Maternal mortality for 181 countries, 1980–2008: a systematic analysis of progress towards Millennium Development Goal 5

Margaret C Hogan, Kyle J Foreman, Mohsen Naghavi, Stephanie Y Ahn, Mengru Wang, Susanna M Makela, Alan D Lopez, Rafael Lozano, Christopher J L Murray

Summary

Background **Maternal mortality remains a major challenge to health systems worldwide. Reliable information about the rates and trends in maternal mortality is essential for resource mobilisation, and for planning and assessment of progress towards Millennium Development Goal 5 (MDG 5), the target for which is a 75% reduction in the maternal mortality ratio (MMR) from 1990 to 2015. We assessed levels and trends in maternal mortality for 181 countries.**

Methods **We constructed a database of 2651 observations of maternal mortality for 181 countries for 1980–2008, from vital registration data, censuses, surveys, and verbal autopsy studies. We used robust analytical methods to generate estimates of maternal deaths and the MMR for each year between 1980 and 2008. We explored the sensitivity of our data to model specification and show the out-of-sample predictive validity of our methods.**

Findings **We estimated that there were 342 900 (uncertainty interval 302 100–394 300) maternal deaths worldwide in 2008, down from 526 300 (446 400–629 600) in 1980. The global MMR decreased from 422 (358–505) in 1980 to 320 (272–388) in 1990, and was 251 (221–289) per 100 000 livebirths in 2008. The yearly rate of decline of the global MMR since 1990 was 1·3% (1·0–1·5). During 1990–2008, rates of yearly decline in the MMR varied between countries, from 8·8% (8·7–14·1) in the Maldives to an increase of 5·5% (5·2–5·6) in Zimbabwe. More than 50% of all maternal deaths were in only six countries in 2008 (India, Nigeria, Pakistan, Afghanistan, Ethiopia, and the Democratic Republic of the Congo). In the absence of HIV, there would have been 281 500 (243 900–327 900) maternal deaths worldwide in 2008.**

Interpretation **Substantial, albeit varied, progress has been made towards MDG 5. Although only 23 countries are on track to achieve a 75% decrease in MMR by 2015, countries such as Egypt, China, Ecuador, and Bolivia have been achieving accelerated progress.**

Funding **Bill & Melinda Gates Foundation.**

Published **Online**
April 12, 2010
DOI:10.1016/S0140-6736(10)60518-1

See **Online/Comment**
DOI:10.1016/S0140-6736(10)60547-8

Institute for Health Metrics and Evaluation (M C Hogan MSc, K J Foreman AB, M Naghavi MD, S Y Ahn BA, M Wang BA, S M Makela BS, Prof R Lozano MD, Prof C J L Murray MD) **and Department of Health Services, School of Public Health** (M C Hogan), **University of Washington, Seattle, WA, USA; and School of Population Health, University of Queensland, Brisbane, QLD, Australia** (Prof A D Lopez PhD)

Correspondence to:
Prof Christopher J L Murray, Institute for Health Metrics and Evaluation, University of Washington, 2301 5th Avenue, Suite 600, Seattle, WA 98121, USA
cjlm@u.washington.edu

Introduction

Maternal mortality—the death of women during pregnancy, childbirth, or in the 42 days after delivery—remains a major challenge to health systems worldwide. Global initiatives to intensify policy intervention for maternal mortality began with the Safe Motherhood Initiative in 1987,[1] a response to growing recognition that primary health-care programmes in many developing countries were not adequately focused on maternal health.[2] The 1994 International Conference on Population and Development strengthened international commitment to reproductive health.[3,4] The focus on maternal mortality was sharpened when reduction in maternal mortality became one of eight goals for development in the Millennium Declaration (Millennium Development Goal [MDG] 5).[5] The target for MDG 5 is to reduce the maternal mortality ratio (MMR) by three-quarters from 1990 to 2015.[6] There is a widespread perception that progress in maternal mortality has been slow, and in many places non-existent.[7–9] Acceleration of progress in maternal mortality has received renewed policy attention in the USA through the Obama administration's proposed Global Health Initiative,[10] and high-profile civil society groups such as the White Ribbon Alliance continue to bring further attention.

The need for accurate monitoring of maternal mortality has long been recognised, both to advocate for resources and policy attention and to track progress.[11–13] Maternal mortality, however, is considered very difficult to measure.[14–17] Several efforts have been made over nearly three decades to improve the quality of information about maternal mortality, including the incorporation of sibling history modules in the Demographic and Health Surveys (DHS) and similar surveys;[18,19] the inclusion of questions about whether recent deaths were related to pregnancy in censuses;[20,21] and the use of record linkage or confidential enquiry to identify under-registration of maternal deaths in vital registration systems.[22,23]

Beginning in 1996, WHO sponsored the development of country estimates of maternal mortality for 1990, 1995, 2000, and 2005.[24–27] The most recent assessment of maternal mortality, which was jointly sponsored by WHO, UNICEF, UNFPA, and the World Bank, reported 576 300 maternal deaths globally in 1990, and

535 900 maternal deaths in 2005—a 0·48% yearly rate of decline.[7] The corresponding decrease in the global MMR (the number of maternal deaths per 100 000 live-births) was 0·37% per year. As a separate analysis, Hill and colleagues[7] estimated a rate of decline of 2·5% per year for a subset of 125 countries with more than one observation. For the two results to be consistent, a substantial proportion of the countries without multiple observations must have had increases in the MMR.

In view of the continued prominence of maternal mortality as a health and development goal, global rates and trends in maternal mortality need to be reassessed. Recent developments provide an opportunity for substantially improved estimates of maternal mortality. First, the Global Burden of Disease (GBD) study[28] has undertaken a detailed analysis of vital registration data to identify misclassified deaths from causes such as maternal mortality. Second, methodological advances allow for the correction of known biases in survey sibling history data, including whether sibling deaths are from maternal causes.[29] Third, population-based verbal autopsy studies have been done that measure maternal mortality both nationally and subnationally. Fourth, a systematic assessment of data sources for adult female mortality has provided estimates of mortality for women of reproductive age (15–49 years) from 1970 to 2010.[30] Finally, methodological developments in other areas have provided improved methods for estimation. In this study, we used all available data to assess levels and trends in maternal mortality from 1980 to 2008 for 181 countries.

Methods

Definitions

Table 1 classifies, by timing and cause, the types of maternal deaths among pregnant or recently pregnant (up to 1 year) women that can be captured by different data systems. Deaths during pregnancy or less than 42 days after termination of pregnancy were defined as early, and those after 42 days up to 1 year were defined as late. Four groups of causes were identified: direct obstetric causes, causes aggravated by pregnancy (often called indirect), HIV infection, and incidental causes unrelated to pregnancy. Vital registration systems using International Classification of Diseases 10th revision (ICD 10) assign deaths in categories A, B, E, and F to chapter O. The ICD manual[31] and the MDG manual[32] recommend that the maternal mortality rate should include deaths in categories A, B, and C. Late maternal deaths and deaths from incidental causes other than HIV should not be included in international comparisons of the MMR.

	Direct	Indirect	HIV	Incidental
Early maternal (<42 weeks)	A	B	C	D
Late maternal (>42 weeks and <1 year)	E	F		

Table 1: **Definitions of maternal death and maternal mortality**

Data sources

We systematically searched for data for maternal mortality from 1980 to the present. Data were divided into four types: vital registration systems; sibling history data from household surveys; data from censuses and surveys for deaths in the household; and published work reporting population-based studies of maternal mortality, both national and subnational.

Vital registration of data for cause of death is the most useful resource to measure maternal mortality. We constructed a dataset based mainly on the WHO mortality database,[33] and supplemented it by an internet search of national statistical offices. Several issues with vital registration data have to be taken into consideration in construction of a time series. First, periodic changes in the ICD rules and codes can lead to discontinuities that are not an indication of true trends. ICD 9 introduced two changes: clear definition of the 42-day period for a maternal death, and the inclusion of indirect causes of maternal death. ICD 10 explicitly added codes for late maternal deaths and made some changes in the coding practice for indirect causes.

Second, maternal deaths can be incorrectly assigned to other causes.[34] Causes that often include misclassified maternal deaths are disseminated intravascular coagulation (D65), peritonitis (K65), septicaemia (A41, A42), pulmonary embolism (I26), acute and chronic renal failure (N18 and N19), acute abdomen (R10), and hypovolaemic shock (R57.1).[23,28,35–37] Additionally, some maternal deaths can be assigned to ill-defined causes of death such as other ill-defined and unspecified causes of mortality (R99), unattended death (R98), and respiratory arrest (R09.2). Naghavi and colleagues[28] have produced a corrected vital registration dataset that provides 2186 country-years for 1980–2008. Correction for misclassification on average increases maternal deaths in the vital registration country-years by 40% (range 0–260), which is consistent with published work examining under-registration of maternal deaths.[38–40] Care is needed in interpretation of previous studies because some include suicides and late maternal deaths as under-registered deaths, which are not included in the official maternal death definition for the MMR. In this analysis, we counted all deaths coded to the maternal chapter in the ICD as maternal deaths, encompassing codes O00–O99. Importantly, the addition of late maternal deaths in ICD 10[41] could have led to some inconsistencies in time trends, but this effect will mostly be small. On average in ICD-10 datasets, less than 2% of maternal deaths are coded as late maternal, but there are some important exceptions, such as the USA.

We analysed sibling history microdata from the DHS[42] and the US Centers for Disease Control and Prevention (CDC) International Reproductive Health Surveys,[43]

www.thelancet.com Published online April 12, 2010 DOI:10.1016/S0140-6736(10)60518-1

totalling 97 surveys from 53 countries. Sibling histories ask respondents to report for all their siblings, including sex, date of birth, current status (alive or dead), and current age or age at death. For sisters who died between 15 and 49 years of age, questions identify whether the death occurred during pregnancy, childbirth, or within 6 weeks or 2 months after the termination of pregnancy. We pooled surveys together within countries and applied Gakidou-King weights to correct for survivor bias.[29,44] With use of these weights, we estimated the age-specific proportion of maternal deaths in women of reproductive age for 5-year periods starting from the time of the most recent survey in each country, for a maximum of 15 years before the most distant survey in each country.

A further 26 observations were based on survey or census information about deaths in households and whether the death occurred during pregnancy, childbirth, or within 6 weeks of delivery for women of reproductive age. Both the sibling history data and the household death data captured pregnancy-related deaths (categories A, B, C, and D in table 1) and thus could be an overestimate of the proportion of deaths attributable to maternal causes.

We undertook a literature review to identify published estimates of maternal mortality. We searched PubMed for the search terms "maternal mortality" and "country name" for all countries not part of the Organisation for Economic Co-operation and Development (OECD); we excluded OECD countries from this search because most of these countries have high-quality vital registration data. We also reviewed all citations in the WHO publication *Maternal Mortality: a Global Factbook*.[45] This search produced 9659 titles, of which 593 abstracts were identified as potentially relevant. 209 papers were identified from these abstracts, from which 61 studies were extracted and added to the database. We also did a search with the term "verbal autopsy" and identified 1042 titles, yielding a further 22 studies with data for maternal causes. We also searched the Chinese language website Wanfang Data with the search term "maternal mortality surveillance" and identified eight papers. Studies were excluded if they were based in a hospital or clinic, were intervention studies, used the indirect sisterhood method, or were judged to be of low quality. Indirect sisterhood studies were excluded because, at best, they provide a summary assessment of maternal mortality covering a long period before the survey.[46,47]

Before we undertook statistical analysis of the dataset combining all these data sources, implausible values or outliers in the data were identified via qualitative review. 314 of 2651 (11·8%) site-years of data were excluded via expert review with the following criteria: outliers relative to other measurements in the same country, outliers relative to what would be expected on the basis of the model predictions, and outliers relative to MMRs observed in countries with similar levels of development and health-system access. Many of these outliers were from subnational studies with implausibly low rates. These points are plotted on the graphs, but did not contribute to the estimation process.

Statistical analysis

From each of the data sources described above, we extracted the proportion of all female deaths that were attributable to maternal causes for 5-year age-groups in the reproductive age period (15–49 years). These proportions were applied to the new time series of adult female mortality based on a systematic assessment of all adult mortality sources for each country in 1970–2010.[30] For computation of MMRs, we used population and livebirths from the UN Population Division.[48]

We modelled both the count of maternal deaths by use of generalised negative binomial regression and the log of the maternal death rate with ordinary least squares (OLS) and robust regression (the webappendix pp 1 and 7 provides details on the sensitivity analysis). We also tested Poisson regression to model the count, but found its performance to be substantially worse than that with the generalised negative binomial (data not shown). On the basis of tests of predictive validity, we selected the modelling strategy with the best out-of-sample performance. Our modelling strategy was a variant of spatial-temporal regression that has been used in disciplines as disparate as geology, agriculture, and meteorology.[49,50] The basic form of the model is:

See Online for webappendix

$$1n\left(\mu_{a,i,t}\right)=\beta X_{a,i,t}+M_{a,i,t}+e$$

where μ is the maternal death rate, a is age, i is country, and t is a year. $X_{a,i,t}$ is a vector of covariates that explains variation in maternal mortality rates. Substantial variation in the maternal mortality rate is not explained by these covariates, and the unexplained component $M_{a,i,t}$ varies systematically over time and across countries. Spatial-temporal regression models capture this systematic variation through local regression with weights on time and space.[51] For Loess regression,[52] weighting occurs only in time and not across countries. e is the stochastic error in the maternal mortality rate due to sampling and to unmeasured factors that are not correlated in time and space.

The model was estimated in two stages: we first estimated the linear model $\beta X_{a,i,t}$ and then used spatial-temporal local regression to estimate $M_{a,i,t}$. Our choice for the linear model was dependent on available covariates; included covariates had to be comparable, complete time series for 1980–2008. On the basis of published work and previous theory, we selected the total fertility rate (TFR), gross domestic product (GDP) per head, HIV seroprevalence, neonatal mortality, age-specific female education, and indicators for 5-year age-groups (15–19, 20–24, 25–29, 30–34, 35–39, 40–44, and 45–49 years). We considered including skilled birth

attendance, but found it was collinear with other covariates (r=0·73 with neonatal mortality, r=0·72 with education, r=0·67 with GDP per head) and did not improve model performance (data not shown). We examined the univariate relation of each covariate with the dependent variable and with the model residuals to select the appropriate transformation of each covariate. We used robust regression, which uses Huber and biweights to keep the effect of outliers on the parameter estimates to a minimum.[53]

To estimate $M_{a,i,t}$ we applied spatial-temporal regression to the residuals over space and time from this first-stage model. The webappendix p 2 provides details of the space and time weights used for the spatial-temporal local regression. Weights were also included across age-groups so that findings for one age-group were informed by adjacent age-groups. Spatial correlation was allowed only within the 21 GBD regions used in this study. If a specific country had both national and subnational data, we assigned a fifth of the weight in the local regression to subnational studies and four-fifths of the weight to national studies to prevent excessive influence from subnational studies. Every local regression was estimated with OLS. We truncated observed residuals to three SDs of the mean of the residuals to reduce the effect of extreme outliers on the spatial-temporal regression.

	Site-years of observation
Vital registration	2186
Sibling histories	204
Surveillance systems	20
Census/survey deaths in household	26
National VA	35
Subnational VA	180
Total	2651

VA=verbal autopsy.

Table 2: **Summary of site-years of observation by source, 1980–2008**

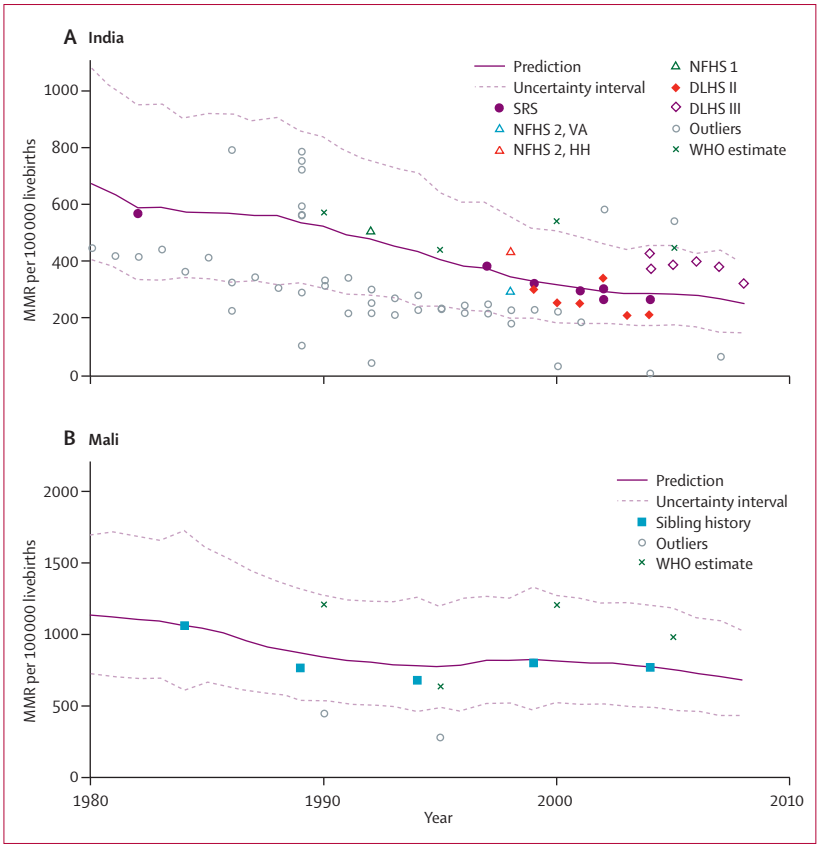

Figure 1: **Predicted maternal mortality ratio (MMR) per 100 000 livebirths for India (A) and Mali (B)**
SRS=sample registration system. NFHS=National Family Health Surveys. VA=verbal autopsy. HH=household. DLHS=District Level Household Surveys.

To validate our modelling approach, we undertook extensive tests of predictive validity. Four different types of predictive validity tests were undertaken: (1) withholding a random sample of 20% of country-years of data; (2) withholding all data from a random sample of 20% of countries; (3) withholding the first 20% of years of data for all countries; and (4) withholding the last 20% of years for all countries. For each of these datasets for which samples of the data had been withheld, we estimated our model including the linear and spatial-temporal local regression components and compared predictions of the MMR to the real data in the 20% of the sample withheld. We repeated these tests 30 times to ensure that our results were not an artifact of a specific random sample of the data being withheld. We also examined the predictive validity of a range of alternative model specifications and model families (webappendix p 8). We present results only for the linear component and the full model for the best performing strategy.

Our uncertainty estimates incorporated four sources of uncertainty: sampling uncertainty in the underlying measurements of the maternal mortality rate from the data sources; parameter uncertainty in both the linear model and the spatial-temporal local regressions;[54] and an estimate of fundamental uncertainty incorporating both the effect of non-sampling variance and systematic variation in the expected value not captured in the model. This conservative approach overestimates uncertainty because we would not want to propagate non-sampling variance into the estimate of uncertainty in the expected value of the maternal death rate. The webappendix pp 3–5 provides further details.

HIV-related maternal deaths were of particular interest. We undertook a counterfactual analysis, exploring the effect on maternal mortality of reducing HIV seroprevalence to zero. We generated counterfactual estimates of HIV-related deaths by use of the final estimated model (including both the linear and $M_{a,i,t}$ components), but set the HIV and HIV-squared covariates to zero. All analyses were done in Stata/MP (version 11.0).

www.thelancet.com Published online April 12, 2010 DOI:10.1016/S0140-6736(10)60518-1

Role of the funding source
The sponsors of the study had no role in study design, data collection, data analysis, data interpretation, or 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 2 shows the source of the 2651 observations included in the dataset. Vital registration data were the dominant source, accounting for 2186 (82%) of the total observations. Other sources contributed 465 observations. 21 countries had no empirical observations during 1980–2008 (webappendix p 10), the largest of which were Angola and Saudi Arabia in terms of births; together these countries accounted for 2·2% of global births. As a region, north Africa and the Middle East was particularly weak in terms of data density, apart from Egypt, Kuwait, and Iran. Because of the availability of sibling history data, many countries in sub-Saharan Africa had more than five observations. Most high-income countries had a nearly complete time series of vital registration data, whereas other low-income settings, such as Bangladesh and Tanzania, had substantial data from surveys and subnational studies.

Figure 1 and webappendix pp 11–12 show four different data scenarios along with our final predictions for the MMR. We had a complete time series of vital registration data from Mexico (webappendix p 11), showing a consistent, downward trend in the MMR from 1980 to 1995, and then a period of little change. The webappendix p 12 shows both vital registration and sibling history data from the Dominican Republic, for which the results of the sibling histories showed higher rates in every year. Our model estimates incorporated both sources of data. India (figure 1A) had the largest number of maternal deaths of any country, and several data sources were available to estimate maternal mortality. Figure 1A shows substantial inconsistencies between sources. In some cases, sources cover only a component of the national population, which could explain these patterns. For example, the Survey of Causes of Death, Rural[55] covers only rural populations and the Medical Certification of Causes of Death covers largely urban populations. We chose to use only national sources with the least apparent bias: the sample registration system,[56] the National Family Health Surveys (NFHS rounds 1 and 2), and the District Level Household Surveys (DLHS rounds 2 and 3). Together, these sources suggested a substantial decrease in maternal mortality, although sources varied substantially for any specific year. The most recent round of the DLHS provided substantially higher estimates than did previous rounds, but was in line with the NFHS 2. Figure 1B shows estimates from Mali, for which we had three DHS including a sibling history module (in 1995, 2001, and 2006). Similar data plots, along with the final estimates, are available for all countries in the webappendix pp 21–202.

The webappendix p 7 shows the β coefficients from the linear model. TFR showed the strongest relation with maternal mortality of all covariates; greater fertility was associated with increased maternal mortality. Of the covariates included in the model, GDP per head had the next strongest relation, with higher GDP being associated with lower rates of maternal mortality. All covariates were significant in the linear model ($p<0·001$), and were in the expected direction.

The webappendix p 8 shows predictive validity results for the four out-of-sample tests. All measures of out-of-sample performance showed better performance with the spatial-temporal model than with the linear model. In terms of median relative error, which is resistant to extreme outliers, for improvements relevant to 160 countries with some data, we noted a 61% (uncertainty interval 53–68) reduction in the error rate for prediction of missing country years, a 49% reduction for forecasting, and a 54% reduction for back-casting. Average relative error was higher than were the other measures, but also showed the substantial improvement with spatial-temporal regression methods.

We estimated that there were 342 900 (uncertainty interval 302 100–394 300) maternal deaths worldwide in 2008, down from 526 300 (446 400–629 600) in 1980, which is a yearly rate of decline of 1·5%. In a counterfactual scenario of a global HIV seroprevalence of zero, this number would be 281 500 (243 900–327 900), compared with 526 200 (444 500–633 900) in 1980, which is a rate of decline of 2·2%. Figure 2 shows the trends in the global number of deaths. With the onset of the HIV epidemic in the early 1990s, there was a slowing in the decline of global maternal deaths, with a rate of decline of 1·8% between 1980 and 1990 and 1·4% from 1990 to 2008. The MMR showed a similar consistent decline; we estimated the global MMR to be 251 (221–289) per 100 000 livebirths in 2008, down from 320 (272–388)

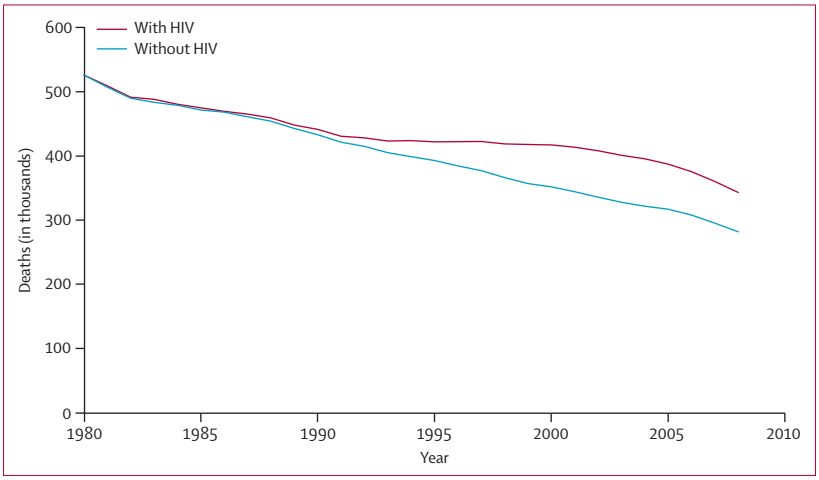

Figure 2: **Global maternal deaths, 1980–2008**

in 1990 and 422 (358–505) in 1980, which is a yearly rate of decline of 1·8%. For comparison, the MDG target of a 75% reduction from 1990 MMRs by 2015 would need a yearly rate of decline of 5·5%. In the absence of HIV prevalence, we estimated that the global MMR in 2008 would be 206 (179–240).

	1980	1990	2000	2008
Asia-Pacific, high income				
Brunei	77 (47–126)	62 (39–97)	44 (29–66)	37 (25–54)
Japan	20 (17–22)	12 (10–13)	8 (7–9)	7 (6–8)
Singapore	18 (13–23)	12 (9–16)	14 (10–18)	16 (11–21)
South Korea	45 (39–52)	18 (16–21)	14 (13–16)	11 (10–13)
Total	28 (26–31)	14 (13–15)	10 (9–11)	8 (8–9)
Asia, central				
Armenia	31 (24–38)	36 (31–41)	39 (30–49)	30 (21–39)
Azerbaijan	71 (59–83)	39 (33–44)	50 (43–58)	37 (30–45)
Georgia	40 (32–48)	28 (24–33)	27 (21–32)	37 (27–48)
Kazakhstan	62 (54–71)	61 (54–69)	58 (51–66)	44 (38–51)
Kyrgyzstan	71 (60–83)	65 (57–75)	71 (61–83)	69 (58–82)
Mongolia	959 (745–1193)	404 (316–501)	257 (203–320)	207 (163–255)
Tajikistan	128 (110–148)	90 (78–101)	72 (62–84)	46 (38–55)
Turkmenistan	77 (64–90)	67 (58–77)	41 (33–50)	22 (18–26)
Uzbekistan	72 (62–83)	61 (54–69)	49 (43–56)	45 (39–51)
Total	105 (96–115)	72 (68–77)	60 (56–64)	48 (45–52)
Asia, east				
China	165 (144–187)	87 (77–99)	55 (49–62)	40 (35–46)
North Korea	130 (47–298)	68 (27–148)	70 (26–154)	64 (24–143)
Taiwan	38 (23–56)	26 (15–37)	12 (7–16)	14 (8–20)
Total	162 (142–183)	86 (76–98)	55 (48–62)	40 (35–46)
Asia, south				
Afghanistan	1640 (632–3527)	1261 (491–2703)	1957 (729–4356)	1575 (594–3396)
Bangladesh	1329 (800–2105)	724 (420–1196)	574 (344–900)	338 (195–546)
Bhutan	2116 (814–4749)	1145 (437–2539)	481 (186–1063)	255 (100–561)
India	677 (408–1080)	523 (310–835)	318 (190–506)	254 (154–395)
Nepal	865 (536–1351)	471 (290–722)	343 (213–533)	240 (149–370)
Pakistan	746 (411–1267)	541 (327–848)	415 (235–679)	376 (230–587)
Total	788 (568–1099)	560 (391–794)	402 (293–555)	323 (232–444)
Asia, southeast				
Burma	1052 (401–2171)	662 (249–1484)	411 (155–874)	219 (87–495)
Cambodia	499 (324–751)	409 (237–658)	511 (322–786)	266 (171–398)
East Timor	1445 (549–3201)	1016 (402–2184)	953 (363–2081)	929 (374–2077)
Indonesia	423 (274–631)	253 (148–411)	290 (166–477)	229 (133–379)
Laos	1780 (1172–2715)	1215 (796–1816)	630 (377–996)	339 (215–511)
Malaysia	137 (118–160)	76 (66–89)	59 (51–67)	42 (37–49)
Maldives	1057 (405–2277)	366 (145–776)	125 (48–272)	75 (28–167)
Mauritius	122 (100–144)	65 (53–77)	34 (26–43)	28 (21–36)
Philippines	443 (289–661)	174 (112–261)	103 (65–160)	84 (53–130)
Sri Lanka	92 (81–105)	52 (46–60)	40 (36–46)	30 (25–35)
Thailand	115 (101–131)	44 (39–50)	43 (38–48)	47 (42–53)
Vietnam	336 (218–504)	158 (102–233)	84 (55–125)	64 (42–95)
Total	438 (337–573)	248 (187–337)	212 (155–293)	152 (112–212)
Australasia				
Australia	9 (7–10)	6 (5–7)	5 (4–6)	5 (4–6)
New Zealand	12 (9–16)	11 (8–14)	8 (6–10)	8 (6–11)
Total	9 (8–11)	7 (6–8)	6 (5–7)	6 (5–7)

(Continues on next page)

www.thelancet.com Published online April 12, 2010 DOI:10.1016/S0140-6736(10)60518-1

The webappendix pp 14–15 provides insights into the changing regional composition of maternal deaths. The number of births globally varied between 124 million in 1980 and 136 million in 2008. The regional composition shifted slowly towards sub-Saharan Africa, with the most noticeable change being the reduction in the number of births in east Asia. The proportion of global maternal deaths in sub-Saharan Africa increased from 23% (18–27) in 1980 to 52% (45–59) in 2008, resulting from both the accelerated increase in the number of maternal deaths in the early 1990s and declines in Asia.

The webappendix pp 16–19 shows how trends in the MMR have differed substantially across regions. Five regions had MMRs below 20 per 100 000 in 2008: Australasia, western Europe, Asia-Pacific high-income, central Europe, and North America high-income. In these five regions, the largest declines occurred in central Europe, with a decrease of more than two-thirds since 1980. Regions in eastern Europe, east Asia, southern Latin America, central Asia, tropical Latin America, and central Latin America had MMRs less than 60 in 2008. East Asia had a decline greater than three-quarters over

	1980	1990	2000	2008
(Continued from previous page)				
Caribbean				
The Bahamas	120 (81–163)	80 (56–104)	66 (50–86)	59 (45–77)
Barbados	99 (72–133)	86 (65–110)	94 (68–121)	78 (54–104)
Belize	120 (83–168)	88 (65–120)	87 (68–107)	74 (55–94)
Cuba	62 (54–71)	47 (41–54)	51 (45–59)	40 (34–46)
Dominican Republic	127 (78–199)	96 (58–154)	74 (45–116)	66 (40–103)
Grenada	155 (60–341)	99 (38–217)	66 (24–143)	47 (18–102)
Guyana	216 (161–281)	162 (134–192)	164 (139–191)	143 (110–178)
Haiti	1122 (708–1726)	898 (562–1413)	783 (488–1244)	582 (352–902)
Jamaica	82 (69–97)	50 (40–61)	37 (29–47)	34 (27–44)
Saint Lucia	162 (61–369)	92 (33–197)	57 (22–125)	46 (18–99)
Saint Vincent and the Grenadines	174 (64–374)	82 (31–181)	59 (23–130)	45 (17–97)
Suriname	175 (140–216)	106 (82–131)	128 (102–159)	116 (91–145)
Trinidad and Tobago	68 (55–82)	66 (55–78)	52 (40–64)	40 (30–51)
Total	426 (293–613)	348 (234–518)	323 (218–483)	254 (168–372)
Europe, central				
Albania	58 (49–69)	36 (31–43)	12 (9–15)	8 (6–11)
Bosnia and Herzegovina	58 (45–73)	32 (25–40)	20 (15–26)	12 (9–15)
Bulgaria	36 (31–43)	34 (29–39)	36 (30–42)	28 (22–35)
Croatia	21 (15–27)	15 (11–19)	15 (11–19)	14 (11–19)
Czech Republic	20 (16–25)	12 (10–15)	7 (5–9)	7 (5–9)
Hungary	22 (18–26)	16 (14–19)	10 (8–12)	7 (5–9)
Macedonia, the Former Yugoslav Republic of	28 (20–38)	20 (14–27)	19 (13–25)	17 (11–23)
Montenegro	79 (31–178)	33 (13–72)	27 (10–60)	19 (8–41)
Poland	22 (19–25)	21 (19–24)	10 (9–12)	7 (6–9)
Romania	139 (122–157)	92 (80–104)	42 (37–48)	26 (22–31)
Serbia	15 (11–20)	12 (8–16)	10 (8–13)	9 (6–11)
Slovakia	19 (14–25)	13 (9–18)	8 (6–11)	7 (5–9)
Slovenia	30 (20–43)	16 (11–22)	21 (15–29)	19 (13–26)
Total	47 (43–51)	34 (31–37)	18 (17–20)	13 (12–14)
Europe, eastern				
Belarus	30 (24–35)	28 (24–32)	26 (21–31)	19 (15–23)
Estonia	34 (26–46)	28 (22–36)	24 (18–33)	22 (16–33)
Latvia	37 (30–45)	30 (24–36)	24 (18–31)	18 (13–25)
Lithuania	33 (26–40)	22 (18–27)	18 (13–22)	16 (12–21)
Moldova	58 (49–68)	42 (36–48)	31 (25–37)	20 (16–26)
Russian Federation	60 (52–68)	48 (43–55)	45 (39–51)	34 (30–39)
Ukraine	44 (38–50)	35 (31–40)	35 (31–40)	30 (26–34)
Total	54 (49–60)	43 (39–48)	41 (37–45)	32 (29–35)

(Continues on next page)

the period, although we noted substantial heterogeneity between countries, whereas eastern Europe had only a slow reduction over the same period. Regions in north Africa and the Middle East, Latin America Andean, southeast Asia, Oceania, and the Caribbean had MMRs less than 280 in 2008. Rates of decrease have been consistent in these regions, apart from the slowdown in the Caribbean that is related to HIV infection, as shown in the HIV counterfactual analysis (webappendix pp 13 and 20). Both south Asia and all regions of sub-Saharan Africa had MMRs higher than 280 in 2008, but south Asia has had a substantial decline since 1980; in all

	1980	1990	2000	2008
(Continued from previous page)				
Europe, western				
Austria	14 (11–17)	8 (6–10)	5 (4–7)	6 (4–7)
Belgium	13 (10–16)	8 (7–10)	10 (8–13)	9 (7–12)
Cyprus	148 (18–278)	98 (12–184)	57 (7–109)	41 (5–78)
Denmark	7 (5–10)	7 (5–9)	7 (5–9)	9 (6–13)
Finland	7 (5–9)	7 (6–10)	7 (5–9)	7 (5–9)
France	19 (17–22)	14 (12–16)	11 (10–13)	10 (9–12)
Germany	20 (18–23)	12 (10–13)	8 (7–9)	7 (6–8)
Greece	18 (15–22)	8 (6–9)	8 (7–10)	8 (6–11)
Iceland	11 (4–24)	9 (4–20)	8 (3–18)	7 (3–16)
Ireland	11 (8–13)	7 (5–9)	7 (5–10)	6 (4–8)
Israel	9 (7–11)	11 (9–13)	8 (6–9)	6 (4–8)
Italy	14 (12–16)	7 (6–8)	5 (4–6)	4 (3–5)
Luxembourg	9 (4–19)	7 (2–15)	6 (2–13)	5 (2–11)
Malta	21 (8–45)	15 (6–33)	9 (4–20)	6 (2–13)
Netherlands	10 (8–11)	9 (8–11)	10 (8–11)	8 (6–9)
Norway	7 (5–10)	7 (5–9)	7 (5–10)	8 (5–10)
Portugal	29 (25–33)	16 (13–19)	12 (9–14)	10 (7–12)
Spain	18 (16–21)	9 (8–10)	7 (6–8)	7 (6–8)
Sweden	6 (5–7)	6 (5–8)	5 (4–6)	5 (3–6)
Switzerland	9 (7–11)	7 (5–9)	7 (5–9)	7 (5–9)
UK	10 (9–12)	8 (7–10)	8 (7–10)	8 (7–10)
Total	16 (15–17)	10 (10–11)	8 (8–9)	7 (7–8)
Latin America, Andean				
Bolivia	547 (344–845)	439 (276–666)	269 (168–413)	180 (110–284)
Ecuador	288 (178–443)	181 (114–281)	121 (69–196)	77 (48–119)
Peru	268 (165–406)	172 (110–262)	125 (79–195)	81 (50–123)
Total	326 (248–426)	229 (176–295)	156 (116–205)	103 (77–134)
Latin America, central				
Colombia	115 (102–130)	71 (62–81)	61 (54–70)	46 (41–53)
Costa Rica	39 (33–46)	32 (27–37)	32 (27–38)	25 (21–30)
El Salvador	216 (139–325)	135 (85–203)	63 (38–99)	37 (23–57)
Guatemala	189 (113–296)	178 (108–279)	111 (68–170)	88 (55–141)
Honduras	174 (104–279)	164 (100–254)	169 (106–257)	105 (66–162)
Mexico	124 (109–140)	73 (64–83)	60 (53–69)	52 (45–58)
Nicaragua	145 (90–224)	101 (60–159)	124 (75–196)	103 (63–162)
Panama	80 (67–92)	61 (51–72)	51 (44–59)	44 (35–54)
Venezuela	74 (65–83)	66 (58–75)	56 (49–63)	48 (42–55)
Total	125 (114–137)	85 (77–94)	70 (64–78)	57 (51–63)
Latin America, southern				
Argentina	80 (71–91)	60 (53–68)	52 (46–59)	49 (43–55)
Chile	70 (62–80)	44 (38–50)	24 (21–28)	21 (18–25)
Uruguay	55 (46–64)	33 (27–39)	26 (21–32)	25 (18–31)
Total	76 (69–84)	54 (49–60)	44 (39–49)	41 (36–45)

(Continues on next page)

www.thelancet.com Published online April 12, 2010 DOI:10.1016/S0140-6736(10)60518-1

	1980	1990	2000	2008
(Continued from previous page)				
Latin America, tropical				
Brazil	149 (84–242)	112 (64–186)	69 (43–106)	55 (34–86)
Paraguay	185 (111–288)	146 (92–224)	129 (80–200)	113 (70–173)
Total	150 (87–240)	113 (66–184)	71 (47–107)	57 (37–87)
North Africa/Middle East				
Algeria	396 (336–464)	189 (159–219)	94 (80–109)	66 (56–77)
Bahrain	132 (84–204)	89 (58–138)	49 (30–70)	36 (23–52)
Egypt	352 (217–550)	195 (120–312)	74 (46–114)	43 (25–71)
Iran	101 (65–155)	64 (40–96)	35 (21–53)	28 (17–43)
Iraq	241 (136–404)	212 (131–335)	174 (107–270)	130 (73–211)
Jordan	214 (133–327)	103 (63–155)	59 (37–91)	35 (19–59)
Kuwait	51 (36–67)	48 (34–65)	31 (22–42)	26 (18–36)
Lebanon	124 (49–269)	76 (30–168)	37 (14–78)	24 (9–53)
Libya	148 (58–319)	124 (46–271)	63 (24–140)	40 (15–89)
Morocco	601 (396–885)	384 (240–570)	262 (165–402)	124 (70–200)
Occupied Palestinian Territory	181 (114–275)	92 (57–144)	52 (30–84)	46 (27–71)
Oman	174 (102–256)	85 (49–126)	41 (26–59)	24 (16–33)
Qatar	52 (21–114)	49 (18–107)	26 (9–62)	14 (5–31)
Saudi Arabia	135 (52–297)	94 (36–208)	47 (19–104)	28 (11–61)
Syria	251 (143–411)	156 (92–251)	67 (39–108)	50 (28–84)
Tunisia	294 (111–643)	141 (57–312)	56 (22–121)	36 (14–79)
Turkey	251 (143–412)	121 (73–188)	69 (41–108)	58 (32–101)
United Arab Emirates	41 (15–91)	31 (12–66)	14 (5–30)	9 (3–19)
Yemen	808 (479–1273)	582 (337–921)	383 (227–606)	269 (162–435)
Total	299 (250–355)	183 (154–218)	111 (92–135)	76 (61–94)
North America, high income				
Canada	7 (6–9)	6 (5–7)	6 (5–7)	7 (5–8)
USA	12 (11–14)	12 (10–13)	13 (12–15)	17 (15–19)
Total	12 (10–13)	11 (10–12)	13 (11–15)	16 (14–18)
Oceania				
Fiji	178 (66–397)	133 (50–285)	111 (41–244)	85 (32–194)
Micronesia, Federated States of	378 (142–825)	227 (87–488)	164 (61–381)	127 (48–279)
Papua New Guinea	585 (343–956)	476 (267–782)	371 (212–603)	312 (184–507)
Samoa	246 (91–554)	173 (65–386)	154 (57–345)	104 (39–236)
Solomon Islands	719 (274–1606)	500 (188–1081)	330 (126–747)	284 (102–638)
Tonga	359 (129–826)	189 (70–400)	130 (48–279)	113 (42–250)
Vanuatu	509 (192–1147)	336 (127–725)	230 (84–505)	178 (66–400)
Total	517 (334–784)	416 (252–649)	329 (202–518)	279 (174–434)
Sub-Saharan Africa, central				
Angola	1309 (492–2909)	1156 (447–2571)	1105 (425–2466)	593 (236–1282)
Central African Republic	990 (623–1512)	1757 (1084–2731)	1988 (1161–3220)	1570 (981–2407)
Congo (Brazzaville)	897 (558–1395)	616 (356–1039)	850 (521–1336)	617 (378–972)
Congo, the Democratic Republic of the	498 (321–746)	550 (314–906)	607 (379–927)	534 (311–856)
Equatorial Guinea	663 (271–1459)	775 (283–1661)	670 (258–1447)	302 (115–655)
Gabon	403 (247–622)	422 (248–692)	637 (408–970)	493 (310–742)
Total	711 (487–1072)	732 (488–1101)	770 (535–1108)	586 (392–839)
Sub-Saharan Africa, east				
Burundi	776 (291–1713)	712 (279–1560)	904 (346–1996)	570 (221–1240)
Comoros	699 (268–1520)	450 (175–989)	293 (110–642)	225 (89–488)
Djibouti	641 (384–1025)	607 (356–961)	565 (337–897)	462 (274–738)
Eritrea	1436 (841–2371)	1293 (790–1970)	874 (526–1389)	751 (442–1210)

(Continues on next page)

parts of sub-Saharan Africa rates have increased in the 1990s. Trends in MMRs, excluding deaths from HIV infection, showed decreases during 1980–2008 in eastern and southern Africa, and a slower decline in central and western Africa.

Table 3 presents the MMR with uncertainty bounds, for each country, in 1980, 1990, 2000, and 2008. Figure 3 shows the results for 2008. In 2008, the highest MMR (in Afghanistan: 1575, uncertainty interval 594–3396) was about 394 times higher than the lowest MMR (in Italy: 4, 3–5). We recorded noticeable variation within regions. Within Latin America and the Caribbean, Paraguay, Bolivia, Guyana, Haiti, Nicaragua, Honduras, and Suriname had MMRs greater than 100 per 100 000 live-

	1980	1990	2000	2008
(Continued from previous page)				
Ethiopia	1061 (665–1639)	968 (600–1507)	937 (543–1537)	590 (358–932)
Kenya	494 (307–768)	452 (263–732)	730 (437–1157)	413 (236–678)
Madagascar	490 (308–747)	484 (305–746)	505 (313–781)	373 (229–574)
Malawi	632 (395–966)	743 (457–1127)	1662 (1034–2551)	1140 (675–1813)
Mozambique	411 (228–668)	385 (241–591)	505 (311–796)	599 (359–957)
Rwanda	755 (468–1171)	813 (508–1223)	952 (610–1449)	383 (249–584)
Somalia	1061 (405–2308)	963 (380–2105)	837 (329–1856)	675 (263–1501)
Sudan	639 (395–971)	593 (367–908)	490 (308–741)	306 (195–463)
Tanzania	603 (380–925)	610 (375–940)	714 (411–1162)	449 (273–721)
Uganda	435 (258–709)	571 (355–893)	604 (366–963)	352 (215–558)
Zambia	599 (359–950)	594 (365–932)	914 (555–1421)	603 (376–928)
Total	707 (586–854)	690 (574–842)	776 (639–948)	508 (430–610)
Sub-Saharan Africa, southern				
Botswana	424 (166–891)	237 (90–529)	655 (255–1468)	519 (199–1133)
Lesotho	588 (369–896)	363 (227–555)	1021 (655–1519)	964 (599–1482)
Namibia	397 (235–639)	354 (226–525)	558 (355–853)	586 (363–899)
South Africa	208 (131–316)	121 (73–190)	155 (95–248)	237 (146–372)
Swaziland	559 (314–923)	359 (208–587)	609 (369–945)	736 (460–1124)
Zimbabwe	219 (135–334)	232 (143–362)	819 (474–1342)	624 (371–976)
Total	242 (184–319)	171 (132–222)	373 (280–499)	381 (288–496)
Sub-Saharan Africa, west				
Benin	829 (476–1370)	588 (343–947)	551 (341–842)	469 (294–716)
Burkina Faso	541 (342–830)	488 (307–745)	456 (286–707)	332 (208–522)
Cameroon	810 (507–1254)	523 (308–845)	886 (549–1415)	705 (393–1155)
Cape Verde	528 (289–854)	229 (118–384)	139 (75–223)	75 (41–120)
Chad	978 (629–1473)	891 (562–1358)	1205 (746–1880)	1065 (661–1636)
Côte d'Ivoire	590 (378–884)	580 (350–916)	1116 (719–1643)	944 (566–1500)
The Gambia	898 (516–1464)	628 (404–936)	396 (246–610)	281 (171–441)
Ghana	731 (444–1157)	549 (336–857)	538 (329–819)	409 (248–633)
Guinea	1140 (726–1722)	965 (610–1453)	976 (616–1491)	860 (529–1314)
Guinea-Bissau	1155 (644–1890)	966 (589–1510)	809 (486–1246)	804 (454–1332)
Liberia	645 (394–1005)	729 (446–1130)	1055 (651–1642)	859 (547–1289)
Mali	1125 (712–1688)	831 (525–1263)	807 (513–1258)	670 (422–1017)
Mauritania	1491 (948–2265)	1295 (761–2099)	866 (505–1386)	712 (451–1119)
Niger	1083 (669–1696)	890 (526–1483)	754 (470–1176)	601 (373–927)
Nigeria	516 (334–757)	473 (306–703)	694 (435–1041)	608 (372–946)
Sao Tome and Principe	607 (241–1312)	531 (210–1188)	420 (164–912)	296 (112–607)
Senegal	670 (395–1064)	542 (352–822)	491 (306–765)	401 (252–622)
Sierra Leone	1240 (800–1880)	1044 (685–1592)	1200 (745–1824)	1033 (635–1627)
Togo	600 (388–906)	540 (351–819)	552 (352–837)	447 (289–672)
Total	683 (577–818)	582 (485–709)	742 (608–915)	629 (508–787)

Regional maternal mortality ratios were calculated by summing regional maternal deaths and dividing by regional births. *Regions defined by the Global Burden of Disease study.[28]

Table 3: **Maternal mortality ratio (uncertainty interval) per 100 000 livebirths by region* and country**

www.thelancet.com **Published online April 12, 2010 DOI:10.1016/S0140-6736(10)60518-1**

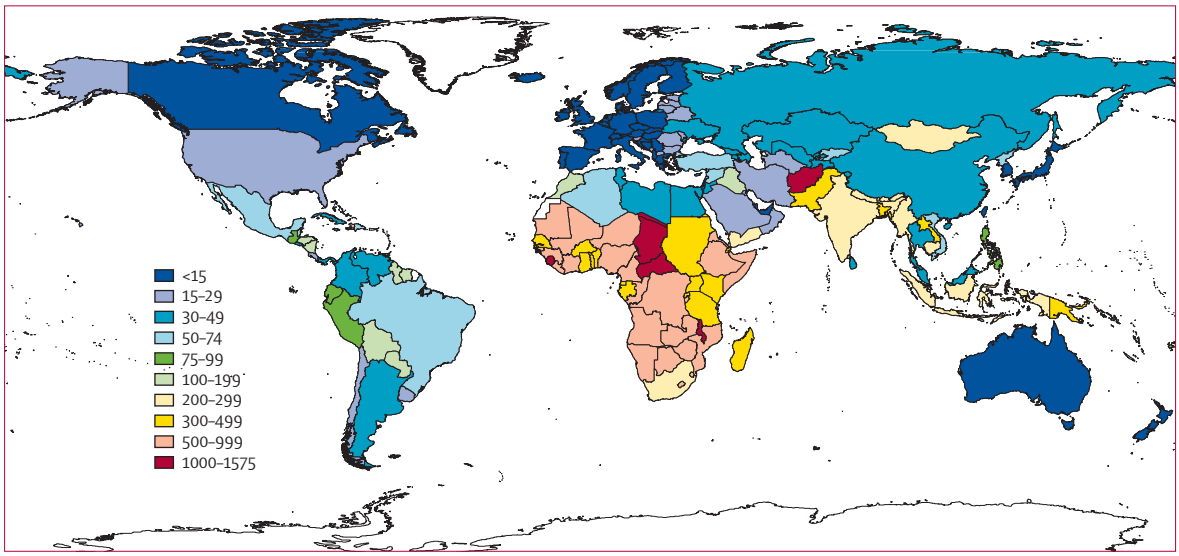

Figure 3: **Maternal mortality ratio per 100 000 livebirths, 2008**

births. Ratios were noticeably low in north Africa and the Middle East, with the exception of Iraq, Yemen, and Morocco, although there were less data available in this region. Ratios were much higher throughout sub-Saharan Africa than in other regions, and ranged from 75 (41–120) in Cape Verde to 1570 (981–2407) in Central African Republic, a ratio of 21. The range across South Asia was substantial, from 1575 (594–3396) in Afghanistan to 240 (149–370) in Nepal; the MMR in India was 254 (154–395). Southeast Asia also showed huge heterogeneity, with the highest ratios reported in East Timor and the lowest in Mauritius (table 3).

The webappendix p 9 shows the 21 countries with the highest numbers of maternal deaths in 2008. Together, these countries represent 79·4% of total global maternal deaths and 60·6% of global livebirths. Although table 3 shows that MMRs were substantially higher in sub-Saharan Africa than in other regions, south Asia was a major contributor in terms of total numbers of maternal deaths.

We focused on the period of the MDGs when considering trends in the time series. Figure 4 shows the yearly rate of change in the MMR for 1990–2008. To elucidate the effect of the HIV epidemic on the MMR, the webappendix p 20 shows the yearly rates of change if we remove HIV-related deaths from the estimated MMR. These data show the substantial variation in performance across countries in reduction of the MMR. Countries in north Africa and the Middle East, parts of Latin America, and south and east Asia had the largest declines. Increases in the MMR have been documented in countries with large HIV epidemics in southern Africa, and in Nigeria, Chad, Gabon, and Central African Republic. Examination of the rates of change with HIV-related deaths excluded showed that southern Africa would have had declines, but that increases in many parts of central and west Africa were not solely related to the HIV epidemic.

Figure 4 also shows the rise in the MMR in the USA, Canada, Norway, and Afghanistan. Although the rise in Afghanistan could be a real trend, improved ascertainment of maternal deaths and the inclusion of late maternal deaths in ICD 10 could explain the increases in the other countries. Other countries with fairly low MMR, such as Cuba and Thailand, had little change in the MMR during the MDG period.

Discussion

Our analysis of all available data for maternal mortality from 1980 to 2008 for 181 countries has shown a substantial decline in maternal deaths. Progress overall would have been greater if the HIV epidemic had not contributed to substantial increases in maternal mortality in eastern and southern Africa. Global progress to reduce the MMR has been similar to progress to reduce maternal deaths, since the size of the global birth cohort has changed little during this period. Across countries, average yearly rates of decline from 1980 to 2008 in the MMR differed widely. This new evidence suggests there is a much greater reason for optimism than has been generally perceived, and that substantial decreases in the MMR are possible over a fairly short time.

Global progress to reduce the MMR should perhaps not be seen as surprising. Four powerful drivers of maternal mortality are improving in most countries. First, the global TFR has dropped from 3·70 in 1980, to 3·26 in 1990 and 2·56 in 2008. Despite rising numbers of women of reproductive age, the decrease in TFR has kept the size of the global birth cohort stable. In addition to the direct effect of fertility on exposure to risk of maternal death,[57] the MMR and TFR are strongly correlated.[5,58] Societies in which the TFR decreases are

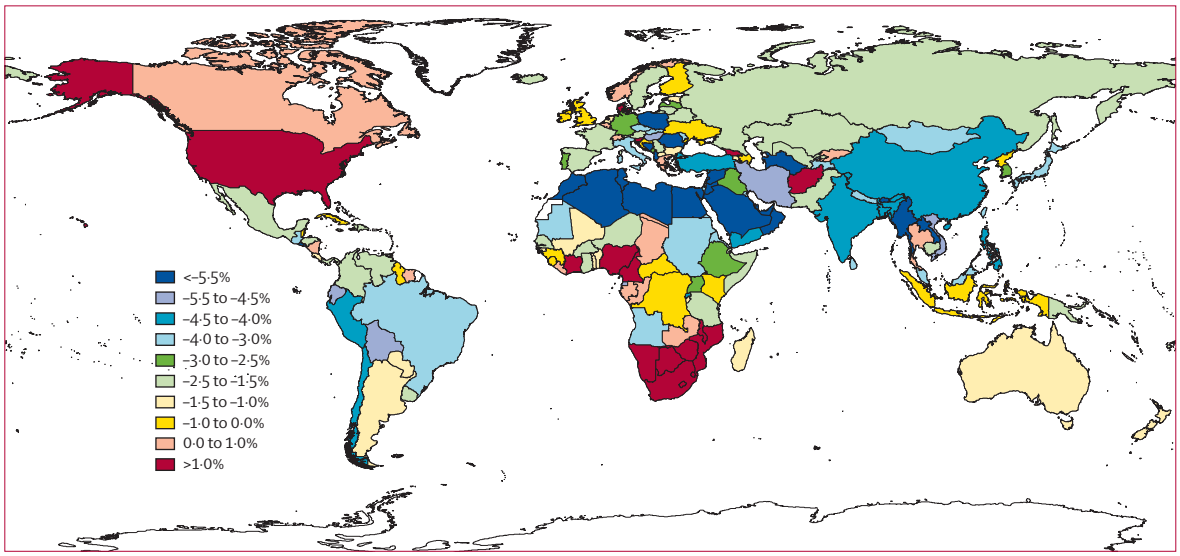

Figure 4: **Yearly rate of decline in maternal mortality ratio, 1990–2008**

also places with declines in the MMR—whether this relation is causal or mediated through social change that drives both is not clear. Second, income per head, which can affect maternal mortality through several channels from nutritional status of mothers to physical and financial access to health care,[59] has been rising particularly in Asia and Latin America. Third, maternal educational attainment, another strong correlate of maternal mortality, has been rising—eg, average years of schooling of women aged 25–44 years in sub-Saharan Africa increased from 1·5 in 1980 to 4·4 in 2008. Finally, although we did not include the proportion of women giving birth with a skilled attendant as a covariate in our model because of collinearity, the steady, albeit slow, rise in coverage of skilled birth attendance could have contributed to maternal mortality declines.[60] Further, some large countries such as India have witnessed quite rapid increases in skilled birth attendance in recent years.[61] The combination of these factors suggests that a finding that the global MMR was not declining would be more surprising.

Our analysis, in line with previous studies,[5,62,63] draws attention to the important adverse effect of the HIV epidemic on the MMR, especially in east and southern Africa. In the absence of HIV, progress in sub-Saharan Africa in reducing the MMR would have been much more extensive than we recorded. The counterfactual analysis of the MMR without HIV-related deaths has important implications for intervention policy. The set of interventions for dealing with HIV infection in pregnant or post-partum women would include access to antiretroviral drugs, which is not part of the set of maternal health interventions targeting women who are HIV negative. Tracking of HIV-related maternal mortality is important but challenging in settings without vital registration. In countries with complete vital registration systems, including South Africa,[30] the use of a checkbox to identify women who were pregnant at the time of death or within 42 days before death could be a useful adjunct.[22,64]

Some countries have had much success in reducing the MMR. In 1990–2008, countries with substantial declines in MMR included Egypt, Romania, Bangladesh, India, and China. In some cases, policy case studies have been written about these countries.[65–70] In others, no policy analyses have yet been published. Although our analysis does not provide explanations for these accelerated decreases, we hope that the results will stimulate detailed policy reviews. By contrast, some countries that are judged to be successful in terms of maternal mortality, such as Indonesia, have not had particularly rapid declines in this ratio.[71] In these cases, whether there are other data sources missing that would change the estimated trend or whether there is a disconnect between increases in skilled birth attendance or other maternal health interventions and actual changes in the MMR needs to be explored.

Comparison of pairs of countries shows the complexity of understanding trends in the MMR. From 1990 to 2008, the MMR decreased 1·9% every year in Mexico and 3·9% in Brazil. Both are large complex federal states that have had many improvements in adult mortality mediated through social, economic, and health-system change. Both have placed substantial policy emphasis to reduce maternal mortality,[72,73] but Brazil has outperformed Mexico in terms of declines. In Asia, India and Indonesia have achieved substantially different rates of decline. In 1980, the MMR was 677 in India, which was substantially higher than the ratio of 423 in Indonesia. Over the MDG period, India has seen a yearly rate of decline of 4·0%, whereas Indonesia has lagged with a yearly decrease of only 0·6%. This differential performance means that the two countries now have similar MMRs.

www.thelancet.com Published online April 12, 2010 DOI:10.1016/S0140-6736(10)60518-1

Egypt and Turkey provide another interesting comparison. Egypt has seen an impressive improvement from 1990 to 2008, with a yearly decrease of 8·4%, whereas Turkey has seen a slower rate of decline of only 4·2%. In 1990, the ratio of MMRs in Egypt compared with Turkey was 1·6, but after nearly 20 years of steady progress in Egypt, Turkey now has a higher MMR than Egypt, with a ratio of 1·3.

One of the most surprising results is the apparent rise in the MMR in the USA, Canada, and Norway. This finding is likely to be partly explained by the introduction of late maternal deaths in the ICD 10, and the inclusion of a separate pregnancy status question on the US death certificate.[74] This addition to the US death certificate was intended to improve ascertainment of pregnancy-related deaths, which our results suggest that it has done. However, it raises important questions about how these maternal deaths were being coded before the introduction of the pregnancy status question on the death certificate.

Our results for 2005 differ substantially from the assessment undertaken by Hill and colleagues.[7] This discrepancy could have several explanations. First, we used a dataset with nearly three times as many observations as Hill and co-workers had. Second, Hill and colleagues modelled the proportion of deaths in women of reproductive age, which is likely to be confounded by the rise of HIV infections. Other investigators have questioned the choice of the proportion as the dependent variable.[75] We modelled the maternal mortality rate. Third, our method captures systematic spatial and temporal variation, shown by improved performance in predictive validity tests. Fourth, this study used improved adult mortality estimates based on a systematic assessment of all available data. Finally, Hill and colleagues developed subjective uncertainty intervals for each country and then made the unusual assumption that uncertainty across countries was perfectly correlated in the generation of global and regional uncertainty intervals; we have taken an approach that uses a statistical framework.

Our study has several important limitations. In countries with complete vital registration systems, we might be overestimating maternal deaths. We have used data for cause of death in which the misclassification of maternal deaths to causes such as septicaemia has been carefully corrected. Vital registration data, however, also include late maternal deaths that occur after 42 days. The UN MDG and ICD manuals recommend that late maternal deaths should not be counted in the MMR but, in most countries, we are unable to identify these deaths from the vital registration data. The proportion of late maternal deaths is probably higher in countries with low MMR than in those with high ratios.[35,74]

In countries with incomplete vital registration systems, we could be underestimating the proportion of deaths attributable to maternal causes. Although vital registration data used in our model have been corrected for misclassification, the proportion might be biased downwards if an incomplete system excludes populations at increased risk of maternal death.

For countries in which the primary source of data is surveys or censuses, our numerator includes incidental deaths in pregnant women from causes such as motor vehicle accidents, burning, or drowning. These deaths should not be counted as maternal deaths since they would bias our estimates upwards, but no clear analytical strategy is available to identify the proportion of pregnancy-related deaths that are incidental. Other analysts have suggested that any overcounting resulting from the incidental deaths captured by these methods will be offset by undercounting because of respondents not knowing about the pregnancy or not wishing to identify a pregnancy;[7,76] however, evidence for this claim is scarce.

Another important limitation is that 21 countries had no data for the entire period from 1980 to 2008. However, the predictive validity results suggest that our model does reasonably well out of sample. Countries with no data could be particularly affected by uncertainty in the covariates, which we have not incorporated into our estimates of uncertainty.

Lastly, for countries that do have data from several sources, such as India, there can be substantial non-sampling error across data sources. Inconsistencies between different datasets have meant that investigators need to make informed, but arbitrary, choices about which set to include. Future data collection or studies might provide new insights that could change the identification of which sources are outliers.

Compared with previous assessments of maternal mortality, we have narrowed the uncertainty around global and national estimates of the MMR. This improved accuracy is a result of an extensive database and the use of analytical methods with increased explanatory power and improved out-of-sample predictive validity. Nevertheless, our uncertainty intervals are biased towards being too large.

On the basis of our systematic assessment, we are optimistic about the ability to monitor maternal mortality over time. More data are available for maternal mortality than for other main causes of child or adult death. For example, WHO estimates more than 200 000 deaths from tuberculosis in reproductive-aged women,[77] yet in countries of low and lower-middle income the number of data points directly measuring tuberculosis as a cause of death is much lower than that for maternal mortality. A comparison of the information base for maternal mortality compared with HIV and many causes of child mortality is similarly favourable.[78,79] Of leading causes of death in children and adults in developing countries, there are more empirical observations for maternal mortality than for any other cause. Continued efforts at strengthening vital registration and the expansion of data collection for pregnancy-related mortality through household surveys and censuses should further

strengthen the global database. However, continuing surveillance of all-cause adult female mortality as an input to tracking maternal mortality is crucial.

This analysis has shown that although countries can achieve substantial progress in reduction of maternal deaths, far too many have not done so. In 5 years, the global health community and country governments will be held accountable for their achievement of the MDGs. Progress needs to be accelerated in countries where further substantial reductions in maternal mortality should be achievable with heath-system reform. The delivery of interventions to women when and where they need them ought to be a purposeful policy of all countries.

Contributors

MCH analysed the data, did the literature review, contributed to the methods development, and wrote the first draft. KJF contributed to the development of the methodological approach and implemented the statistical analysis. MN interpreted results and did the garbage code redistribution. SYA and MW did the verbal autopsy literature review and contributed to the figures and tables. SMM analysed the vital registration data and contributed to the figures and tables. ADL provided conceptual and technical guidance and made contributions in the report revisions. RL interpreted results, provided feedback on model development, and contributed to the first draft. CJLM conceptualised the methodology and guided the analysis, interpreted data and results, and contributed to the first draft and revisions.

Conflicts of interest

We declare that we have no conflicts of interest.

Acknowledgments

This research was supported by funding from the Bill & Melinda Gates Foundation. We thank Janaki O'Brien for assistance with data preparation; Emmanuela Gakidou for valuable inputs on the final draft; Julie K Rajaratnam and Stephen S Lim for contributions to the analytical process; and Haidong Wang, David Phillips, Krycia Cowling, Jacob Marcus, Rebecca Myerson, Kathryn Andrews, Laura Dwyer, and Alison Levin-Rector for assistance with data.

References

1 Starrs AM. Safe motherhood initiative: 20 years and counting. *Lancet* 2006; **368:** 1130–32.

2 Rosenfield A, Maine D. Maternal mortality—a neglected tragedy: where is the M in MCH? *Lancet* 1985; **326:** 83–85.

3 International Conference on Population and Development. Summary of the ICPD Program of Action. International Conference on Population and Development 2010. March, 1995. http://www.unfpa.org/icpd/summary.cfm (accessed March 12, 2010).

4 Obaid TA. Fifteen years after the International Conference on Population and Development: what have we achieved and how do we move forward? *Int J Gynaecol Obstet* 2009; **106:** 102–05.

5 Ronsmans C, Graham WJ, on behalf of The Lancet Maternal Survival Series steering group. Maternal mortality: who, when, where, and why. *Lancet* 2006; **368:** 1189–200.

6 United Nations General Assembly. United Nations Millennium Declaration. A/RES/55/2. New York: United Nations, 2000.

7 Hill K, Thomas K, AbouZahr C, et al, on behalf of the Maternal Mortality Working Group. Estimates of maternal mortality worldwide between 1990 and 2005: an assessment of available data. *Lancet* 2007; **370:** 1311–19.

8 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.

9 United Nations. The Millennium Development Goals Report 2009. New York: United Nations, 2009.

10 The United States President's Emergeny Plan for AIDS Relief: Global Health Initiative. http://www.pepfar.gov/ghi/index.htm (accessed March 12, 2010).

11 Graham WJ, Foster LB, Davidson L, Hauke E, Campbell OMR. Measuring progress in reducing maternal mortality. *Best Pract Res Clin Obstet Gynaecol* 2008; **22:** 425–45.

12 Graham WJ, Hussein J. Universal reporting of maternal mortality: an achievable goal? *Int J Gynaecol Obstet* 2006; **94:** 234–42.

13 Shiffman J. Can poor countries surmount high maternal mortality? *Stud Fam Plann* 2000; **31:** 274–89.

14 Yazbeck AS. Challenges in measuring maternal mortality. *Lancet* 2007; **370:** 1291–92.

15 Graham WJ, Ahmed S, Stanton C, Abou-Zahr CL, Campbell OM. Measuring maternal mortality: an overview of opportunities and options for developing countries. *BMC Med* 2008; **6:** 12.

16 Campbell OMR. Measuring progress in Safe Motherhood programmes: uses and limitations of health outcome indicators. Safe Motherhood Initiatives: Critical Issues. London: Blackwell Science, 1999.

17 AbouZahr C, Wardlaw T. Maternal mortality at the end of a decade: signs of progress? *Bull World Health Organ* 2001; **79:** 561–68.

18 Graham W, Brass W, Snow RW. Estimating maternal mortality: the sisterhood method. *Stud Fam Plann* 1989; **20:** 125–35.

19 Stanton C, Abderrahim N, Hill K. An assessment of DHS maternal mortality indicators. *Stud Fam Plann* 2000; **31:** 111–23.

20 Stanton C, Hobcraft J, Hill K, et al. Every death counts: measurement of maternal mortality via a census. *Bull World Health Organ* 2001; **79:** 657–64.

21 Hill K, Queiroz BL, Wong L, et al. Estimating pregnancy-related mortality from census data: experience in Latin America. *Bull World Health Organ* 2009; **87:** 288–95.

22 Atrash HK, Alexander S, Berg CJ. Maternal mortality in developed countries: not just a concern of the past. *Obstet Gynecol* 1995; **86:** 700–05.

23 Schuitemaker N, van Roosmalen J, Dekker G, Van Dongen P, Van Geijn H, Gravenhorst JB. Underreporting of maternal mortality in The Netherlands. *Obstet Gynecol* 1997; **90:** 78–82.

24 WHO, UNICEF. Revised 1990 estimates of maternal mortality: a new approach by WHO and UNICEF. Geneva: World Health Organization, 1996.

25 WHO, UNICEF, UNFPA. Maternal mortality in 1995: estimates developed by WHO, UNICEF, and UNFPA. Geneva: World Health Organization, 2001.

26 WHO, UNICEF, UNFPA, World Bank. Maternal mortality in 2005: estimates developed by WHO, UNICEF, UNFPA and the World Bank. Geneva: World Health Organization. 2007.

27 UNICEF, UNFPA, WHO. Maternal mortality in 2000: estimates developed by WHO, UNICEF and UNFPA. Geneva: World Health Organization, 2004.

28 Naghavi M, Makela S, Foreman K, O'Brien J, Lozano R. Algorithms for enhancing public health utility of national causes of death data. *Popul Health Metr* (in press).

29 Gakidou E, King G. Death by survey: estimating adult mortality without selection bias from sibling survival data. *Demography* 2006; **43:** 569–85.

30 Rajaratnam JK, Marcus JR, Levin-Rector A, et al. Worldwide mortality in men and women aged 15–59 years from 1970 to 2010: a systematic analysis. *Lancet* (in press).

31 WHO. International statistical classification of diseases and related health problems, tenth revision instruction manual (2 edn). Geneva: World Health Organization, 2004.

32 United Nations Development Group. Indicators for monitoring the millennium development goals: definitions, rationale, concepts, and sources. Report. New York: United Nations, 2003.

33 WHO. WHO Mortality Database. Geneva: World Health Organization, 2010. http://www.who.int/whosis/mort/download/en/index.html (accessed March 23, 2010).

34 Pattinson R, Say L, Souza JP, Broek N, Rooney C. WHO maternal death and near-miss classifications. *Bull World Health Organ* 2009; **87:** 734.

35 Turner LA, Cyr M, Kinch RA, et al. Under-reporting of maternal mortality in Canada: a question of definition. *Chronic Dis Can* 2002; **23:** 22–30.

36 Kao S, Chen LM, Shi L, Weinrich MC. Underreporting and misclassification of maternal mortality in Taiwan. *Acta Obstet Gynecol Scand* 1997; **76:** 629–36.

37 Ordi J, Ismail MR, Carrilho C, et al. Clinico-pathological discrepancies in the diagnosis of causes of maternal death in sub-Saharan Africa: retrospective analysis. *PLoS Med* 2009; **6:** e1000036.

38 Karimian-Teherani D, Haidinger G, Waldhoer T, Beck A, Vutuc C. Under-reporting of direct and indirect obstetrical deaths in Austria, 1980-98. *Acta Obstet Gynecol Scand* 2002; **81:** 323–27.

39 Horon IL. Underreporting of maternal deaths on death certificates and the magnitude of the problem of maternal mortality. *Am J Public Health* 2005; **95:** 478–82.

40 Deneux-Tharaux C, Berg C, Bouvier-Colle MH, et al. Underreporting of pregnancy-related mortality in the United States and Europe. *Obstet Gynecol* 2005; **106:** 684–92.

41 Laurenti R, Buchalla CM. Indicators of maternal and infant health: implications of the 10th revision of the International Classification of Diseases. *Rev Panam Salud Publica* 1997; **1:** 18–22.

42 MEASURE DHS. Demographic and Health Surveys. Calverton: ICF Macro, 2010.

43 CDC. International Reproductive Health Surveys Program. Atlanta: Centers for Disease Control and Prevention, 2010.

44 Obermeyer Z, Rajaratnam JK, Park CH, et al. Measuring adult mortality using sibling survival: a new analytical method and new results for 44 countries, 1974–2006. *PLoS Med* (in press).

45 WHO. Maternal mortality: a global factbook. Geneva: World Health Organization, 1991.

46 Hill K, el Arifeen S, Koenig M, Al-Sabir A, Jamil K, Raggers H. How should we measure maternal mortality in the developing world? A comparison of household deaths and sibling history approaches. *Bull World Health Organ* 2006; **84:** 173–80.

47 Garenne M, Friedberg F. Accuracy of indirect estimates of maternal mortality: a simulation model. *Stud Fam Plann* 1997; **28:** 132–42.

48 United Nations Population Division. World population prospects: the 2008 revision population database. New York: United Nations, 2009.

49 Handcock MS, Wallis JR. An Approach to Statistical Spatial-Temporal Modeling of Meteorological Fields. *J Am Stat Assoc* 1994; **89:** 368–78.

50 Landagan OZ, Barrios EB. An estimation procedure for a spatial-temporal model. *Stat Probab Lett* 2007; **77:** 401–06.

51 Knotters M, Brus DJ, Oude Voshaar JH. A comparison of kriging, co-kriging and kriging combined with regression for spatial interpolation of horizon depth with censored observations. *Geoderma* 1995; **67:** 227–46.

52 Cleveland WS, Devlin SJ. Locally weighted regression: an approach to regression analysis by local fitting. *J Am Stat Assoc* 1988; **83:** 596–610.

53 StataCorp LP. Stata Base reference manual: release 11. College Station: Stata Press, 2009.

54 Tomz M, Wittenberg J, King G. CLARIFY: Software for interpreting and presenting statistical results. *J Stat Software* 2003; **8:** 1–30.

55 Institute of Health Systems, Indian Cause of Death Dataset Version 1.3. Hyderabad: Institute of Health Systems, 2002.

56 Registrar General, India. Sample Registration System. New Delhi: Registrar General of India, 2006.

57 Fortney JA, Leong M. Saving Mother's Lives: Programs that work. *Clin Obstet Gynecol* 2009; **52:** 224.

58 Vahidnia F. Case study: fertility decline in Iran. *Popul Environ* 2007; **28:** 259–66.

59 Borghi J, Ensor T, Somanathan A, Lissner C, Mills A, on behalf of *The Lancet* Maternal Survival Series steering group. Mobilising financial resources for maternal health. *Lancet* 2006; **368:** 1457–65.

60 The Millennium Development Goals Report 2008. New York: United Nations, 2008.

61 Macro International Inc. MEASURE DHS STATcompiler, 2010. http://www.measuredhs.com (accessed April 6, 2010).

62 Bicego G, Boerma J, Ronsmans C. The effect of AIDS on maternal mortality in Malawi and Zimbabwe. *AIDS* 2002; **16:** 1078–81.

63 McIntyre J. Mothers infected with HIV: reducing maternal death and disability during pregnancy. *Br Med Bull* 2003; **67:** 127–35.

64 MacKay AP, Rochat R, Smith JC, Berg CJ. The check box determining pregnancy status to improve maternal mortality surveillance. *Am J Prev Med* 2000; **19:** 35–39.

65 Campbell O, Gipson R, Issa AH, et al. National maternal mortality ratio in Egypt halved between 1992-93 and 2000. *Bull World Health Organ* 2005; **83:** 462–71.

66 Mills S, Williams JE, Wak G, Hodgson A. Maternal mortality decline in the Kassena-Nankana district of northern Ghana. *Matern Child Health J* 2008; **12:** 577–85.

67 Li J, Luo C, Deng R, Jacoby P, de Klerk N. Maternal mortality in Yunnan, China: recent trends and associated factors. *BJOG* 2007; **114:** 865–74.

68 Fang J, Kaufman J. Reproductive health in China: improve the means to the end. *Lancet* 2008; **372:** 1619–20.

69 Chowdhury ME, Botlero R, Koblinsky M, Saha SK, Dieltiens G, Ronsmans C. Determinants of reduction in maternal mortality in Matlab, Bangladesh: a 30-year cohort study. *Lancet* 2007; **370:** 1320–28.

70 Yadamsuren B, Merialdi M, Davaadorj I, et al. Tracking maternal mortality declines in Mongolia between 1992 and 2007: the importance of collaboration. *Bull World Health Organ* 2010; **88:** 192–98.

71 Goodburn E, Campbell O. Reducing maternal mortality in the developing world: sector-wide approaches may be the key. *BMJ* 2001; **322:** 917–20.

72 Frenk J. Bridging the divide: global lessons from evidence-based health policy in Mexico. *Lancet* 2006; **368:** 954–61.

73 Technical Group for Monitoring the Millennium Development Goals. Millennium Development Goals: Brazilian Monitoring Report. Brasilia: Institute for Applied Economic Research, 2004.

74 Hoyert DL. Maternal mortality and related concepts. *Vital Health Stat 3* 2007; **33:** 1–13.

75 Hakkert R. Country estimates of maternal mortality: an alternative model. *Stat Med* 2001; **20:** 3505–24.

76 Stecklov G. Maternal mortality estimation: separating pregnancy-related and non-pregnancy-related risks. *Stud Fam Plann* 1995; **26:** 33–38.

77 WHO. The Global Burden of Disease: 2004 update. Geneva: World Health Organization, 2008.

78 Morris SS, Black RE, Tomaskovic L. Predicting the distribution of under-five deaths by cause in countries without adequate vital registration systems. *Int J Epidemiol* 2003; **32:** 1041–51.

79 Boschi-Pinto C, Velebit L, Shibuya K. Estimating child mortality due to diarrhoea in developing countries. *Bull World Health Organ* 2008; **86:** 710–17.