 (111·6–117·0)	72·7 (70·9–74·6)	40·7 (39·2–42·3)	24·6 (21·6–28·9)
Latin America, central					
Colombia	86·8 (84·0–89·8)	52·8 (51·2–54·4)	33·3 (32·0–34·5)	24·7 (23·6–25·8)	15·3 (13·1–17·7)
Costa Rica	73·6 (70·5–77·2)	33·1 (31·5–34·8)	21·4 (20·2–22·6)	14·8 (13·7–16·0)	8·7 (7·3–10·2)
El Salvador	160·4 (152·6–168·1)	110·7 (106·5–116·3)	59·4 (56·6–62·1)	34·2 (32·3–36·3)	19·2 (16·7–22·3)
Guatemala	175·1 (169·8–181·1)	120·7 (117·8–124·1)	75·8 (73·6–77·7)	49·9 (47·7–52·5)	31·9 (27·6–36·9)
Honduras	149·5 (142·3–158·5)	92·9 (90·3–95·8)	56·3 (54·2–58·1)	36·6 (35·3–38·2)	22·6 (19·7–25·4)
Mexico	107·5 (104·3–110·6)	70·0 (67·9–72·2)	41·9 (40·2–43·8)	25·8 (24·4–27·4)	16·6 (14·7–18·4)
Nicaragua	166·2 (160·2–172·7)	102·3 (99·2–105·2)	63·9 (62·0–66·0)	39·3 (37·8–40·8)	26·6 (23·1–31·0)
Panama	54·7 (52·5–57·2)	36·8 (35·2–38·7)	27·8 (26·3–29·3)	23·3 (21·7–25·1)	18·0 (15·3–20·9)
Venezuela	58·8 (55·6–62·2)	38·6 (36·4–40·9)	29·4 (27·5–31·1)	23·2 (21·5–25·0)	16·1 (13·2–19·4)
Latin America, southern					
Argentina	72·6 (72·0–73·3)	37·7 (37·3–38·2)	28·0 (27·6–28·3)	19·7 (19·4–20·0)	12·9 (10·5–15·8)
Chile	92·1 (85·4–98·8)	37·3 (34·4–40·3)	18·2 (16·7–19·8)	11·1 (10·3–12·1)	6·5 (5·4–7·9)
Uruguay	56·0 (54·5–57·7)	40·7 (39·2–42·1)	22·2 (21·2–23·3)	16·5 (15·7–17·3)	11·5 (9·3–14·4)
Latin America, tropical					
Brazil	120·8 (117·2–124·7)	83·6 (80·7–86·1)	52·0 (50·3–54·1)	30·8 (28·5–32·9)	19·9 (17·3–23·0)
Paraguay	73·9 (71·4–76·9)	56·6 (54·9–58·7)	37·7 (36·1–39·1)	27·7 (26·2–29·5)	20·9 (17·9–24·8)

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mortality at each age are seen between the sexes, especially in the neonatal period in which male mortality generally exceeds female mortality.[36,37] The level of mortality at each age for both sexes combined is a function of the level for each sex and the relative size of the population of each sex; modelling mortality for the finer age groups cannot be based on combined under-5 mortality alone.

We estimated sex-specific under-5 mortality by modelling the relation between the ratio of male under-5 mortality to female under-5 mortality and level of mortality for both sexes combined by use of vital registration data

	1970	1980	1990	2000	2010
(Continued from previous page)					
North Africa and Middle East					
Algeria	172·4 (162·2–183·5)	100·9 (96·0–106·6)	52·4 (49·8–55·1)	34·1 (31·3–37·2)	19·3 (14·3–25·1)
Bahrain	70·2 (63·3–78·7)	29·6 (26·8–32·5)	19·0 (17·2–21·0)	12·2 (10·9–13·5)	7·4 (6·1–8·8)
Egypt	236·7 (231·2–242·8)	157·9 (154·8–160·9)	85·4 (83·7–87·0)	45·6 (44·4–46·7)	24·7 (22·4–27·4)
Iran	183·1 (162·3–211·5)	107·2 (100·7–114·2)	65·5 (62·1–69·7)	46·7 (43·2–50·8)	31·1 (24·2–38·9)
Iraq	111·2 (98·4–126·9)	78·2 (73·3–83·8)	58·4 (55·7–61·7)	42·7 (40·2–45·0)	31·6 (26·9–36·6)
Jordan	86·6 (82·5–91·2)	54·4 (52·3–56·6)	33·4 (32·1–34·8)	23·7 (22·6–24·9)	14·1 (11·6–16·7)
Kuwait	52·8 (47·8–58·3)	35·0 (31·2–39·5)	12·8 (11·3–14·8)	12·4 (11·0–14·1)	7·8 (6·0–10·3)
Lebanon	68·0 (60·3–77·1)	43·4 (40·4–47·0)	31·4 (28·5–34·5)	13·8 (12·5–15·3)	10·2 (7·3–14·4)
Libya	118·4 (111·8–125·2)	61·8 (58·6–65·1)	37·6 (35·6–39·8)	22·1 (19·4–25·0)	12·9 (9·9–16·6)
Morocco	178·2 (173·3–183·1)	124·0 (121·0–126·9)	76·9 (74·8–78·7)	50·5 (48·6–52·3)	32·4 (27·9–37·7)
Occupied Palestinian territories	116·1 (90·1–147·2)	70·6 (62·5–79·6)	41·9 (38·9–45·0)	29·3 (26·1–32·8)	22·1 (17·8–27·5)
Oman	190·0 (165·8–216·3)	97·6 (85·3–115·2)	37·1 (30·5–45·5)	15·9 (11·7–21·9)	9·3 (6·6–13·4)
Qatar	52·3 (43·6–64·4)	27·5 (24·6–30·9)	15·9 (14·5–17·2)	12·8 (11·6–14·1)	10·5 (8·8–12·6)
Saudi Arabia	204·9 (167·3–260·1)	71·9 (63·3–81·9)	29·5 (24·8–35·2)	21·8 (18·0–26·8)	15·0 (11·5–19·8)
Syria	85·3 (81·3–89·4)	48·2 (45·8–50·4)	31·8 (30·6–33·2)	18·8 (17·7–19·8)	11·4 (9·6–13·7)
Tunisia	147·4 (142·2–153·4)	80·7 (78·3–83·6)	47·4 (45·4–49·8)	27·2 (24·5–29·8)	15·2 (11·8–19·4)
Turkey	194·1 (185·5–203·8)	123·9 (119·3–128·7)	71·3 (68·4–74·2)	40·0 (37·7–42·5)	29·2 (22·6–39·1)
United Arab Emirates	81·1 (71·9–91·1)	38·1 (32·3–45·4)	16·1 (12·9–20·2)	7·0 (5·2–9·9)	3·0 (2·1–4·3)
Yemen	285·1 (275·0–296·3)	188·1 (181·9–195·5)	128·3 (123·1–133·3)	93·2 (88·7–98·1)	60·0 (50·8–69·6)
North America, high income					
Canada	26·1 (25·7–26·6)	12·9 (12·6–13·2)	8·8 (8·6–9·1)	6·6 (6·4–6·8)	4·9 (4·0–6·0)
USA	25·7 (25·5–25·9)	16·0 (15·8–16·1)	11·6 (11·5–11·7)	8·3 (8·2–8·4)	6·7 (5·8–7·6)
Oceania					
Fiji	55·0 (52·0–58·3)	42·1 (38·0–46·4)	35·2 (30·5–40·7)	30·8 (26·3–36·4)	26·6 (21·6–32·8)
Federated States of Micronesia	115·6 (87·4–147·0)	86·5 (73·3–102·3)	56·3 (48·5–66·9)	37·7 (29·4–48·0)	25·7 (19·4–34·1)
Kiribati	134·3 (117·1–152·8)	102·9 (84·8–125·1)	75·8 (68·6–83·6)	59·2 (53·4–65·3)	46·4 (36·1–60·3)
Marshall Islands	49·8 (38·9–64·2)	50·0 (41·3–60·4)	50·9 (43·8–58·0)	47·3 (42·1–54·6)	37·9 (30·9–45·3)
Papua New Guinea	133·1 (121·1–147·3)	106·0 (99·5–113·8)	100·2 (93·1–108·0)	91·7 (77·6–108·3)	82·7 (65·7–106·9)
Samoa	57·0 (51·9–62·9)	36·5 (31·2–42·0)	29·6 (24·9–35·3)	24·5 (21·3–28·2)	18·6 (15·3–22·8)
Solomon Islands	89·2 (78·6–101·4)	56·3 (47·0–67·6)	38·4 (33·8–43·5)	34·6 (31·3–38·6)	29·4 (23·9–35·6)
Tonga	36·5 (32·4–41·6)	29·5 (25·5–33·9)	25·8 (20·7–32·6)	22·2 (17·6–28·5)	19·2 (15·0–24·6)
Vanuatu	116·2 (100·0–135·1)	81·0 (71·5–91·4)	52·8 (45·6–60·2)	34·9 (29·2–41·5)	23·0 (18·3–29·6)
Sub-Saharan Africa, central					
Angola	305·9 (267·8–356·3)	266·3 (250·8–283·4)	236·3 (222·6–248·2)	193·6 (181·1–206·7)	134·8 (113·8–155·1)
Central African Republic	205·6 (193·8–216·1)	178·7 (172·3–185·3)	163·8 (158·1–170·1)	153·5 (141·2–165·8)	138·1 (117·2–160·9)
Congo	144·9 (127·6–163·9)	122·4 (114·5–131·7)	109·4 (103·5–115·3)	114·5 (107·6–122·2)	107·5 (92·4–124·1)
Democratic Republic of the Congo	241·6 (216·1–270·2)	207·8 (198·0–217·9)	182·9 (176·1–190·0)	165·1 (154·3–176·0)	131·1 (117·2–145·6)
Equatorial Guinea	209·6 (183·8–238·8)	191·1 (180·5–201·7)	178·7 (169·4–187·7)	180·3 (166·7–195·7)	180·1 (155·5–210·8)
Gabon	167·8 (152·0–185·5)	118·1 (112·5–123·6)	93·8 (89·3–97·6)	83·1 (77·3–89·3)	68·3 (58·5–79·8)
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(3253 points) and DHS complete birth history data (525 points) from 147 countries. This model produced predictions of the ratio of male to female under-5 mortality that were then combined with the sex ratio at birth (from UNPD[10] if available, and assuming 1·05 if not available) to form a system of two equations that could be solved to generate estimates of under-5 mortality for boys and under-5 mortality for girls. This model included year as a covariate, and regional and national random effects on intercept and slope.

We then modelled the probability of an under-5 death occurring during the neonatal, postneonatal, and childhood periods to the sex-specific under-5 mortality rate, again by use of data from vital registration systems (1234 points) and DHS complete birth histories (526 points) from 122 countries. These models also included regional

	1970	1980	1990	2000	2010
(Continued from previous page)					
Sub-Saharan Africa, east					
Burundi	229·8 (219·7–241·0)	192·1 (184·1–199·0)	175·8 (166·5–187·2)	150·1 (141·5–158·6)	130·3 (115·1–148·0)
Comoros	197·8 (182·1–214·4)	159·5 (153·3–166·1)	115·6 (110·9–120·6)	83·4 (75·1–92·8)	61·5 (52·9–72·1)
Djibouti	116·2 (100·2–133·8)	111·3 (103·5–119·2)	110·0 (104·6–116·1)	89·6 (84·8–94·4)	66·7 (58·9–74·6)
Eritrea	232·0 (217·7–248·5)	185·8 (178·3–191·8)	142·7 (138·2–148·4)	100·6 (93·0–108·7)	78·2 (66·9–94·5)
Ethiopia	255·4 (240·1–270·5)	237·1 (229·1–245·6)	201·9 (194·9–209·3)	136·9 (130·7–142·3)	101·0 (89·3–117·6)
Kenya	142·0 (137·2–146·7)	112·2 (109·3–115·0)	103·8 (101·2–106·8)	100·4 (95·9–104·4)	82·2 (72·0–91·9)
Madagascar	188·4 (179·0–197·4)	180·8 (174·5–186·7)	158·0 (153·0–163·2)	104·5 (99·3–109·6)	70·5 (62·9–79·7)
Malawi	343·9 (330·3–358·1)	260·6 (252·3–270·1)	211·3 (204·8–217·6)	148·4 (143·4–153·4)	96·8 (84·3–111·6)
Mozambique	271·3 (255·9–287·9)	231·5 (223·2–241·1)	226·6 (218·7–236·1)	163·5 (156·1–170·8)	133·7 (114·3–157·9)
Rwanda	232·3 (222·9–241·5)	203·7 (194·5–213·9)	169·4 (161·7–177·6)	166·0 (158·0–174·6)	102·9 (88·2–118·6)
Somalia	206·3 (178·7–240·6)	189·0 (171·0–205·4)	174·2 (164·8–184·1)	145·1 (137·3–153·3)	111·4 (98·4–123·4)
Sudan	152·1 (146·8–157·3)	141·2 (136·4–146·2)	118·1 (111·4–124·3)	103·7 (89·7–118·8)	92·1 (77·5–110·3)
Tanzania	207·7 (199·5–215·9)	173·2 (167·9–178·0)	153·1 (147·9–158·0)	127·1 (121·7–133·0)	98·4 (85·6–116·2)
Uganda	190·4 (183·8–196·3)	185·9 (181·5–190·7)	167·8 (163·5–172·1)	141·1 (136·8–145·6)	116·7 (105·0–127·5)
Zambia	181·8 (175·0–189·4)	168·3 (163·2–173·4)	172·8 (167·9–178·1)	143·4 (138·4–149·1)	118·8 (106·3–134·0)
Sub-Saharan Africa, southern					
Botswana	98·4 (92·4–103·8)	62·1 (59·1–65·6)	54·2 (48·5–61·1)	59·0 (50·3–69·8)	49·1 (37·7–62·2)
Lesotho	172·0 (160·9–182·3)	113·9 (109·1–118·8)	94·5 (90·8–98·2)	104·9 (100·2–109·7)	96·8 (78·8–115·6)
Namibia	111·5 (105·1–118·2)	95·4 (91·7–99·6)	72·0 (69·3–75·2)	62·1 (59·2–65·7)	54·9 (45·6–64·4)
South Africa	132·8 (119·2–146·8)	86·8 (81·2–92·2)	57·6 (54·2–61·1)	37·3 (37·0–37·6)	50·9 (43·2–60·3)
Swaziland	188·0 (167·2–210·3)	122·3 (115·0–130·5)	73·7 (69·3–78·4)	99·3 (93·7–106·4)	101·2 (79·5–126·0)
Zimbabwe	111·3 (106·5–116·4)	93·2 (89·9–96·9)	73·3 (70·4–76·1)	73·7 (70·1–77·4)	70·4 (57·3–86·1)
Sub-Saharan Africa, west					
Benin	280·6 (269·5–293·1)	222·1 (215·0–228·1)	176·5 (172·0–180·9)	137·0 (132·7–141·8)	100·7 (89·3–111·3)
Burkina Faso	319·5 (305·5–334·2)	250·2 (242·5–258·0)	204·7 (198·2–211·0)	172·4 (165·4–179·7)	133·7 (114·3–155·8)
Cameroon	214·3 (205·8–223·6)	174·4 (169·1–181·0)	143·5 (138·4–148·3)	140·3 (134·1–146·5)	114·4 (94·3–140·1)
Cape Verde	116·2 (107·0–130·5)	79·3 (74·5–83·3)	58·2 (54·8–61·3)	45·4 (40·8–51·5)	32·3 (26·9–39·1)
Chad	260·0 (243·3–276·9)	245·4 (238·6–253·2)	210·8 (204·9–216·5)	189·0 (182·2–196·6)	168·7 (149·1–190·0)
Côte d'Ivoire	225·3 (217·1–234·8)	170·4 (165·0–175·5)	149·2 (145·3–153·6)	128·7 (123·7–133·4)	107·3 (95·3–121·5)
Ghana	174·7 (170·0–179·6)	149·4 (146·3–152·9)	122·2 (119·5–125·0)	98·6 (96·1–101·1)	77·5 (72·2–83·4)
Guinea	318·9 (300·7–336·9)	274·0 (266·3–281·2)	226·8 (220·9–232·5)	174·2 (168·4–180·2)	132·7 (119·3–146·1)
Guinea-Bissau	295·0 (263·4–330·2)	262·4 (250·5–275·9)	233·2 (224·9–242·0)	191·1 (182·4–199·6)	158·6 (143·3–177·9)
Liberia	271·6 (257·9–285·6)	240·6 (227·8–252·7)	235·4 (223·6–247·7)	172·2 (163·4–181·5)	98·9 (86·6–113·0)
Mali	370·3 (359·4–382·3)	301·7 (294·3–309·7)	254·0 (247·2–260·0)	212·4 (205·7–219·3)	161·2 (142·6–179·5)
Mauritania	189·9 (182·6–196·7)	143·1 (138·9–147·2)	112·8 (109·4–116·2)	100·3 (96·4–104·7)	85·5 (77·8–95·0)
Niger	354·7 (341·4–368·2)	326·5 (317·1–336·2)	297·0 (289·2–305·3)	223·7 (216·0–231·5)	161·1 (142·0–185·3)
Nigeria	224·4 (214·1–236·5)	200·5 (192·2–208·7)	194·1 (187·1–201·8)	177·0 (169·2–185·8)	157·0 (140·9–174·0)
Sao Tome and Principe	132·1 (119·1–146·3)	114·8 (106·6–124·7)	109·4 (101·5–118·3)	74·9 (67·4–82·8)	62·2 (50·2–76·2)
Senegal	278·5 (270·6–287·1)	203·1 (197·4–208·2)	146·5 (142·0–150·4)	123·5 (119·1–128·2)	86·5 (77·7–97·0)
Sierra Leone	351·4 (325·7–378·8)	292·4 (279·7–306·1)	241·6 (232·7–250·7)	196·9 (188·8–207·2)	139·1 (124·7–152·8)
The Gambia	291·0 (263·8–324·0)	209·8 (195·4–224·6)	146·0 (138·0–154·1)	120·8 (113·9–128·1)	80·7 (69·5–93·7)
Togo	225·8 (218·4–233·8)	175·0 (170·5–180·2)	142·4 (137·9–147·5)	114·0 (108·3–119·6)	91·4 (82·1–101·8)

Countries are grouped into 21 regions on the basis of epidemiological profiles and geography. Under-5 mortality is defined as the probability of death between birth and age 5 years.

Table 1: **Under-5 mortality (uncertainty interval) per 1000, by decade**

and national random effects on both intercept and slope and the resulting probabilities were scaled to sum to 1·0 and converted to age-specific probabilities of death conditional on survival to the beginning of the period. For both steps, a range of different model specifications were explored and out-of-sample validity tests undertaken. The best performing models from these analyses were implemented. In out-of-sample predictive validity tests, with the models fitted repeatedly with data from random sets of 80% of countries, the median relative error in the

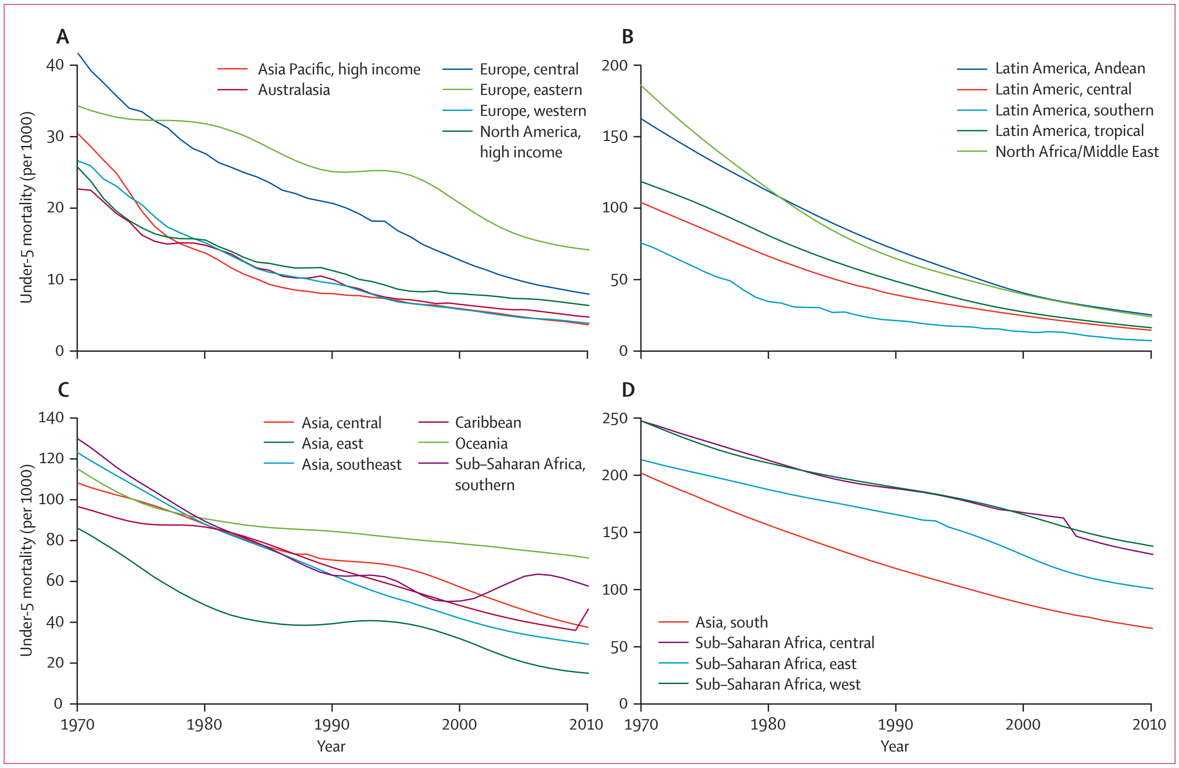

***Figure 4*: Under-5 mortality from 1970 to 2010, by region**
Under-5 mortality is defined as the probability of death between birth and age 5 years.

first model for estimates from the knocked out countries was 2·4% for boys and 3·1% for girls; in the same predictive validity tests for the second model, the median relative error was 7·1% for the neonatal model, 9·1% for the postneonatal model, and 8·8% for the childhood model (the results of other predictive validity tests are provided in webappendix pp 9–10). The uncertainty from the GPR process was propagated through these two models to estimate the uncertainty in our final neonatal, postneonatal, and childhood mortality estimates (further details are provided in webappendix p 8).

Aggregate numbers of deaths

To compute aggregate numbers of deaths for each country, we combined estimates of neonatal and postneonatal mortality to obtain an estimate of the infant mortality rate. We obtained deaths in infants younger than 1 year by applying the infant mortality rate (the probability of death from birth to age 1 year) to the number of births in the current and previous years with the following formula (which gives more weight to the births in the current year because most deaths in infants younger than 1 year occur in the first few months of life):

$$_{1}D_{0(t)}=B_{(t)}*\left(1-{_1a_{0(t)}}\right)*IMR_{(t)}+B_{(t-1)}*{_1a_{0(t-1)}}*IMR_{(t-1)}$$

where $_1D_0$ represents deaths under age 1 year, t is the current year, B is births, $_1a_0$ is the mean time lived by a child who dies under age 1 year, and IMR is the infant mortality rate. We used a similar method to estimate deaths in children aged between 1 year and 5 years.

Deaths in children younger than 5 years were the sum of deaths in infants younger than 1 year and deaths in children aged between 1 year and 5 years. This method of computing deaths in children younger than 5 years is more accurate than is use of under-5 mortality and births in the current year, because it better accounts for changing cohort sizes and mortality rates from year to year. We validated this method by comparing it with other approaches (ie, use of under-5 mortality and births, and by converting infant and childhood probabilities of death to mortality rates and multiplying by population estimates) in countries with complete vital registration data.

In addition to computing under-5 mortality and number of deaths by country, we generated results for 21 regions of the world. These regions were grouped on the basis of epidemiological profiles and geography (see webappendix p 205 for regions).[38] Analyses were undertaken in Stata (version 11.0), R citation (version 2.9.0), and Python (version 2.5). We used the PyMC package (version 2.0) in Python to implement the Markov chain Monte Carlo sampling.

Role of the funding source

The sponsors of the study had no role in study design, data collection, data analysis, data interpretation, or

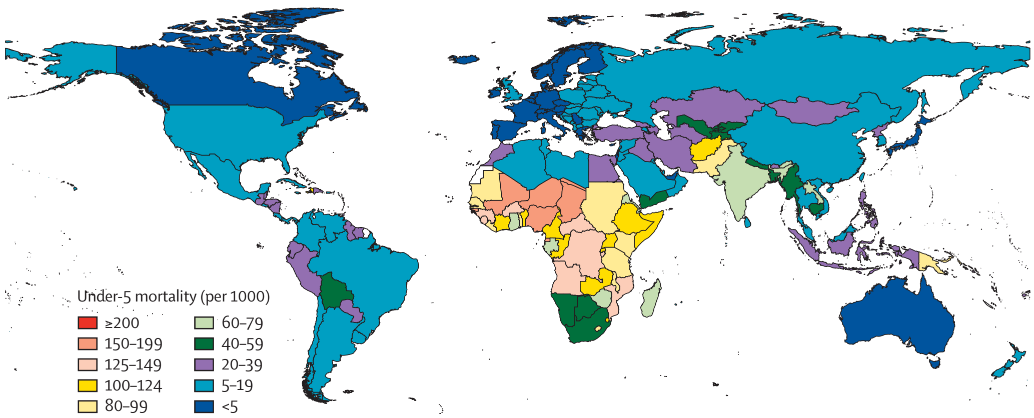

Figure 5: **Under-5 mortality in 2010**
Under-5 mortality is defined as the probability of death between birth and age 5 years.

writing of the report. The corresponding author had full access to all data in the study and had final responsibility for the decision to submit for publication.

Results

Table 1 shows our estimates and uncertainty intervals for under-5 mortality in all 187 countries every 10 years from 1970 to 2010. A full time series of results is available for each country in the webappendix (pp 18–204); four examples of these data plots are shown in figure 1. Norway is an example of a country with complete vital registration data. Our GPR model produced estimates that were very close to the observed data with narrow uncertainty intervals, representing sampling uncertainty only (figure 1). El Salvador has data from survey and vital registration systems. The vital registration data are biased downwards, suggesting incomplete registration of child deaths. Nevertheless, the survey estimates are quite consistent with each other, and fairly consistent with the trend in the vital registration data. The GPR estimates track at the level of the survey estimates and have narrow uncertainty intervals. El Salvador is on course to meet MDG 4. Few data were available for Laos. The uncertainty intervals are wide, and broaden as the estimates move further away from the data. Liberia is not on track to meet MDG 4, but has recently shown a steep decline in under-5 mortality, falling from 235 (uncertainty interval 224–248) per 1000 in 1990 to 99 (870–113) per 1000 by 2010. Liberia had data from various sources, including DHS and a malaria indicator survey (MIS). The GPR model tracks the DHS data more closely than the MIS data because there is less non-sampling error in DHS data (see webappendix pp 6–7).

In 2010, we estimate that there will be 7·7 million child deaths worldwide, a decrease from 16 million in 1970 and 11·9 million in 1990 (figure 2). These 7·7 million deaths comprise 3·1 million neonatal deaths, 2·3 million postneonatal deaths, and 2·3 million deaths in children aged 1–4 years. Between 1970 and 2010, the number of deaths in children younger than 5 years has fallen by more than 52%, even though the total number of births has increased by 16% in the same period.[10] Our estimates are substantially lower than those produced by UNICEF[9] and UNPD[10] and those reported in the 2007 study by Murray and colleagues.[1] The most recent estimates provided by UNICEF are from 2008; we estimated that there were 7·95 million deaths in 2008 compared with UNICEF's estimation of 8·77 million. Worldwide, this represents a 30% decline since 1990. Compared with the 2008 UNICEF estimates, our estimates were higher for 73 countries and lower for 110 countries. Where our estimates were lower than UNICEF's, the most substantial differences occurred for the Democratic Republic of the Congo, Afghanistan, Nigeria, Kenya, Angola, China, Burma, Somalia, Pakistan, and Burkina Faso. In most cases, the differences were a result of the more recent data used in our analysis. In the case of Afghanistan, UNICEF estimated child mortality without taking into account the more recently available data sources.

Figure 3 shows worldwide neonatal, postneonatal, and childhood mortality rates from 1970 to 2010. Rates in all three age components of under-5 mortality are declining. Neonatal mortality has fallen by 57%, from 53 (uncertainty interval 42–65) per 1000 in 1970 to 23 (18–28) per 1000 in 2010; postneonatal mortality has declined by 62% and childhood mortality by 60% during this period. These reductions equate to rates of decline of 2·1%, 2·3%, and 2·2% per year in the neonatal, postneonatal, and childhood periods, respectively. Although the absolute decreases in the rates of all three components of under-5 mortality are similar, the higher rates of neonatal mortality in each year mean that the relative share of deaths that are caused by neonatal causes has increased from 38·9% in 1970 to 40·7% in 2010. Table 2 provides

	1990			2010		
	Neonatal	Postneonatal	Childhood	Neonatal	Postneonatal	Childhood
Asia Pacific, high income						
Brunei	6·9 (3·9–9·6)	3·2 (1·3–5·7)	1·4 (0·5–3·7)	4·3 (2·1–7·1)	2·2 (0·8–4·2)	0·9 (0·3–2·6)
Japan	3·4 (2·5–4·2)	2·3 (1·6–2·9)	1·0 (0·6–1·7)	1·5 (1·0–2·0)	1·3 (0·9–1·7)	0·5 (0·3–0·9)
Singapore	4·6 (3·6–5·5)	2·2 (1·6–2·9)	1·0 (0·6–1·6)	1·3 (0·8–1·9)	0·9 (0·6–1·2)	0·4 (0·2–0·7)
South Korea	6·8 (3·5–10·3)	3·1 (1·2–6·1)	1·4 (0·5–3·8)	2·9 (1·3–5·0)	1·6 (0·6–3·3)	0·7 (0·2–1·9)
Asia, central						
Armenia	22·7 (18·1–28·3)	22·7 (18·4–26·8)	6·3 (4·1–9·6)	11·6 (9·0–14·2)	5·7 (3·7–8·2)	2·1 (1·2–3·7)
Azerbaijan	30·1 (23·9–37·3)	38·2 (31·5–44·5)	12·2 (8·4–18·0)	17·2 (13·5–21·9)	12·3 (8·3–17·6)	4·6 (2·7–7·4)
Georgia	20·3 (11·7–30·7)	18·4 (9·7–26·8)	6·7 (2·9–14·7)	13·1 (7·4–19·3)	7·7 (3·4–14·1)	3·2 (1·1–7·9)
Kazakhstan	22·0 (17·4–27·8)	24·6 (19·8–28·7)	7·5 (4·9–11·3)	15·3 (11·5–19·7)	12·2 (8·2–17·5)	4·1 (2·5–7·1)
Kyrgyzstan	28·3 (22·5–35·5)	31·9 (26·0–37·0)	10·8 (7·3–16·2)	20·7 (16·1–25·6)	16·4 (11·5–21·1)	5·9 (3·6–9·7)
Mongolia	33·0 (19·5–53·6)	48·4 (28·9–63·5)	16·0 (7·7–31·1)	16·7 (9·5–24·8)	12·5 (6·2–19·9)	4·9 (1·9–10·9)
Tajikistan	35·7 (21·6–59·1)	57·7 (36·2–75·3)	18·8 (9·3–36·7)	21·6 (12·8–34·4)	21·3 (11·6–32·1)	7·6 (3·5–16·5)
Turkmenistan	33·5 (20·1–56·1)	51·3 (32·5–68·0)	16·8 (8·3–33·3)	13·7 (8·0–21·9)	9·0 (3·9–16·5)	3·6 (1·3–9·4)
Uzbekistan	23·6 (17·9–30·3)	27·2 (21·8–32·0)	16·5 (11·5–23·2)	17·8 (13·1–23·1)	15·8 (11·0–20·9)	10·5 (6·6–15·7)
Asia, east						
China	25·3 (16·0–33·4)	11·6 (5·4–19·7)	3·1 (1·2–7·9)	9·4 (5·1–13·5)	4·7 (1·8–8·2)	1·3 (0·4–3·8)
North Korea	32·7 (21·4–41·8)	15·0 (7·0–25·2)	3·9 (1·5–9·5)	21·1 (13·4–27·5)	9·9 (4·5–16·9)	2·6 (1·0–6·8)
Taiwan	5·3 (3·0–7·4)	2·8 (1·1–4·9)	0·8 (0·3–2·4)	3·6 (1·9–5·3)	2·0 (0·7–3·5)	0·6 (0·2–1·8)
Asia, south						
Afghanistan	69·8 (44·4–100·5)	49·0 (28·4–71·5)	54·4 (29·6–84·6)	56·0 (35·1–80·2)	35·8 (20·2–54·0)	34·7 (17·7–57·8)
Bangladesh	64·5 (52·1–76·4)	37·9 (30·0–45·0)	43·9 (31·9–57·9)	31·3 (25·4–36·9)	14·2 (10·9–17·6)	11·4 (7·5–16·6)
Bhutan	63·7 (40·9–91·1)	42·9 (24·8–64·1)	45·7 (24·4–71·8)	30·1 (19·1–41·5)	14·5 (7·2–23·8)	10·4 (4·5–20·2)
India	53·9 (43·4–64·5)	31·4 (24·8–37·7)	33·5 (24·1–45·4)	34·3 (27·7–40·8)	15·9 (12·1–19·7)	13·6 (9·0–19·7)
Nepal	59·1 (47·2–71·5)	40·0 (31·9–47·6)	45·0 (33·3–59·7)	25·4 (20·5–30·9)	12·7 (9·5–16·3)	10·0 (6·5–15·2)
Pakistan	54·8 (44·9–64·3)	36·2 (28·8–42·4)	26·7 (18·5–37·3)	42·7 (34·8–52·1)	24·3 (18·3–31·3)	15·4 (9·6–23·9)
Asia, southeast						
Cambodia	41·5 (32·5–51·7)	46·2 (38·0–54·5)	38·7 (28·0–51·0)	26·2 (18·7–35·9)	22·8 (15·3–33·9)	12·0 (5·9–23·6)
Burma	40·5 (23·3–62·9)	40·0 (22·3–57·5)	44·9 (22·5–69·7)	24·4 (14·4–38·5)	17·7 (8·7–30·9)	13·9 (5·8–28·0)
Indonesia	27·5 (21·5–33·8)	25·8 (20·8–30·4)	20·0 (14·1–27·4)	17·8 (14·0–22·2)	12·5 (9·4–15·8)	6·8 (4·3–10·4)
Laos	44·8 (26·8–71·2)	47·9 (28·3–71·1)	59·3 (33·4–87·4)	28·3 (15·8–46·5)	22·2 (10·4–39·0)	19·4 (7·2–38·7)
Malaysia	9·5 (7·5–11·4)	4·5 (3·3–5·8)	2·5 (1·5–4·0)	3·6 (2·9–4·6)	1·1 (0·7–1·7)	0·4 (0·2–0·8)
Maldives	33·3 (19·8–51·5)	29·3 (16·6–43·6)	28·7 (15·3–46·9)	9·0 (5·4–12·5)	3·6 (1·3–7·2)	1·5 (0·5–4·6)
Mauritius	15·3 (12·6–17·9)	7·1 (5·1–9·1)	2·2 (1·4–3·6)	9·3 (7·5–11·1)	2·9 (1·8–4·5)	0·7 (0·4–1·5)
Philippines	20·2 (15·0–25·8)	16·9 (13·4–20·5)	18·1 (12·8–24·3)	13·3 (9·7–17·0)	8·5 (6·0–11·3)	7·0 (4·5–10·8)
Seychelles	14·7 (8·7–21·1)	7·8 (3·6–13·3)	4·3 (1·7–9·9)	9·9 (5·5–15·3)	4·2 (1·5–8·6)	1·9 (0·5–5·6)
Sri Lanka	19·0 (15·1–23·5)	9·6 (7·3–12·3)	7·2 (4·7–10·9)	7·1 (5·0–10·2)	2·2 (1·3–3·8)	0·8 (0·3–1·9)
Thailand	14·8 (12·1–17·1)	5·7 (4·2–7·3)	2·9 (1·8–4·7)	6·5 (5·2–7·9)	1·8 (1·1–2·6)	0·7 (0·3–1·3)
Timor-Leste	36·2 (21·4–57·2)	33·6 (19·2–49·7)	35·2 (19·3–55·6)	26·8 (15·6–42·3)	20·7 (10·1–33·1)	17·0 (7·2–33·9)
Vietnam	20·9 (15·9–26·2)	11·4 (8·8–14·4)	14·7 (10·1–20·4)	8·3 (6·0–11·8)	2·5 (1·4–4·3)	2·1 (1·0–4·4)
Australasia						
Australia	6·0 (4·7–7·1)	3·0 (2·1–4·0)	1·0 (0·6–1·7)	2·8 (2·0–3·6)	1·5 (1·0–2·1)	0·5 (0·3–0·9)
New Zealand	5·4 (4·1–6·9)	4·6 (3·4–5·8)	1·1 (0·7–1·9)	2·7 (1·9–3·6)	2·5 (1·7–3·2)	0·6 (0·3–1·0)

(Continues on next page)

estimates and uncertainty intervals for neonatal, postneonatal, and childhood mortality in all 187 countries for 1990 and 2010.

Webappendix p 206 shows the annual number of deaths in children younger than 5 years in the 21 regions. As worldwide child mortality has fallen, south Asia and the regions of sub-Saharan Africa together have accrued an increasing share of child mortality caused by relative changes in under-5 mortality and fertility. In 1970, these regions accounted for a combined 55% of all child deaths. In 2010, they account for more than 82% (33·0% in south Asia and 49·6% in sub-Saharan Africa). By comparison, the proportion of deaths in children younger than 5 years occurring in the Caribbean, east

	1990			2010		
	Neonatal	Postneonatal	Childhood	Neonatal	Postneonatal	Childhood
(Continued from previous page)						
Caribbean						
Antigua and Barbuda	33·7 (21·0–47·1)	22·0 (11·1–33·2)	10·1 (4·3–20·5)	38·4 (22·7–59·4)	25·6 (13·2–40·8)	12·0 (5·0–26·0)
Barbados	14·8 (8·9–20·6)	8·3 (3·8–13·6)	3·5 (1·4–7·9)	6·4 (3·5–9·6)	3·1 (1·1–5·6)	1·2 (0·4–3·3)
Belize	23·5 (14·5–32·8)	14·4 (7·1–22·6)	6·3 (2·7–13·4)	12·9 (7·8–18·7)	7·0 (3·2–11·9)	2·9 (1·1–7·1)
Cuba	7·9 (6·3–9·5)	4·6 (3·4–5·9)	1·4 (0·9–2·4)	2·8 (2·1–3·7)	1·7 (1·2–2·3)	0·7 (0·4–1·2)
Dominica	33·2 (20·8–46·2)	21·6 (11·4–32·7)	9·9 (4·3–20·9)	26·1 (15·5–40·8)	16·2 (7·8–27·1)	7·3 (3·0–16·2)
Dominican Republic	25·4 (19·9–31·2)	19·3 (15·5–22·9)	13·4 (9·3–19·2)	14·9 (11·4–18·5)	8·1 (5·5–11·3)	4·7 (2·7–7·8)
Grenada	15·1 (9·2–21·2)	8·4 (3·9–13·9)	3·5 (1·4–8·3)	6·9 (4·1–10·2)	3·4 (1·4–6·3)	1·3 (0·4–3·7)
Guyana	32·0 (20·1–44·9)	20·8 (10·8–31·5)	9·4 (4·2–19·5)	20·7 (12·9–30·0)	12·3 (5·9–21·1)	5·4 (2·1–12·5)
Haiti	44·0 (34·4–55·5)	56·8 (46·3–66·8)	56·4 (42·1–71·5)	30·4 (23·0–39·7)	39·2 (30·4–47·2)	36·8 (25·7–49·9)
Jamaica	18·7 (11·5–26·1)	10·9 (5·3–17·8)	4·7 (2·0–10·5)	10·6 (6·1–15·2)	5·6 (2·4–9·5)	2·3 (0·8–5·7)
Saint Lucia	13·2 (7·8–18·3)	7·2 (3·2–12·0)	3·0 (1·2–7·0)	6·8 (3·8–10·1)	3·3 (1·3–6·0)	1·3 (0·5–3·6)
Saint Vincent and the Grenadines	14·1 (8·5–19·6)	7·7 (3·5–13·0)	3·2 (1·3–7·6)	13·1 (7·8–19·6)	7·2 (3·1–12·4)	3·0 (1·1–7·5)
Suriname	24·9 (15·2–35·1)	15·3 (7·6–23·6)	6·8 (2·8–14·4)	19·4 (11·0–27·9)	11·4 (5·1–19·0)	5·0 (1·8–11·4)
The Bahamas	19·7 (12·2–27·8)	11·7 (5·7–18·9)	5·0 (2·0–11·1)	9·2 (5·3–13·3)	4·7 (2·0–8·4)	1·9 (0·6–4·8)
Trinidad and Tobago	20·3 (17·1–23·2)	7·0 (5·0–9·3)	3·0 (1·8–5·0)	17·4 (13·6–22·4)	5·8 (3·9–8·4)	2·5 (1·4–4·3)
Europe, central						
Albania	9·2 (6·9–12·6)	24·3 (20·5–27·4)	7·0 (4·7–10·2)	3·7 (2·5–5·3)	8·3 (6·2–11·0)	3·2 (2·0–5·0)
Bosnia and Herzegovina	9·8 (5·7–13·8)	6·5 (2·9–10·5)	1·5 (0·6–4·2)	4·5 (2·4–6·9)	2·6 (1·0–4·4)	0·8 (0·2–2·2)
Bulgaria	8·9 (6·9–11·3)	7·6 (5·8–9·3)	1·9 (1·2–3·0)	5·4 (3·8–7·1)	4·1 (2·9–5·7)	1·3 (0·7–2·1)
Croatia	9·0 (7·4–10·4)	3·6 (2·5–4·8)	0·9 (0·5–1·6)	3·8 (3·0–4·5)	1·3 (0·8–1·8)	0·4 (0·2–0·8)
Czech Republic	7·9 (4·6–11·4)	5·1 (2·3–8·2)	1·2 (0·4–3·5)	2·5 (1·3–3·6)	1·2 (0·4–2·3)	0·4 (0·1–1·4)
Hungary	11·6 (9·7–13·4)	4·1 (2·9–5·7)	1·1 (0·6–1·9)	3·4 (2·7–4·4)	1·6 (1·1–2·2)	0·5 (0·3–0·9)
Macedonia	15·2 (12·1–18·6)	9·7 (7·1–12·3)	1·6 (1·0–2·6)	7·4 (5·5–9·7)	3·7 (2·4–5·5)	0·8 (0·4–1·4)
Montenegro	13·6 (7·5–21·0)	9·7 (4·2–16·2)	2·0 (0·7–5·7)	5·4 (3·0–8·0)	3·2 (1·3–5·7)	0·9 (0·3–2·6)
Poland	12·1 (10·1–13·9)	5·7 (4·1–7·5)	1·3 (0·8–2·2)	4·4 (3·3–5·8)	1·6 (1·0–2·3)	0·5 (0·3–0·9)
Romania	10·6 (8·2–13·8)	16·9 (13·5–20·0)	3·2 (2·0–5·0)	6·2 (4·5–8·2)	7·4 (5·2–10·0)	1·6 (1·0–2·6)
Serbia	8·1 (5·9–10·9)	3·7 (2·3–5·6)	0·9 (0·5–1·7)	2·7 (2·1–3·3)	1·0 (0·6–1·4)	0·3 (0·2–0·6)
Slovakia	7·7 (6·2–9·3)	5·2 (3·9–6·4)	1·3 (0·8–2·1)	3·8 (2·7–5·0)	2·2 (1·4–3·3)	0·7 (0·4–1·2)
Slovenia	6·6 (5·3–7·8)	3·1 (2·2–4·2)	0·9 (0·5–1·6)	2·1 (1·5–2·6)	0·8 (0·5–1·2)	0·4 (0·2–0·7)
Europe, eastern						
Belarus	12·8 (7·7–17·7)	6·6 (3·0–11·5)	2·2 (0·8–6·1)	5·7 (3·1–8·6)	3·6 (1·5–5·9)	1·2 (0·4–3·4)
Estonia	10·9 (8·7–13·2)	5·3 (3·9–6·9)	2·0 (1·2–3·3)	3·3 (2·4–4·2)	2·2 (1·6–2·9)	0·8 (0·5–1·3)
Latvia	10·0 (7·9–12·2)	5·5 (4·0–7·0)	1·8 (1·1–3·0)	5·2 (3·8–6·8)	3·2 (2·3–4·3)	1·1 (0·6–1·9)
Lithuania	8·1 (6·3–9·8)	4·9 (3·6–6·2)	1·5 (0·9–2·5)	3·4 (2·5–4·5)	2·6 (1·9–3·4)	0·8 (0·5–1·4)
Moldova	17·2 (13·5–21·5)	14·8 (11·6–17·8)	3·5 (2·3–5·6)	5·6 (4·2–7·7)	6·6 (4·9–8·1)	1·5 (0·9–2·5)
Russia	16·1 (9·7–21·9)	8·1 (3·6–13·7)	2·7 (1·0–7·1)	8·2 (4·5–12·1)	4·8 (2·0–7·8)	1·6 (0·6–4·3)
Ukraine	14·2 (11·6–16·5)	4·9 (3·5–6·5)	2·6 (1·6–4·3)	9·9 (7·7–12·4)	3·7 (2·6–5·1)	2·0 (1·2–3·3)

(Continues on next page)

and southeast Asia, north Africa and the Middle East, and regions of Latin America has decreased by 63% between 1970 and 2010. Less than 1% of child deaths occur in high-income countries.

Figure 4 shows the trends in under-5 mortality for each of the 21 regions between 1970 and 2010. Among regions with the lowest rates of under-5 mortality (figure 4A), western Europe, Australasia, Asia-Pacific high income, and North America high income have tracked each other closely. However, high income countries in North America have seen less progress in the past 15 years, largely driven by rates in the USA. Central and eastern Europe have notably higher rates of mortality throughout the entire period. Across all regions of Latin America and north Africa and the Middle East, there has been sustained decline in under-5 mortality (figure 4B). The fluctuations in post-1990 under-5 mortality in southern sub-Saharan Africa show the effect of HIV in the region (figure 4C). Consistently high rates of mortality in Oceania indicate poor progress. The four regions with the highest rates of under-5 mortality are east, west, and central sub-Saharan Africa, and south Asia (figure 4D).

	1990			2010		
	Neonatal	Postneonatal	Childhood	Neonatal	Postneonatal	Childhood
(Continued from previous page)						
Europe, western						
Andorra	5·8 (3·3–7·8)	2·8 (1·1–5·0)	0·8 (0·3–2·5)	3·0 (1·6–4·1)	1·4 (0·5–2·7)	0·5 (0·1–1·4)
Austria	6·6 (5·3–7·8)	3·3 (2·4–4·5)	0·9 (0·6–1·6)	2·2 (1·6–2·9)	1·3 (0·8–1·7)	0·4 (0·2–0·7)
Belgium	5·8 (4·4–7·0)	3·6 (2·5–4·6)	0·9 (0·5–1·6)	2·2 (1·6–3·0)	1·7 (1·1–2·2)	0·4 (0·2–0·8)
Cyprus	7·9 (4·6–10·6)	3·8 (1·5–6·8)	1·2 (0·4–3·3)	1·7 (0·9–2·6)	0·8 (0·3–1·6)	0·3 (0·1–0·9)
Denmark	5·4 (4·3–6·4)	2·4 (1·7–3·3)	0·9 (0·5–1·5)	2·5 (1·8–3·3)	1·2 (0·7–1·7)	0·4 (0·2–0·8)
Finland	4·6 (3·7–5·5)	1·8 (1·2–2·4)	0·7 (0·4–1·2)	1·9 (1·4–2·5)	0·8 (0·5–1·2)	0·3 (0·2–0·6)
France	5·1 (4·0–6·2)	3·5 (2·5–4·4)	0·9 (0·6–1·6)	2·1 (1·5–2·8)	1·4 (0·9–1·9)	0·4 (0·2–0·7)
Germany	5·5 (3·1–7·4)	2·6 (1·0–4·8)	0·8 (0·3–2·4)	2·5 (1·3–3·6)	1·2 (0·4–2·3)	0·4 (0·1–1·3)
Greece	7·5 (6·2–8·5)	3·0 (2·1–3·9)	0·7 (0·4–1·3)	2·4 (1·8–3·1)	1·0 (0·7–1·4)	0·3 (0·1–0·5)
Iceland	4·1 (2·3–5·8)	2·0 (0·7–3·7)	0·6 (0·2–1·9)	1·6 (0·8–2·4)	0·8 (0·3–1·5)	0·3 (0·1–0·9)
Ireland	5·9 (4·6–7·0)	3·1 (2·2–4·1)	0·9 (0·5–1·6)	2·5 (1·8–3·2)	1·2 (0·8–1·7)	0·4 (0·2–0·7)
Israel	7·1 (5·6–8·4)	3·8 (2·8–4·9)	1·2 (0·8–2·1)	2·7 (1·9–3·5)	1·5 (1·0–2·0)	0·5 (0·3–0·9)
Italy	7·0 (5·8–7·9)	2·3 (1·6–3·2)	0·7 (0·4–1·3)	2·3 (1·8–2·9)	0·7 (0·5–1·1)	0·3 (0·1–0·5)
Luxembourg	5·6 (3·2–7·7)	2·7 (1·0–4·9)	0·8 (0·3–2·5)	1·8 (1·0–2·7)	0·9 (0·3–1·6)	0·3 (0·1–1·0)
Malta	7·0 (3·9–9·6)	3·3 (1·3–6·0)	1·0 (0·3–3·1)	3·2 (1·7–5·0)	1·6 (0·5–3·0)	0·5 (0·2–1·6)
Netherlands	5·7 (4·5–6·7)	2·3 (1·6–3·2)	0·9 (0·6–1·6)	2·7 (2·1–3·5)	1·1 (0·7–1·5)	0·4 (0·2–0·8)
Norway	5·2 (4·0–6·2)	2·7 (1·9–3·6)	1·0 (0·6–1·7)	1·9 (1·4–2·5)	1·0 (0·7–1·4)	0·4 (0·2–0·7)
Portugal	8·3 (6·6–10·1)	5·0 (3·7–6·3)	1·8 (1·1–2·9)	1·9 (1·3–2·6)	0·9 (0·6–1·3)	0·5 (0·3–0·9)
Spain	5·7 (3·3–7·7)	2·7 (1·1–4·9)	0·8 (0·3–2·5)	2·3 (1·2–3·3)	1·1 (0·4–2·1)	0·4 (0·1–1·2)
Sweden	4·6 (3·6–5·4)	2·0 (1·4–2·7)	0·6 (0·4–1·1)	1·5 (1·1–2·1)	0·9 (0·6–1·2)	0·3 (0·1–0·5)
Switzerland	5·4 (4·2–6·4)	2·5 (1·7–3·4)	0·9 (0·5–1·6)	2·6 (1·9–3·4)	1·2 (0·8–1·7)	0·4 (0·2–0·8)
UK	5·6 (4·5–6·8)	3·3 (2·4–4·3)	0·8 (0·5–1·4)	3·1 (2·4–4·0)	1·7 (1·1–2·4)	0·5 (0·3–0·8)
Latin America, Andean						
Bolivia	35·7 (27·8–44·8)	37·9 (30·8–44·6)	34·1 (24·8–45·3)	19·3 (13·9–24·1)	17·1 (12·5–20·9)	11·0 (6·9–15·4)
Ecuador	14·4 (11·3–18·2)	23·7 (19·8–27·1)	12·9 (9·1–18·0)	6·0 (4·5–8·1)	10·9 (8·6–13·0)	4·1 (2·6–6·3)
Peru	25·9 (20·0–32·7)	25·4 (20·4–30·1)	23·2 (16·7–31·0)	11·3 (8·6–14·5)	8·2 (6·0–10·5)	5·3 (3·3–8·3)
Latin America, central						
Colombia	14·8 (11·7–18·4)	12·8 (10·1–15·3)	6·0 (4·0–9·2)	8·6 (7·0–10·8)	5·0 (3·6–6·9)	1·8 (1·1–3·2)
Costa Rica	11·2 (9·0–13·6)	8·5 (6·4–10·4)	1·8 (1·1–3·1)	5·3 (4·1–6·6)	3·0 (1·9–4·0)	0·5 (0·2–0·9)
El Salvador	22·4 (12·9–34·7)	25·4 (14·2–34·9)	12·8 (5·9–23·3)	9·3 (5·1–14·2)	7·7 (3·6–11·8)	2·4 (0·9–6·1)
Guatemala	22·8 (17·5–28·9)	34·6 (28·4–39·6)	20·4 (14·4–27·5)	10·2 (7·5–13·7)	16·2 (12·8–19·6)	5·9 (3·7–9·2)
Honduras	22·4 (17·0–28·3)	19·1 (15·2–22·8)	15·9 (11·1–21·9)	11·4 (8·8–14·4)	7·0 (5·1–9·0)	4·3 (2·5–6·8)
Mexico	14·0 (10·9–18·1)	21·2 (17·7–24·2)	7·1 (4·8–10·6)	6·6 (4·9–8·5)	8·2 (6·2–9·7)	1·9 (1·1–3·1)
Nicaragua	22·4 (17·4–28·3)	28·8 (23·7–33·2)	14·1 (9·8–20·1)	11·3 (8·5–14·8)	11·4 (8·7–14·6)	4·2 (2·6–6·7)
Panama	12·8 (9·9–15·7)	10·5 (8·3–12·6)	4·8 (3·0–7·2)	8·9 (6·7–11·1)	6·6 (4·8–8·5)	2·6 (1·4–4·1)
Venezuela	14·8 (11·7–18·1)	11·3 (8·7–13·8)	3·5 (2·3–5·6)	9·3 (7·1–11·6)	5·4 (3·7–7·6)	1·4 (0·8–2·5)
Latin America, southern						
Argentina	15·5 (12·6–18·6)	10·5 (7·9–13·0)	2·2 (1·4–3·6)	8·2 (6·4–10·1)	3·8 (2·4–5·5)	0·9 (0·5–1·7)
Chile	9·2 (7·2–11·2)	7·6 (5·6–9·4)	1·5 (0·9–2·5)	3·8 (2·9–4·9)	2·1 (1·3–3·0)	0·6 (0·3–1·0)
Uruguay	11·6 (9·3–14·0)	9·2 (7·0–11·2)	1·5 (1·0–2·5)	6·2 (4·6–8·2)	4·5 (3·0–6·0)	0·9 (0·5–1·6)
Latin America, tropical						
Brazil	21·6 (17·1–27·0)	23·8 (19·2–27·3)	7·5 (5·0–11·1)	10·1 (7·7–12·4)	8·2 (5·8–10·3)	1·7 (1·0–2·9)
Paraguay	16·7 (12·9–20·5)	13·6 (10·8–16·0)	7·9 (5·2–11·3)	10·3 (7·9–13·7)	7·3 (5·3–9·9)	3·5 (2·1–5·8)

(Continues on next page)

Figure 5 shows worldwide under-5 mortality in 2010 (worldwide under-5 mortality in 1970 and 1990 is shown in webappendix pp 207–08). Improvement in under-5 mortality is visible in all regions—by 2010, mortality is less than 200 per 1000 in all countries, whereas in 1970, 40 countries had rates higher than this level. The USA, UK, New Zealand, and South Korea lag behind other high-income countries, having failed to reach rates of under-5 mortality of less than five per 1000 by 2010. Latin America and the Caribbean have

	1990			2010		
	Neonatal	Postneonatal	Childhood	Neonatal	Postneonatal	Childhood
(Continued from previous page)						
North Africa and Middle East						
Algeria	25·0 (15·5–36·2)	18·6 (9·9–27·7)	9·8 (4·4–19·2)	11·8 (6·9–16·4)	5·6 (2·0–10·1)	2·0 (0·6–5·7)
Bahrain	11·2 (9·3–14·2)	5·4 (4·1–7·3)	2·5 (1·6–4·2)	4·7 (3·5–6·0)	2·1 (1·3–3·0)	0·7 (0·4–1·3)
Egypt	32·4 (25·8–39·7)	32·0 (26·4–37·1)	23·5 (16·8–32·0)	14·4 (11·7–16·9)	7·5 (5·5–9·6)	3·0 (1·8–4·9)
Iran	29·1 (17·9–43·2)	24·0 (13·5–35·0)	13·8 (6·7–25·7)	17·1 (10·4–24·7)	10·0 (4·8–16·5)	4·4 (1·7–10·1)
Iraq	27·0 (16·3–39·3)	20·9 (11·5–30·7)	11·6 (5·4–21·9)	17·3 (10·4–25·2)	10·1 (4·9–17·2)	4·5 (1·7–10·5)
Jordan	18·0 (14·7–21·3)	11·1 (8·6–13·6)	4·7 (3·0–7·1)	9·4 (7·8–11·4)	3·6 (2·4–5·1)	1·1 (0·6–2·1)
Kuwait	8·0 (6·4–9·8)	3·8 (2·5–5·1)	1·1 (0·6–1·9)	5·3 (4·0–6·9)	2·0 (1·2–3·2)	0·5 (0·3–1·0)
Lebanon	17·1 (10·6–23·8)	10·2 (5·0–16·0)	4·4 (1·8–9·7)	7·0 (4·1–10·4)	2·5 (1·0–5·2)	0·7 (0·2–2·4)
Libya	19·6 (12·2–27·8)	12·6 (6·4–19·6)	5·8 (2·5–12·2)	8·5 (5·0–12·2)	3·4 (1·3–6·3)	1·1 (0·3–3·2)
Morocco	34·5 (27·9–41·2)	26·1 (20·9–30·8)	18·3 (12·9–25·6)	19·1 (15·4–22·7)	9·2 (6·3–12·3)	4·4 (2·5–7·1)
Occupied Palestinian territories	21·3 (13·4–30·2)	14·3 (7·4–21·9)	6·9 (2·9–13·9)	13·1 (7·7–18·5)	6·6 (2·8–11·4)	2·5 (0·9–6·1)
Oman	19·3 (12·2–28·2)	12·4 (6·1–19·9)	5·8 (2·5–13·0)	6·6 (3·6–8·5)	2·2 (0·7–4·3)	0·6 (0·1–1·8)
Qatar	10·1 (6·3–13·5)	4·4 (1·9–7·8)	1·4 (0·5–3·9)	7·2 (4·3–9·6)	2·6 (1·0–5·1)	0·7 (0·2–2·4)
Saudi Arabia	16·4 (9·6–22·8)	9·5 (4·3–15·4)	3·9 (1·4–9·5)	9·6 (5·6–13·6)	4·1 (1·6–7·8)	1·3 (0·4–4·0)
Syria	17·4 (10·7–24·0)	10·3 (5·0–16·5)	4·5 (1·9–9·8)	7·7 (4·9–10·3)	2·9 (1·1–5·6)	0·9 (0·3–2·6)
Tunisia	21·3 (16·9–26·3)	16·4 (13·1–19·9)	10·4 (7·1–15·0)	9·4 (6·7–12·3)	4·2 (2·6–6·5)	1·6 (0·8–3·2)
Turkey	30·3 (24·5–37·4)	29·8 (24·6–34·7)	12·9 (8·8–18·8)	16·4 (11·5–17·6)	9·7 (6·0–11·3)	3·4 (1·8–5·0)
United Arab Emirates	10·2 (6·2–14·2)	4·4 (1·8–8·1)	1·5 (0·5–4·2)	2·4 (1·4–3·4)	0·5 (0·1–1·4)	0·1 (0·0–0·4)
Yemen	46·0 (35·6–57·3)	49·0 (39·7–57·2)	39·2 (28·4–52·7)	27·8 (21·9–34·6)	21·3 (15·8–27·1)	12·1 (7·4–19·1)
North America, high income						
Canada	5·4 (4·3–6·5)	2·6 (1·8–3·5)	0·8 (0·5–1·4)	2·9 (2·1–3·8)	1·5 (1·0–2·1)	0·5 (0·3–0·8)
USA	7·2 (5·8–8·5)	3·4 (2·4–4·6)	1·0 (0·6–1·7)	3·9 (3·0–4·9)	2·2 (1·5–2·9)	0·6 (0·3–1·1)
Oceania						
Fiji	18·6 (10·6–27·2)	11·9 (5·4–18·8)	5·1 (2·0–11·2)	14·5 (8·2–22·2)	8·8 (3·9–14·8)	3·6 (1·4–8·5)
Federated States of Micronesia	28·3 (16·6–42·0)	19·8 (10·1–31·1)	9·2 (3·9–18·9)	14·1 (7·5–21·3)	8·3 (3·5–14·4)	3·5 (1·3–8·3)
Kiribati	36·6 (21·8–51·9)	27·6 (14·7–40·5)	13·4 (6·0–26·0)	23·8 (13·5–35·0)	16·1 (7·8–25·3)	7·2 (3·0–15·5)
Marshall Islands	25·6 (15·1–37·2)	18·0 (8·7–27·4)	8·1 (3·3–16·7)	19·9 (11·1–29·3)	12·8 (6·0–19·8)	5·6 (2·1–12·4)
Papua New Guinea	46·6 (28·6–68·0)	37·7 (20·8–55·4)	19·2 (9·0–36·0)	39·3 (23·4–61·1)	30·4 (15·6–47·4)	15·2 (6·6–30·7)
Samoa	15·9 (9·2–23·6)	9·8 (4·5–16·5)	4·1 (1·6–9·7)	10·5 (5·7–15·3)	5·9 (2·5–10·2)	2·3 (0·9–6·1)
Solomon Islands	20·0 (11·8–28·8)	13·1 (6·1–21·1)	5·7 (2·3–12·6)	15·8 (8·9–23·0)	9·7 (4·3–16·2)	4·1 (1·5–9·4)
Tonga	14·0 (7·9–20·5)	8·4 (3·7–14·2)	3·5 (1·3–8·3)	10·8 (5·7–15·9)	6·1 (2·5–10·1)	2·4 (0·8–6·3)
Vanuatu	26·7 (15·5–39·1)	18·5 (9·4–29·0)	8·5 (3·6–18·2)	12·7 (7·3–19·1)	7·4 (3·2–13·0)	3·0 (1·1–7·5)
Sub-Saharan Africa, central						
Angola	52·3 (29·3–90·5)	84·1 (49·9–121·2)	120·1 (76·2–160·2)	37·3 (20·4–64·2)	47·0 (26·6–70·0)	56·9 (31·1–84·5)
Central African Republic	46·6 (35·6–60·3)	60·0 (48·8–71·7)	66·9 (50·9–85·1)	41·2 (31·4–54·5)	50·2 (39·1–63·0)	53·5 (38·1–71·2)
Congo	30·1 (22·7–40·0)	38·3 (30·9–46·8)	45·2 (34·8–58·2)	29·7 (22·5–39·6)	37·7 (30·0–46·9)	44·2 (32·6–59·5)
Democratic Republic of the Congo	39·8 (29·4–53·1)	65·9 (52·1–80·1)	89·0 (69·3–107·9)	32·6 (24·0–43·9)	47·1 (36·6–57·7)	57·5 (42·8–73·6)
Equatorial Guinea	44·0 (24·7–75·8)	63·0 (37·3–90·9)	83·1 (50·7–115·7)	44·4 (24·4–75·3)	63·6 (37·0–93·7)	83·8 (50·0–119·2)
Gabon	31·1 (22·8–40·2)	29·7 (23·2–35·6)	36·1 (26·7–46·4)	25·6 (18·7–33·6)	20·9 (15·4–26·5)	23·4 (15·8–32·9)

(Continues on next page)

made good progress overall, but Bolivia, Haiti, Dominica, and Antigua and Barbuda have rates higher than 40 per 1000. Of all 38 countries in the world with under-5 mortality higher than 80 per 1000 in 2010, 34 are in sub-Saharan Africa. Countries in southern Africa have notably lower under-5 mortality rates than do countries in other sub-Saharan regions; the west sub-Saharan African countries of Nigeria, Guinea-Bissau, Niger, Mali, Chad, and Equatorial Guinea have the highest rates of under-5 mortality in the world. In north Africa and the Middle East, only Yemen has a rate of under-5 mortality of more than 40 per 1000 and 12 countries have rates of

	1990			2010		
	Neonatal	Postneonatal	Childhood	Neonatal	Postneonatal	Childhood
(Continued from previous page)						
Sub-Saharan Africa, east						
Burundi	37·6 (28·2–51·7)	46·5 (36·4–60·1)	101·8 (84·3–122·3)	31·2 (22·3–42·2)	35·7 (27·0–46·2)	69·0 (51·6–89·9)
Comoros	46·9 (37·4–57·5)	39·3 (31·7–46·4)	34·1 (24·8–46·0)	29·2 (22·7–37·1)	20·5 (15·4–26·1)	13·1 (8·2–20·0)
Djibouti	32·3 (18·1–54·8)	37·2 (21·0–55·2)	44·8 (25·0–66·4)	22·4 (12·2–36·8)	23·3 (12·7–34·4)	22·5 (11·5–36·8)
Eritrea	33·7 (24·2–45·3)	36·8 (28·2–46·2)	78·8 (62·7–93·8)	22·1 (15·6–30·4)	21·8 (16·5–28·0)	36·3 (25·9–47·5)
Ethiopia	58·5 (44·7–75·1)	65·0 (51·6–78·3)	93·4 (72·7–114·8)	35·0 (26·6–45·7)	33·5 (26·3–43·2)	36·2 (25·3–50·1)
Kenya	30·1 (22·2–39·5)	38·6 (31·1–45·5)	38·8 (28·7–50·2)	25·9 (18·2–33·4)	31·0 (23·1–37·5)	27·6 (18·1–36·1)
Madagascar	37·4 (28·0–49·0)	55·1 (44·0–67·2)	74·3 (57·9–91·7)	22·0 (16·2–28·5)	25·7 (20·3–31·4)	24·6 (17·1–33·8)
Malawi	48·6 (36·3–64·1)	70·1 (55·2–85·3)	108·6 (86·0–130·6)	26·9 (19·9–36·0)	35·4 (27·5–44·0)	37·7 (26·2–52·1)
Mozambique	59·4 (46·1–75·6)	94·0 (76·0–109·3)	92·5 (70·1–115·9)	39·0 (28·1–50·3)	57·5 (44·0–69·1)	43·5 (29·2–58·6)
Rwanda	45·4 (33·3–59·5)	48·6 (37·9–59·9)	85·5 (67·3–103·6)	32·0 (23·9–42·3)	30·9 (23·2–39·7)	43·7 (30·3–58·1)
Somalia	44·4 (25·4–74·9)	56·6 (33·1–83·5)	83·9 (50·4–115·7)	32·6 (18·2–55·1)	37·4 (21·4–56·1)	45·7 (25·1–68·3)
Sudan	35·7 (26·7–47·0)	30·9 (24·1–38·3)	56·3 (44·1–70·9)	30·3 (21·9–39·0)	24·3 (18·1–30·7)	40·3 (28·4–54·7)
Tanzania	38·5 (29·1–50·4)	56·6 (45·4–67·8)	66·4 (51·6–82·9)	28·3 (20·7–37·1)	37·5 (28·9–46·0)	36·0 (24·6–49·1)
Uganda	42·2 (31·2–55·3)	56·1 (43·8–68·0)	79·5 (61·7–96·3)	31·9 (23·2–42·0)	40·5 (31·5–49·9)	49·0 (34·1–63·0)
Zambia	36·7 (27·5–48·2)	57·5 (45·0–70·5)	88·9 (71·0–106·7)	28·5 (21·4–38·2)	41·1 (31·9–51·0)	54·0 (40·1–69·3)
Sub-Saharan Africa, southern						
Botswana	21·1 (15·6–26·7)	18·5 (13·9–22·9)	15·6 (10·6–21·6)	19·8 (14·4–27·0)	16·3 (11·0–23·4)	13·9 (8·2–21·7)
Lesotho	38·6 (29·8–47·9)	35·1 (28·1–41·6)	23·8 (16·4–33·1)	39·2 (28·9–50·4)	36·0 (25·5–47·3)	24·8 (14·7–36·8)
Namibia	26·1 (19·3–33·6)	22·9 (18·0–27·8)	24·8 (18·0–33·2)	22·5 (16·5–28·7)	16·4 (11·9–21·5)	17·1 (11·0–24·7)
South Africa	17·7 (13·2–23·0)	26·0 (21·1–30·2)	15·1 (10·3–20·8)	16·3 (12·0–21·6)	22·9 (17·6–28·6)	12·6 (8·1–19·0)
Swaziland	19·1 (13·9–25·5)	30·7 (24·5–36·6)	25·8 (18·8–34·1)	22·9 (16·6–31·6)	43·5 (31·4–58·1)	38·3 (25·2–54·5)
Zimbabwe	23·0 (17·2–29·8)	25·6 (20·6–30·7)	26·5 (19·4–34·8)	22·6 (16·8–29·7)	24·4 (17·8–32·5)	25·1 (16·6–35·2)
Sub-Saharan Africa, west						
Benin	45·4 (33·3–59·8)	53·2 (41·9–64·9)	88·8 (69·9–107·5)	29·4 (20·9–39·8)	30·6 (23·8–38·2)	44·2 (32·7–57·2)
Burkina Faso	46·0 (34·2–60·6)	58·6 (45·4–73·7)	114·5 (93·0–135·5)	31·6 (22·8–43·3)	38·7 (28·7–49·7)	69·4 (51·6–87·0)
Cameroon	41·4 (30·6–54·6)	41·7 (33·1–51·2)	67·6 (53·0–83·8)	33·8 (24·5–46·5)	33·7 (25·6–43·3)	51·5 (37·2–69·9)
Cape Verde	20·2 (9·8–33·9)	17·3 (9·1–27·3)	21·9 (10·8–34·0)	13·0 (5·9–21·7)	9·4 (4·4–15·4)	10·3 (4·5–18·6)
Chad	50·6 (37·7–65·8)	65·7 (51·0–80·9)	110·3 (87·8–130·9)	41·5 (29·9–56·5)	53·5 (41·0–68·4)	83·6 (62·4–108)
Côte d'Ivoire	48·3 (36·8–61·8)	48·9 (39·2–58·5)	60·1 (45·6–76·3)	36·6 (27·0–48·0)	35·6 (27·7–44·3)	39·2 (28·1–53·7)
Ghana	39·5 (29·0–51·5)	30·4 (23·6–37·5)	57·5 (44·1–71·0)	28·1 (20·3–37·1)	19·2 (14·8–24·4)	32·2 (23·8–41·7)
Guinea	60·3 (45·5–78·6)	69·2 (54·7–84·7)	116 (92·3–139·8)	38·9 (28·7–51·7)	41·2 (31·5–51·2)	58·8 (43·1–76·7)
Guinea-Bissau	59·5 (34·7–100·7)	68·5 (40·0–103·5)	124·9 (80·0–164·7)	43·3 (24·1–74·4)	47·0 (26·9–71·4)	77·2 (45·6–107·1)
Liberia	65·6 (50·3–85·2)	95·7 (77·0–113·8)	95·1 (72·4–119·5)	31·7 (23·0–41·6)	39·1 (30·1–49·5)	31·5 (21·3–43·2)
Mali	68·5 (51·2–89·6)	64·8 (50·3–81·2)	143·7 (116·5–169·1)	47·0 (35·2–63·0)	41·6 (32·6–53·0)	81·6 (63·9–102·3)
Mauritania	40·6 (30·0–51·4)	30·4 (23·6–36·8)	46·3 (34·2–58·0)	33·2 (23·9–42·7)	22·7 (16·8–27·9)	32·1 (22·1–42·8)
Niger	53·8 (39·8–72·3)	76·8 (58·2–98·6)	195·2 (164·4–219·5)	31·3 (22·1–43·5)	43·4 (32·2–55·6)	94·7 (72·7–116·5)
Nigeria	49·0 (36·0–64·6)	50·1 (38·3–62·4)	107·9 (86·3–127·3)	41·3 (30·3–55·4)	40·5 (31·2–50·5)	83·5 (64·0–103·1)
Sao Tome and Principe	32·6 (17·0–56·3)	32·5 (18·3–50·3)	48·5 (27·0–70·2)	21·2 (10·1–37·2)	18·4 (9·7–30·3)	23·9 (10·9–39·7)
Senegal	39·3 (28·3–53·0)	33·8 (25·8–43·0)	80·4 (64·7–96·8)	29·2 (21·1–39·5)	19·8 (15·1–25·8)	40·1 (29·8–52·6)
Sierra Leone	61·8 (46·9–79·7)	95·2 (77·4–111·6)	106·6 (81·6–132·3)	38·6 (28·7–51·2)	55·0 (42·9–66·1)	52·3 (37·7–67·8)
The Gambia	40·8 (22·1–69·9)	43·0 (24·4–67·1)	69·6 (40·7–96·6)	25·8 (13·1–44·6)	23·9 (13·1–38·6)	33·3 (17·1–53·2)
Togo	41·5 (30·4–55·3)	37·4 (29·4–46·9)	70·5 (54·8–86·5)	30·1 (21·5–40·3)	24·0 (18·4–31·5)	40·2 (28·4–54·3)

Countries are grouped into 21 regions on the basis of epidemiological profiles and geography. See text for definitions of neonatal, postneonatal, and childhood mortality.

Table 2: **Neonatal, postneonatal, and childhood mortality (uncertainty interval) per 1000 in 1990 and 2010**

less than 20 per 1000. Pakistan and Afghanistan have the highest rates of under-5 mortality in south Asia. In southeast Asia, under-5 mortality is less than ten per 1000 in Thailand and Malaysia. Rates of under-5 mortality in the Philippines and Indonesia are twice as high as those in other countries in southeast Asia; Laos, Cambodia, Timor-Leste, and Burma have rates that are three to four times higher.

The GPR method and enhanced database used in this study allow for a detailed assessment of rates of decline

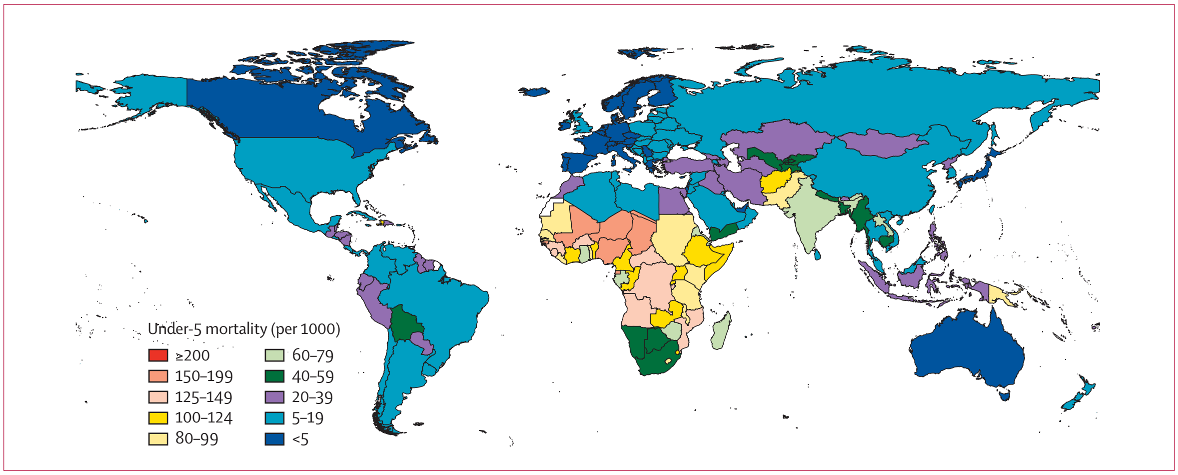

Figure 6: Yearly percentage decline in mortality in children younger than 5 years between 1990 and 2010

in under-5 mortality. Webappendix p 209 shows the frequency distribution of yearly rates of change, calculated at each single year increment, across all countries from 1970 to 2010. The median yearly rate of decline was 3·3% and the 10th percentile and 90th percentile rates of change were 0·8% and 6·4%, respectively. The empirical distribution of rates of change also shows that the MDG 4 target rate of change corresponds to the 67th percentile. In 1970–90, the median rate of change across all country-years was 3·2%, whereas in 1990–2010, the median rate of change was 3·3%. Yearly rates of change by country from 1990 to 2010 (calculated over the entire period) are shown in figure 6. Across all developing countries, the yearly rate of decline in under-5 mortality is 2·1%, a 35% decline overall. The fastest rates of decline occurred in many Latin American and north African countries. Some countries in sub-Saharan Africa have had yearly rates of decline of more than 3%—Comoros, Eritrea, Ethiopia, Liberia, Madagascar, Malawi, and Niger.

Figure 7 shows, for each of the 21 regions, the yearly rate of decline in under-5, neonatal, postneonatal, and childhood mortality from 1990 to 2010. In regions that consist of developing countries, the yearly rate of decline has been faster for childhood mortality than for postneonatal mortality, and slowest for neonatal mortality. The fastest rates of decline have been more than 6% per year for childhood mortality in Latin America Andean, Latin America tropical, Latin America central, and north Africa and the Middle East. The lowest rates of decline during the MDG 4 target window have been in Oceania and southern sub-Saharan Africa. In regions with developed countries, rates of decline are more uniform across neonatal, postneonatal, and childhood mortality and have stayed between 3% and 5% per year. Rates of decline in high-income countries in North America have, however, been notably lower.

During the MDG period (1990 to 2010), there is clear evidence of acceleration and deceleration in rates of decline in child mortality. Between 1990 and 2000, 31% of country-years had rates of decline that were above the MDG 4 target rate of 4·4% per year. This proportion increased to 34% of country-years in 2000–10. Figure 8 shows the yearly percentage decline (median across countries) in under-5 mortality in 1990–2000 compared with 2000–10 for the 21 regions. Regions below the 45° equivalence line are showing deceleration and regions above the 45° line are showing acceleration. In 13 regions of the world, including all regions in sub-Saharan Africa, there is evidence of accelerating declines from 2000 to 2010 compared with 1990 to 2000. Three high-income regions are showing a slowdown in decline, but 11 developing country regions are showing accelerations. This finding is particularly important since policy attention for the MDGs since the Millennium Declaration in 2000 might be leading to accelerations. The marked accelerations in decline in east Asia and central Asia deserve note since several studies[39–41] have reported the slow rate of improvement, especially in China, in the 1990s. From the perspective of the countries with the highest rates of mortality, the accelerations in rates of decline seen in all regions in sub-Saharan Africa are the most encouraging. Clearly these regions are far from the MDG 4 rate of decline, but there are signs of improving progress. Webappendix p 210 provides the rate of decline for each country in sub-Saharan Africa. Rates of decline have increased in 34 countries in sub-Saharan Africa for 2000–10 compared with 1990–2000 and have increased by 1% or more in Angola, Botswana, Cameroon, Congo, Democratic Republic of the Congo, Kenya, Lesotho, Liberia, Rwanda, Senegal, Sierra Leone, Swaziland, and The Gambia. In 25 countries in sub-Saharan Africa, rates of decline now exceed 2% per year; 11 countries have rates of decline in 1990–2000 and 2000–10 that are faster than the global median.

Discussion

Our analysis of 16 174 measurements of child mortality in 187 countries shows that the number of deaths in children younger than 5 years dropped from 16 million in 1970 to

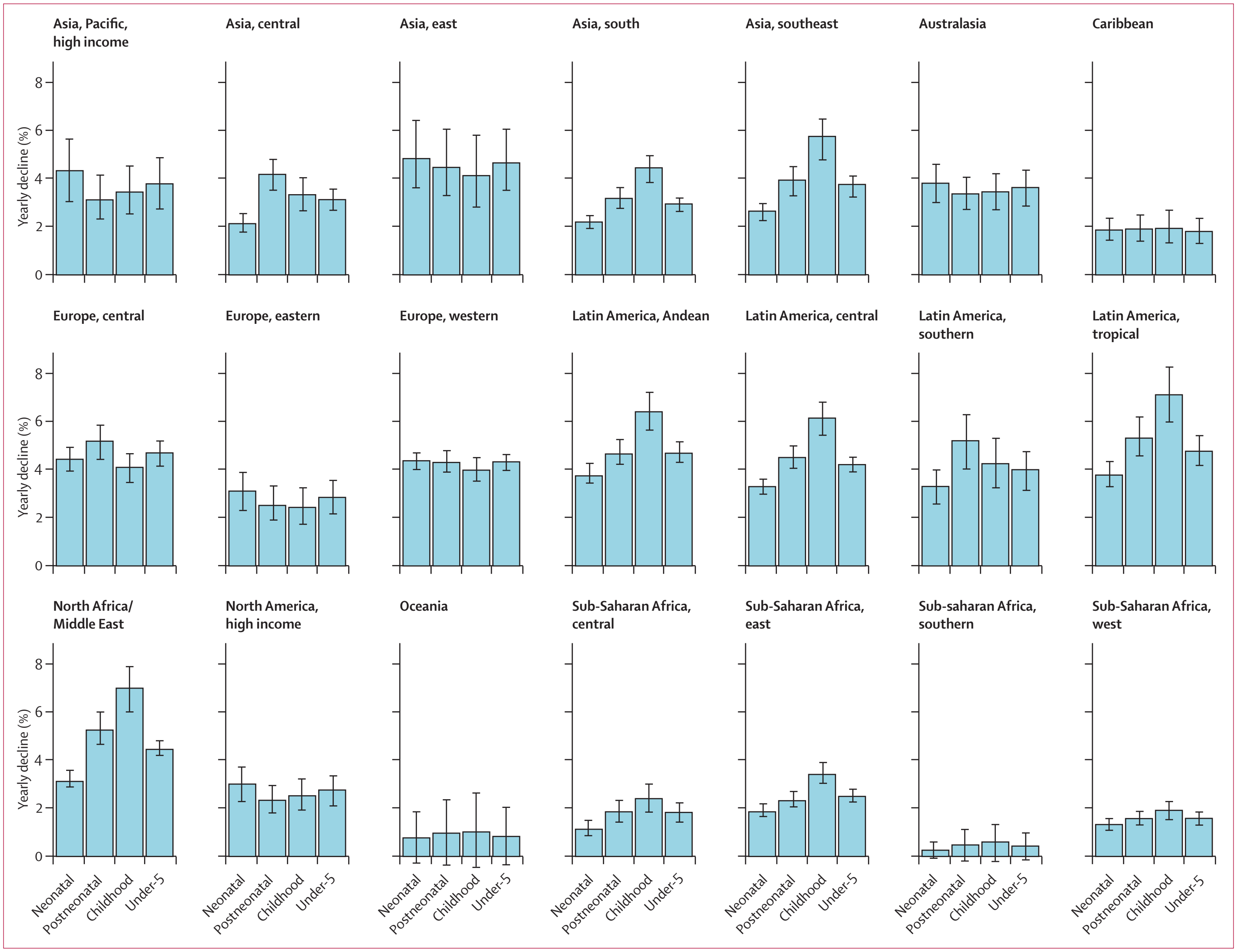

***Figure 7*: Yearly percentage decline in under-5, neonatal, postneonatal, and childhood mortality between 1990 and 2010, by region**
Error bars represent uncertainty intervals. Under-5 mortality is defined as the probability of death between birth and age 5 years. See text for definitions of neonatal, postneonatal, and childhood mortality.

7·7 million in 2010. In developing countries, mortality in children younger than 5 years declined by 35% from 1990 to 2010, a yearly rate of 2·1%. This rate of decline is lower than the MDG 4 target of 4·4% per year but represents substantial progress across countries; no countries have a rate of under-5 mortality of more than 200 per 1000 in 2010 whereas 12 did in 1990. Although progress has been slowest in sub-Saharan Africa and Oceania, there is clear evidence of accelerating rates of decline in under-5 mortality in all regions of sub-Saharan Africa. Rates of under-5 mortality in 25 countries in sub-Saharan Africa are now declining at more than 2% per year; in 34 countries in this region, the rate of decline has increased in the period 2000–10 compared with 1990–2000.

This assessment yields substantially lower estimates of child mortality than did previous studies. For example, UNICEF reported 8·77 million deaths in 2008, and we estimated 7·95 million for the same year. Our lower estimate is largely driven by newer surveys that show that declines in child mortality have been faster than projected and by the improved predictive validity of GPR compared with other methods. Loess forecasts used in the 2007 analysis by Murray and colleagues[1] tend towards the average long-term rate of decline in countries; when mortality decline is accelerating, these forecasts proved to be too conservative. The change in the overall numbers and the even more striking change in the estimated rates of decline from 1990 to 2008 due to new data and improved methods highlight why it is important to continually update and refine the measurement of child mortality. Our assessment of rates of change is also notably different than that done by UNICEF; the correlation coefficient of

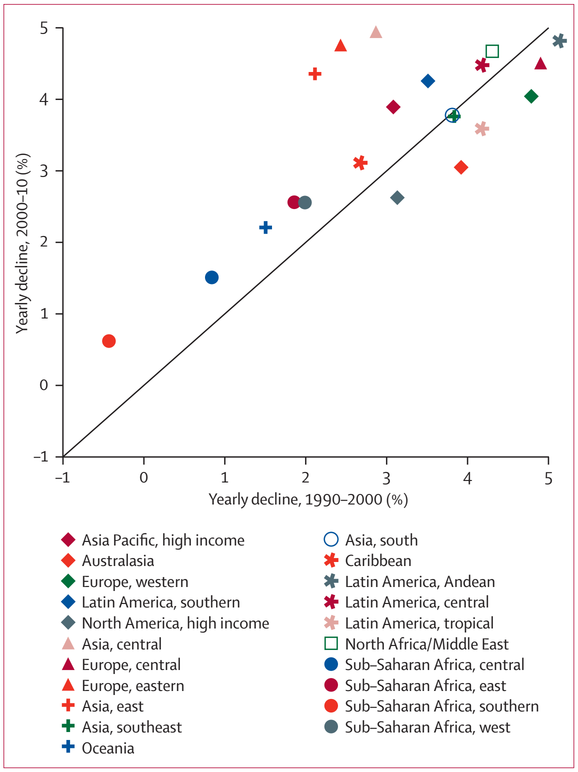

***Figure 8*: Yearly percentage decline (median country) in under-5 mortality in 2000–10 compared with 1990–2000, by region**

Under-5 mortality is defined as the probability of death between birth and age 5 years.

yearly rates of change from 1990 to 2008 in the two analyses is 0·46. Our assessment of rates of change was based on more extensive data and methods that more carefully track changes in countries than was the UNICEF study. We can draw important lessons from countries with rapid rates of decline in child mortality, but equally, we might draw the wrong inferences if we study countries that are not really showing outstanding improvements. The study of positive deviants needs particularly robust measurement.

There is compelling evidence that several low-income countries in sub-Saharan Africa are experiencing an accelerated decline in child mortality. Our descriptive analysis does not explain this occurrence. Increasing coverage of health interventions such as immunisation, insecticide-treated nets, prevention of mother-to-child transmission of HIV, or antiretroviral drugs could be contributing to the accelerated decline in mortality, although this study provides no direct evidence of this relation. In an era in which the effectiveness of development assistance for health has become increasingly important, following up this study with careful country case studies will be crucial. Can we link the accelerated declines in mortality to the delivery of known, effective interventions? Are there policy lessons on how governments and other organisations have tackled particular child health problems? A further next step will be to relate levels and trends in child mortality to changes in the key drivers of child mortality, including income per head, levels of maternal education, the HIV epidemic, and possibly the secular trend in malaria intensity[16] to help understand where country performance has been better than expected.

Examination of the distribution of yearly rates of change in under-5 mortality shows that the MDG 4 target of a reduction rate of 4·4% per year corresponds to performance at the 67th percentile level. With hindsight, we can ask whether setting the target at this level was appropriate or not. How much of a stretch should targets be? Looking past 2015, when a new round of health targets might be formulated, it will be important to base the choice of targets on an informed discussion of the distribution of progress across countries. This distribution of progress for child mortality also highlights that in 10% of country-years, rates of decline can exceed 6·4% per year. Bursts of rapid decline are possible. For example, 66 countries have decreased child mortality by more than 30% in just 5 years during the period of this study. Such remarkable declines provide hope that accelerated progress is possible. At the same time, there is evidence of a slowing decline in mortality in some countries—the USA, UK, New Zealand, and South Korea show rates of decline that are slower than expected. These cases deserve further scrutiny to identify factors responsible for slowdowns in progress which might be amenable to intervention.

This study has several limitations. For the analysis of complete birth histories, concerns have been raised that in recent DHS surveys, interviewers might have been transferring births from year 5 to year 6 in the interview to avoid extra questions.[42,43] We have analysed complete birth histories for 2-year intervals, which attenuates this effect. Additionally, we have included in the overall analysis the summary birth history data that are not affected by this occurrence. Results of a sensitivity analysis, which are covered in more detail in webappendix pp 10–16, suggest that birth transference has little effect on our estimates with the exception of Liberia. A study has shown that summary birth histories are very robust and might actually have less bias than do complete birth histories for the most recent periods.[19] The same study also showed that in the presence of rapid mortality change, summary birth histories can smooth out true changes. In other words, in the presence of mortality shocks or accelerated declines, we might be underestimating the increase or decrease in mortality.

As noted in the methods section, the HIV epidemic might be leading to underestimation or in some cases overestimation of under-5 mortality rates in countries with large HIV epidemics. Our sensitivity analysis suggests that the range of biases is likely to be between an underestimation of ten per 1000 for the under-5 death rate to an overestimation of six per 1000. The scale-up of interventions for HIV are probably decreasing these biases in the recent periods. The uncertainty in the measurement of the level and trend in under-5 mortality rates introduced by the HIV epidemic deserve increased attention by the mortality measurement research community.

The GPR procedure captures sampling error related to the size and design of each survey or study and some features of non-sampling error are also captured. One of the major advantages of the GPR method is that it provides a coherent approach to the assessment of uncertainty, both cross-sectionally and over time, that incorporates sampling error, non-sampling error, and parameter uncertainty. Nevertheless, there might be features of non-sampling error that are idiosyncratic to a particular survey in a particular country that are not captured in the analysis. For surveys with complete birth histories, we analysed both the summary birth history and the complete birth history from the same source; the estimated rates of mortality in children younger than 5 years in any given year from both analyses are not strictly independent so that stochastic sampling variance might be underestimated. Finally, there is always the concern that future surveys will show that some of the surveys in the current analysis record anomalous trends. To aid the work of others, we plan to release computer code to make it practical to implement GPR for child mortality synthesis and forecasting.

UNICEF has called for a focus on selected countries with the greatest number of child deaths.[14] Although this strategy is logical, if there are substantial fixed costs associated with maintaining effective programmes at the national level, it might be negated by the acceleration in progress in some countries. The resources and policy effort triggered by the MDGs and by advocation for greater attention to child health might finally be proving effective through accelerations in the rate of decline in some countries with the highest rates of child mortality. Most countries with accelerated progress will not achieve MDG 4. Nevertheless, the international community, through resources and technical support, might be able to play an important part in nurturing these trends. Rapidly reducing child deaths must remain a global health priority. This reduction will be aided by regular, careful, and rigorous assessments with new and comparable methods that inspire confidence in the level, and more importantly, the rate of decline of child mortality worldwide.

Contributors

JKR managed the research process, including data management, data analysis, and interpretation of results, and co-wrote the first draft of the report. JRM participated in data management, methods development, data analysis and interpretation, and contributed to the writing of the report. ADF contributed to methods development, and reviewed the report. HW, AL-R, MC, and LD contributed to data management and analysis, and reviewed the report. ADL conceived the research idea, contributed to data analysis and interpretation, and contributed to the writing of the report. CJLM conceived the research idea, contributed to data analysis and interpretation, and co-wrote the first draft of the report.

Conflicts of interest

We declare that we have no conflicts of interest.

Acknowledgments

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References

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

2 Bryce J, Terreri N, Victora CG, et al. Countdown to 2015: tracking intervention coverage for child survival. *Lancet* 2006; **368:** 1067–76.

3 Countdown Coverage Writing Group on behalf of the Countdown to 2015 Core Group. Countdown to 2015 for maternal, newborn, and child survival: the 2008 report on tracking coverage of interventions. *Lancet* 2008; **371:** 1247–58.

4 Child Mortality Coordination Group. Tracking progress towards the Millennium Development Goals: reaching consensus on child mortality levels and trends. *Bull World Health Organ* 2006; **84:** 225–32.

5 Department for International Development. The International Health Partnership launched today. 2007. http://www.dfid.gov.uk/Media-Room/News-Stories/2007/The-International-Health-Partnership-Launched-Today/ (accessed March 18, 2010).

6 Global Health Council News. Women and children first: a sneak peak at the global business plan for maternal, newborn and child health. 2007. http://www.globalhealth.org/news/article/9098 (accessed Sept 13, 2007).

7 UNFPA News. Second Regular Session UNDP/UNFPA Executive Board: statement by Thoraya Ahmed Obaid, Executive Director, UNFPA. 2007. http://www.unfpa.org/news/news.cfm?ID=1030 (accessed March 18, 2010).

8 UNICEF. Child mortality database: estimates for 2007. Nov 20, 2009. http://www.childmortality.org (accessed March 18, 2010).

9 UNICEF. Child mortality database: estimates for 2008. Nov 20, 2009. http://www.childmortality.org (accessed March 18, 2010).

10 United Nations Population Division. World population prospects: the 2008 revision population database. 2009. http://esa.un.org/unpp (accessed March 18, 2010).

11 Rohde J, Cousens S, Chopra M, et al. 30 years after Alma-Ata: has primary health care worked in countries? *Lancet* 2008; **372:** 950–61.

12 Kleinschmidt I, Schwabe C, Benavente L, et al. Marked increase in child survival after four years of intensive malaria control. *Am J Trop Med Hyg* 2009; **80**: 882–88.

13 Ndirangu J, Newell ML, Tanser F, Herbst AJ, Bland R. Decline in early life mortality in a high HIV prevalence rural area of South Africa: evidence of HIV prevention or treatment impact? *AIDS* 2010; **24:** 593–602.

14 You D, Wardlaw T, Salama P, Jones G. Levels and trends in under-5 mortality, 1990–2008. *Lancet* 2010; **375:** 100–03.

15 Ravishankar N, Gubbins P, Cooley RJ, et al. Financing of global health: tracking development assistance for health from 1990 to 2007. *Lancet* 2009; **373:** 2113–24.

16 WHO. World malaria report 2008. http://www.who.int/malaria/publications/atoz/9789241563697/en/index.html (accessed March 18, 2010).

17 GAVI Alliance. Investing in immunisation through the GAVI Alliance: the evidence base. 2010. http://www.gavialliance.org/resources/GAVI_Alliance_Evidence_Base_March_2010.pdf (accessed March 18, 2010).

18 Boerma JT, Stanecki KA, Newell ML, et al. Monitoring the scale-up of antiretroviral therapy programmes: methods to estimate coverage. *Bull World Health Organ* 2006; **84:** 145–50.

19 Rajaratnam JK, Tran LN, Lopez AD, Murray CJL. Measuring under-five mortality: validation of new low-cost methods. *PLoS Med* 2010; **7:** e1000253.

20 Garenne M, Gakusi E. Health transitions in sub-Saharan Africa: overview of mortality trends in children under 5 years old (1950–2000). *Bull World Health Organ* 2006; **84:** 470–78.

21 Brass W. Methods for estimating fertility and mortality from limited and defective data. Chapel Hill, NC: Laboratories for Population Statistics at the University of North Carolina at Chapel Hill, 1975.

22 Gaskell GD, Wright DB, O'Muircheartaigh CA. Telescoping of landmark events: implications for survey research. *Public Opin Q* 2000; **64:** 77–89.

23 Lessler JT, Sirken MG. Laboratory-based research on the cognitive aspects of survey methodology: the goals and methods of the National Center for Health Statistics Study. *Milbank Q* 1985; **63:** 565–81.

24 Wiener N. Extrapolation, interpolation, and smoothing of stationary time series. Cambridge, MA: MIT Press, 1949.

25 Thompson P. Optimum smoothing of two-dimensional fields. *Tellus* 1956; **8:** 84–93.

26 Paciorek P. Nonstationary Gaussian process for regression and spatial modeling. Pittsburgh, PA: Carnegie Mellon University, 2003.

27 Rasmussen CE, Williams CKI. Gaussian processes for machine learning. Cambridge, MA: MIT Press, 2006.

28 Uppsala Conflict Data Program. UCDP/PRIO armed conflict dataset v.4-2009, 1946–2008. 2009. http://www.ucdp.uu.se/database (accessed March 2, 2010).

29 Uppsala Conflict Data Program. UCDP non-state conflict dataset v. 2.1 2002–2007. 2009. http://www.ucdp.uu.se/database (accessed March 2, 2010).

30 Uppsala Conflict Data Program. UCDP non-state actor dataset v. 1-2009. 2009. http://www.pcr.uu.se/research/UCDP/data_and_publications/datasets.htm (accessed March 2, 2010).

31 Centre for Research on the Epidemiology of Disasters. Deaths due to natural disasters, 1900–2007. 2009. http://www.emdat.be/advanced-search (accessed Oct 12, 2009).

32 Centre for Research on the Epidemiology of Disasters. CE-DAT: The Complex Emergency Database. 2009. http://www.cedat.org (accessed March 11, 2010).

33 Ward P, Zaba B. The effect of HIV on the estimation of child mortality using the children surviving/children ever born technique. *South Afr J Demogr* 2008; **11**: 39–73.

34 Mahy M. Measuring child mortality in AIDS-affected countries. Sept 4, 2003. http://www.un.org/esa/population/publications/adultmort/UNICEF_Paper15.pdf (accessed Dec 18, 2009).

35 Nakiyingi JS, Bracher M, Whitworth JAG, et al. Child survival in relation to mother's HIV infection and survival: evidence from a Ugandan cohort study. *AIDS* 2003; **17:** 1827–34.

36 Drevenstedt GL, Crimmins EM, Vasunilashorn S, Finch CE. The rise and fall of excess male infant mortality. *Proc Natl Acad Sci USA* 2008; **105**: 5016–21.

37 Hammoud EI. Studies in fetal and infant mortality. II. Differentials in mortality by sex and race. *Am J Public Health Nations Health* 1965; **55:** 1152–63.

38 Harvard University, Institute for Health Metrics and Evaluation at the University of Washington, Johns Hopkins University, University of Queensland, WHO. Global Burden of Disease Study operations manual. 2009. http://www.globalburden.org/GBD_Study_Operations_Manual_Jan_20_2009.pdf (accessed March 9, 2010).

39 Preker AS, Wang J, Bos E, Peabody J, Jamison DT. Measuring country performance on health: selected indicators for 115 countries. World Bank, 1999.

40 World Bank. World development report 1993: investing in health. New York, NY: Oxford University Press, 1993.

41 Guillot M, Lim S. Infant mortality in Kyrgyzstan before and after the break-up of the Soviet Union. In: Harris K, Moffit R, eds. Population Association of America Annual Meeting; Detroit, MI, USA; April 30, 2009.

42 Arnold F. Assessment of the quality of birth history data in the demographic and health surveys. Report No. 1: an assessment of DHS-I data quality. 1990. http://www.measuredhs.com/pubs/pdf/MR1/MR1.pdf (accessed March 18, 2010).

43 Curtis SL. Assessment of the quality of data used for direct estimation of infant and child mortality in DHS-II surveys. Occasional Papers No. 3. 1995. http://www.measuredhs.com/pubs/pdf/OP3/OP3.pdf (accessed March 18, 2010).

44 Gregson S, Hallett TB, Kurwa F, et al. Monitoring progress towards Millennium Development Goal 4 in generalised HIV epidemics: measurement and correction for bias in child mortality statistics. IUSSP International Population Conference; Marrakech, Morocco; Sept 27, 2009.

45 Artzrouni M, Zaba B. HIV-induced bias in the estimation of child mortality using birth history reports. Technical Meeting on HIV and Child Mortality London; London, UK; March, 2003.