

Global, regional, and national levels and trends in maternal mortality between 1990 and 2015, with scenario-based projections to 2030: a systematic analysis by the UN Maternal Mortality Estimation Inter-Agency Group



Leontine Alkema*, Doris Chou*, Daniel Hogan, Sanqian Zhang, Ann-Beth Moller, Alison Gemmill, Doris Ma Fat, Ties Boerma, Marleen Temmerman, Colin Mathers, Lale Say, on behalf of the United Nations Maternal Mortality Estimation Inter-Agency Group collaborators and technical advisory group

Summary

Background Millennium Development Goal 5 calls for a 75% reduction in the maternal mortality ratio (MMR) between 1990 and 2015. We estimated levels and trends in maternal mortality for 183 countries to assess progress made. Based on MMR estimates for 2015, we constructed projections to show the requirements for the Sustainable Development Goal (SDG) of less than 70 maternal deaths per 100 000 livebirths globally by 2030.

Methods We updated the UN Maternal Mortality Estimation Inter-Agency Group (MMEIG) database with more than 200 additional records (vital statistics from civil registration systems, surveys, studies, or reports). We generated estimates of maternal mortality and related indicators with 80% uncertainty intervals (UIs) using a Bayesian model. The model combines the rate of change implied by a multilevel regression model with a time-series model to capture data-driven changes in country-specific MMRs, and includes a data model to adjust for systematic and random errors associated with different data sources.

Results We had data for 171 of 183 countries. The global MMR fell from 385 deaths per 100 000 livebirths (80% UI 359–427) in 1990, to 216 (207–249) in 2015, corresponding to a relative decline of 43·9% (34·0–48·7), with 303 000 (291 000–349 000) maternal deaths worldwide in 2015. Regional progress in reducing the MMR since 1990 ranged from an annual rate of reduction of 1·8% (0·0–3·1) in the Caribbean to 5·0% (4·0–6·0) in eastern Asia. Regional MMRs for 2015 ranged from 12 deaths per 100 000 livebirths (11–14) for high-income regions to 546 (511–652) for sub-Saharan Africa. Accelerated progress will be needed to achieve the SDG goal; countries will need to reduce their MMRs at an annual rate of reduction of at least 7·5%.

Interpretation Despite global progress in reducing maternal mortality, immediate action is needed to meet the ambitious SDG 2030 target, and ultimately eliminate preventable maternal mortality. Although the rates of reduction that are needed to achieve country-specific SDG targets are ambitious for most high mortality countries, countries that made a concerted effort to reduce maternal mortality between 2000 and 2010 provide inspiration and guidance on how to accomplish the acceleration necessary to substantially reduce preventable maternal deaths.

Funding National University of Singapore, National Institute of Child Health and Human Development, USAID, and the UNDP/UNFPA/UNICEF/WHO/World Bank Special Programme of Research, Development and Research Training in Human Reproduction.

Introduction

At the landmark Millennium Summit in September, 2000, world leaders agreed to improve the lives of the world's poor people through the acceptance of the Millennium Development Goals (MDGs).¹ The goals committed countries and international agencies to monitor progress on development and health outcomes between 1990 and 2015, including MDG 5 which calls for a reduction of 75% in the maternal mortality ratio (MMR; panel 1) between 1990 and 2015.

Monitoring progress towards MDG 5 exposed the difficulties of measuring MMR—many countries lack high-quality data. Although maternal mortality had been recognised as a concern and discussed at the 1987 Safe

Motherhood Conference (Nairobi, Kenya), the 1994 International Conference on Population and Development (Cairo, Egypt), the 1995 Fourth World Congress on Women (Beijing, China), and the 1997 Safe Motherhood Technical Consultation (Colombo, Sri Lanka), the MDG announcement provided significant technical and political impetus to improve maternal health.

To assist in the monitoring of progress towards MDG 5, the UN's Maternal Mortality Estimation Inter-Agency Group (consisting of WHO, UNICEF, UNFPA, World Bank Group, and UNPD) has regularly produced estimates for maternal mortality, focusing on country-specific estimates going back to 1990.^{3–9} 2015 marks the end of the MDG era and is the right time to reflect on the

Published Online
November 12, 2015
[http://dx.doi.org/10.1016/S0140-6736\(15\)00838-7](http://dx.doi.org/10.1016/S0140-6736(15)00838-7)

*Contributed equally

University of Massachusetts Amherst, Amherst, MA, USA (L Alkema PhD); World Health Organization, Geneva, Switzerland (D Chou MD, D Hogan PhD, A-B Moller MA, D Ma Fat BA, T Boerma PhD, Prof M Temmerman PhD, C Mathers PhD, L Say MD); Harvard University, Cambridge, MA, USA (S Zhang BSc); and University of California, Berkeley, CA, USA (A Gemmill MA)

Correspondence to: Dr Doris Chou, World Health Organization, Department of Reproductive Health and Research, 1211 Geneva, Switzerland
choud@who.int

Research in context**Evidence before this study**

All publicly available data on maternal mortality are compiled on a regular basis by the United Nations Maternal Mortality Inter-Agency Group (UN MMEIG) to improve monitoring of progress towards maternal survival goals, and to enhance the capacity of countries to produce timely estimates of maternal mortality. Before our study, the global database contained 2374 records and UN MMEIG estimates of maternal mortality levels and trends were constructed using that database and a multilevel regression model for countries without sufficient high-quality information from vital registration systems.

Added value of this study

This study extended the existing UN MMEIG global database by including 234 additional records. We constructed estimates for 183 countries that capture data-driven trends in all countries, while accounting for systematic and random errors in the observations. For the first time, we provide country-specific estimates of the maternal mortality ratio (MMR) up to the Millennium Development Goal target year (2015) and assess achievements in reducing the MMR between 1990 and 2015.

See [Online](#) for appendix

Globally, MMR declined from 385 deaths per 100 000 livebirths (80% uncertainty interval [UI] 359–427) in 1990, to 216 (207–249) in 2015. In the next 15 years, 3.9 million women would die from a maternal cause of death if each country continues to reduce its MMR at the present rate of 2.9%, which was the median annual reduction for 2000–10. The Sustainable Development Goals aim for a total number of projected cumulative maternal deaths between 2016 and 2030 of no more than 2.5 million, 1.4 million lower than is expected based on present rates of change.

Implications of all the available evidence

With the vision of ending preventable maternal deaths and the mission to reduce the global MMR to 70 deaths per 100 000 in the next 15 years, urgent action is needed to accelerate progress, particularly in countries with substantial maternal mortality. Future action might be guided by past successes in countries that have reduced the MMR. Future research on what efforts contribute most effectively to maternal mortality reductions will help the allocation of resources and setting priorities.

Panel 1: Definitions related to maternal and pregnancy-related mortality**Maternal death**

Death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management, but not from accidental or incidental causes.

Pregnancy-related death

Death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the cause of death.

Late maternal death

Death of a woman from direct or indirect obstetric causes, more than 42 days, but less than 1 year, after termination of pregnancy.

Proportion of maternal deaths (PM)

Proportion of maternal deaths among deaths of women of reproductive age.

Proportion of pregnancy-related deaths (pregnancy-related PM)

Proportion of pregnancy-related deaths among deaths of women of reproductive age.

Maternal mortality ratio

Number of maternal deaths per 100 000 livebirths.

Maternal mortality rate

The ratio of maternal deaths to the women-years of exposure for women aged 15–49 years.

Lifetime risk

The probability of a 15-year-old girl eventually dying from a maternal cause, assuming she is subjected throughout her lifetime to the risks of maternal death as estimated for that country-year.²

Annual (continuous) rate of reduction

Measure of relative decline per year, defined as:

$$\log(\text{MMR}_{t_2}/\text{MMR}_{t_1})/(t_1-t_2)$$

where t_1 and t_2 refer to different years with $t_1 < t_2$, and MMR is the maternal mortality ratio.

progress made. For this final MDG 5 reporting year, the UN's Maternal Mortality Estimation Inter-Agency Group comprehensively assessed the MMR for 183 countries using a new Bayesian model¹⁰ that extends previous methods.^{7–9} The resulting estimates provide the first comprehensive overview of the progress that has been made in reducing the MMR from 1990 to 2015, worldwide, within regions, and within individual countries. 2015 also marks the start of the Sustainable Development Goals (SDGs), which include the target of reducing global maternal mortality to less than 70 deaths per 100 000 livebirths by 2030, with no individual country exceeding an MMR of 140 maternal deaths per 100 000 livebirths.¹¹ To assess the potential effect of meeting this target, we constructed projections based on the SDG target from 2016 to 2030, and compared them with a projection based on past rates of change.

Methods**Data for maternal mortality**

The UN Maternal Mortality Estimation Inter-Agency Group maintains a publicly available dataset with nationally representative data relevant to maternal mortality including vital statistics from civil registration systems, special inquiries, surveillance sites, population-based household surveys (including Demographic Health Surveys, Multiple Indicator Cluster Surveys, and Reproductive and Health Surveys), and censuses. The appendix (p 1) shows our data compilation and search strategy. Table 1 summarises how information relating to maternal mortality is collected and categorised and table 2 summarises what information related to maternal mortality we used to estimate MMR. Generally, we used

	Method of collection	Type of death reported	Timeframe of death reported after pregnancy termination
Civil registration vital statistics	Death certificate data; certifier provides cause of death information which is coded into ICD	Maternal	ICD-9 coding, up to 1 year; ICD-10 coding, up to 42 days, and between 42 days and 1 year
Specialised studies (eg, confidential inquiries, reproductive-age mortality studies, studies using verbal autopsy, studies comparing maternal mortality surveillance systems with civil registration data)	Review of causes or specific review for under-reporting (combination of misclassification and incompleteness)	Maternal	Depends on review parameters
Population-based surveys that collect sibling histories (eg, Demographic Health Surveys, MICS4, Reproductive Health Survey, Maternal Mortality Survey, Family Health Survey)	Direct sisterhood method: a representative sample of women are asked about the survival of all their sisters to determine their age, how many are alive, how many are dead, and—for those who died—age at death and whether the sister died during pregnancy, delivery, or within 2 months of pregnancy	Pregnancy related	2 months
Census, post-census enumeration survey	Population censuses can include questions about deaths in households in defined reference periods; reported deaths of reproductive-aged women trigger questions about the timing of death relative to pregnancy	Pregnancy related	Up to 1 year
Other sources reporting on maternal mortality (eg, maternal mortality surveillance systems, Ministries of Health, national statistical offices)	Review of causes	Maternal or pregnancy related	Depends on review parameters

ICD=International Classification of Diseases.

Table 1: Overview of data sources

the proportion of maternal deaths among deaths in women aged 15–49 years (panel 1), and we used the reported MMR only if the proportion of maternal deaths was not available.

The full database (and all model specifications) that we used is available online. The 2015 update to the database included more than 200 additional records (referring to vital statistics from civil registration systems, reporting years, studies, or reports), resulting in a database with 2608 records providing 3634 country-years of information in total for 171 countries, from 1985 to 2015 (table 2). The appendix (pp 5–75) provides source details for all datapoints not taken from vital statistics.

Most data sources for maternal mortality have substantial uncertainty or biases. The estimation approach attempts to account for these random and systematic errors (table 2). For civil registration vital statistics data, the reported proportion of maternal deaths among all deaths to women aged 15–49 years were the data inputted. For vital registration country-years based on International Classification of Disease (ICD)-9, we used deaths coded to 630–676, and for those based on ICD-10, we used codes O00–O95, O98–O99, and A34 (which include only those maternal deaths for which the timing corresponds to the definition of a maternal death). An important systematic bias associated with vital registration data is the potential misclassification of maternal deaths resulting from errors in medical reporting and certification of the cause of death or errors in applying the correct ICD code. Such

misclassification tends to result in undercounting of maternal deaths because there is higher likelihood of misclassifying a maternal death as a non-maternal death than the opposite. Many nationally representative studies^{7–9} of reporting of maternal deaths suggest that vital registration systems fail to record around 50% of maternal deaths.

Some studies were able to record information for only pregnancy-related deaths (table 1). Such information is subject to systematic error because pregnancy-related deaths tend to exceed maternal deaths because of the inclusion of deaths that are not causally related to the pregnancy. However, because pregnancy-related deaths are reported by a family member and pertain to deaths occurring during pregnancy rather than deaths for which the cause has been medically classified, surveys such as the Demographic Health Survey and other sources that report pregnancy-related deaths might also be subject to under-reporting, especially for deaths occurring early in pregnancy (and thus unknown to the reporting family member; table 2).¹²

Sources and construction of other model inputs

We used several other inputs to estimate MMR and related outcomes, including entries from WHO life tables, which provide estimates of all-cause deaths among women of reproductive age,¹³ estimates of livebirths from UNPD,¹⁴ and estimates of deaths due to HIV/AIDS among women aged 15–49 years from

For the full database see <http://www.who.int/reproductivehealth/publications/monitoring/maternal-mortality-2015/en/>

	Information used to construct maternal mortality estimates	Assumptions about systematic errors (reporting problems that result in biases)	Assumptions about random errors	Number of records	Country-years
Civil registration vital statistics					
ICD-9	PM	Misclassification of maternal deaths or incompleteness; inclusion of late maternal deaths	Observations are subject to stochastic errors	1078	1078
ICD-10	PM	Misclassification of maternal deaths or incompleteness	Observations are subject to stochastic errors	947	947
Specialised studies	Maternal deaths are used if a rigorous assessment confirms that all deaths to women of reproductive age were captured; otherwise, the PM or MMR is used*	None	Observations are subject to stochastic errors	224	364
Other data sources reporting on maternal mortality	PM or MMR*	Under-reporting of maternal deaths	Observations might be subject to sampling, stochastic, or additional random error	178	206
Other data sources reporting on pregnancy-related mortality (eg, through sibling histories)	Pregnancy-related PM or pregnancy-related MMR*	Under-reporting of pregnancy-related deaths; over-reporting of maternal deaths due to the inclusion of pregnancy-related deaths that are not maternal	Observations might be subject to sampling, stochastic, or additional random error	181	1038

Stochastic errors refer to differences between observed PMs and expected PMs due to the randomness associated with the event of a maternal death—ie, when considering the event of a maternal death as the outcome of a random variable with a Bernoulli distribution with the probability of a maternal death given by the expected PM. Sampling error arises in recorded PMs that are obtained from samples that are a subset of the population—eg, in surveys or sample registration systems. In addition to sampling or stochastic errors, results might be due to additional random errors, which are non-systematic errors that occur during data collection—eg, due to how a questionnaire was administered or due to data entry errors. PM=proportion of all-cause deaths that are maternal. MMR=maternal mortality ratio. ICD=International Classification of Diseases. *PM takes precedence over MMR.

Table 2: Data included in the maternal mortality model

UNAIDS.¹⁵ We used three covariates in the statistical analysis: the gross domestic product per capita, the general fertility rate, and the proportion of births delivered by skilled health personnel.¹⁶ The appendix (pp 2–3) provides sources and details on constructing trends for these covariates.

Statistical analysis

We estimated indicators of maternal mortality using a new Bayesian maternal mortality estimation model.¹⁰ This model refines the approach previously used by the Maternal Mortality Estimation Inter-Agency Group to better incorporate trends in country data and surrounding uncertainty. The model is able to track high-quality data very closely, handle countries that changed from using survey-based data sources to newly scaled up vital registration, and combine information from data and covariates for countries with limited data while producing covariate-driven estimates for countries without data. The model eliminates the need to group countries on the basis of data availability: one model is used for all countries, irrespective of the data sources available. A full technical description of the model and software has been published elsewhere.¹⁰

The MMR for each country-year was modelled as the sum of the AIDS MMR and the non-AIDS MMR, where non-AIDS MMR refers to maternal deaths due to direct obstetric causes or to indirect causes other than HIV, whereas AIDS maternal deaths are those deaths caused by AIDS for which pregnancy was a substantial aggravating factor. Because of the substantial effect of the HIV/AIDS epidemic on mortality in many countries,

the AIDS MMR was modelled separately to capture the trends in maternal mortality associated with the epidemic, following the same procedure used previously.^{7–9}

The model for the non-AIDS MMR consists of two components. The main component is a Bayesian hierarchical regression model. This regression model assumes that the logged proportion of non-AIDS maternal deaths among all non-AIDS deaths to women of reproductive age (the dependent variable) is a linear function of random country-specific intercepts and three predictor variables: gross domestic product, general fertility rate, and the proportion of births delivered by skilled health personnel. This model has been used previously to estimate non-AIDS MMR for countries without sufficient high-quality data from vital registration systems.^{7–9} In this study, we extended this regression model to capture country-specific trends in the non-AIDS MMR as suggested by the data: the regression-based and thus covariate-driven estimates for rates of reduction in the non-AIDS MMR were combined with country-year-specific distortion terms. We modelled these distortion terms with a time-series model and estimated them for all country-years. The effect was as follows: if data for a country suggested that the non-AIDS MMR decreased faster in year t than expected based on covariates, the data-driven distortion term for that year was estimated to be greater than 0, to capture the acceleration in the MMR reduction beyond the reduction captured by covariates. Similarly, if the MMR reduced less than expected based on covariates, the distortion was estimated to be negative to capture the deceleration in the MMR reduction compared with the expected covariate-based reduction.

For countries with ample data across time, the distortion term had a more dominant role in the estimation, allowing for the model to track patterns in country data, whereas for countries with limited data, the estimates are more strongly supported by the expected trend implied by the covariates. For countries with continuous time series of high-quality vital registration data, the model follows the data very closely (given adjustments for misclassification).

We used data quality models to account for systematic and random errors associated with the recorded proportion of maternal deaths: we assumed that each recorded logged proportion of maternal deaths was equal to the sum of the true logged proportion of maternal deaths, adjusted for reporting problems (to make it comparable to the reported value) and additional error, which was assumed to be normally distributed.^{10,16} Adjustments for reporting issues (table 2) were similar to adjustments used in previous studies.⁷⁻⁹ However, late maternal deaths were excluded from proportions of maternal deaths based on ICD-10 to be in keeping with our definition of maternal death, and adjustments were updated accordingly. We accounted for uncertainty in the adjustment parameters through prior distributions on the adjustment parameters by increasing the overall error variance of the observation. For each observation, total error variance was set equal to its stochastic or sampling error variance, combined with a non-sampling or additional random error variance term for observations from surveys and miscellaneous sources. We accounted for the resulting total error variances in the model fitting such that, with systematic errors being equal, observations of the proportion of maternal deaths with smaller error variances carried a greater weight in determining the estimates than did observations with larger error variances.

Maternal mortality indicators

In addition to the MMR estimates, we also calculated the annual (continuous) rate of reduction, the lifetime risk of maternal mortality,² and the maternal mortality rate (panel 1).

We estimated indicators of maternal mortality with a Bayesian model. We used a Markov chain Monte Carlo algorithm to generate samples of the posterior distributions of all model parameters. We implemented the algorithm using JAGS software (version 3.3.0) and did the analysis with R. Software programs and input data are available online.

The sampling algorithm produced a set of trajectories of the MMR for each country, from which we derived other indicators and aggregate outcomes. Point estimates for maternal mortality indicators were based on posterior medians or equivalently, 50th percentiles of posterior distributions. To obtain point estimates of relative reductions, annual rates of reduction, and aggregate outcomes (eg, worldwide MMR), we used unrounded point estimates of the MMR. We computed 80% uncertainty

intervals (UIs) for the MMR and all related outcomes using the 10th and 90th percentiles of the posterior distributions. There is a 10% chance that the true outcome is below the interval, and there is a 10% chance that the true outcome is above the interval. We report 80% UIs rather than 95% UIs because of the substantial uncertainty inherent in maternal mortality outcomes: intervals based on higher uncertainty levels quickly lose their ability to present meaningful summaries of a range of likely outcomes.

The UIs for the MMR and related maternal mortality outcomes assess the uncertainty in the indicators based on the available data and uncertain model parameters, such as data adjustment parameters. The uncertainty assessment does not include the uncertainty in any of the demographic indicators that were used as inputs to our model, including the total number of deaths to women of reproductive ages and the number of births.

Country consultation

We consulted with WHO member states, providing the opportunity for them to share data or provide additional information about national data sources. The process does not involve obtaining approval from countries regarding the estimates. Our estimates are intended to be internationally comparable; thus, they might differ from national estimates developed by other methods. During the country consultation, we received new data from 33 countries that were deemed to be of sufficient quality for inclusion (Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Cambodia, Canada, Costa Rica, Croatia, Cuba, Dominican Republic, Ecuador, El Salvador, Georgia, Guatemala, Honduras, Hungary, Latvia, Lithuania, Malaysia, Mexico, Mongolia, Panama, South Korea, Rwanda, Singapore, Slovakia, Slovenia, Spain, Sweden, Turkey, USA).

Projections for 2030

We constructed scenario-based projections for 2030 to assess the potential effect of meeting the targets proposed in the SDGs.¹¹ We also generated country-specific MMR projections from 2016 to 2030, based on the median of the country-specific continuous annual rates of reduction for 2000–10, to represent what would happen if countries' typical experiences continued until 2030. We used annual rates of reduction for 2000–10, as opposed to later periods, to exclude more recent years for which MMR estimates are driven by modelling for most countries. We calculated the median annual rates of reduction based on all countries, irrespective of the MMR in 2000, because SDG target rates will apply to all countries irrespective of their starting level in 2015.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. LA, DC, SZ, A-BM, and DH had full access to

For the software and data see <http://www.who.int/reproductivehealth/publications/monitoring/maternal-mortality-2015/en>

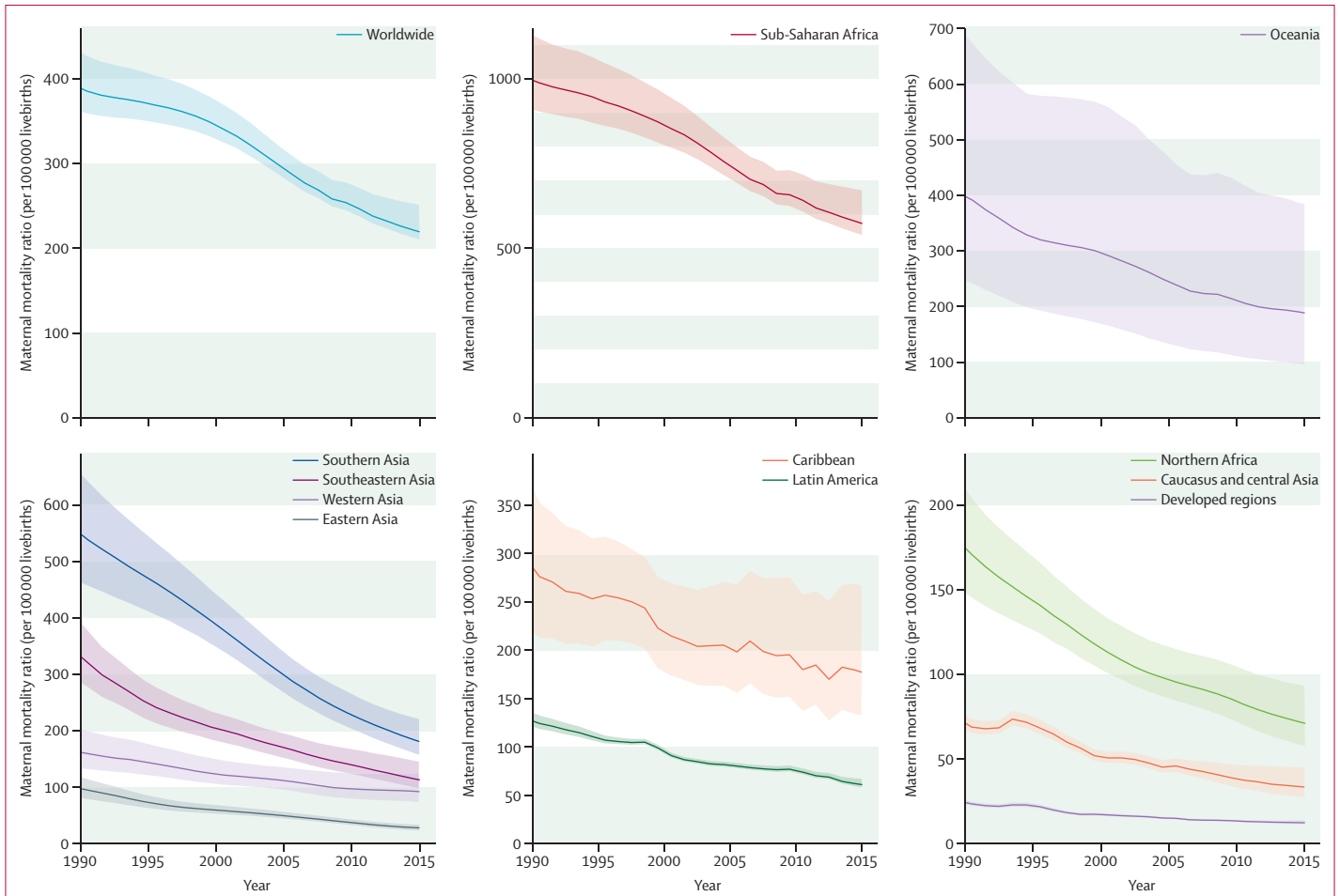


Figure 1: Global and regional estimates of maternal mortality ratio from 1990 to 2015
Shaded areas are 80% uncertainty intervals. Shaded areas in background are comparable.

all the data in the study and all authors had final responsibility for the decision to submit for publication.

Results

The global maternal mortality ratio decreased from 385 deaths per 100 000 livebirths (80% UI 359–427) in 1990, to 216 (207–249) in 2015, corresponding to a 43·9% (34·0–48·7) decline and an annual continuous rate of reduction of 2·3% (1·7–2·7; figure 1, appendix pp 76–88). We define regions and developmental status according to the MDG classification. The progress made and present levels of maternal mortality differ greatly between regions. The highest regional rate of decline for 1990–2015 occurred in eastern Asia (annual continuous rate of reduction 5·0%, 80% UI 4·0–6·0) and the lowest was in the Caribbean (1·8%, 0·0–3·1). Regional MMRs for 2015 ranged from 12 deaths per 100 000 livebirths (80% CI 11–14) for developed regions to 546 (511–652) for sub-Saharan Africa.

The yearly number of global maternal deaths decreased from 532 000 (80% UI 496 000–590 000) in

1990, to 303 000 (291 000–349 000) in 2015. The largest proportion in 2015 occurred in sub-Saharan Africa (201 000 deaths [66·3%], 80% UI 188 000–240 000). Estimates for all years are available online. Between 1990 and 2015, 10·7 million women worldwide died from maternal causes.

Regional findings can mask variation between individual countries within the region and regional MMRs might be driven by the MMRs of countries with many livebirths. The appendix (pp 76–88) shows country-specific MMR estimates. Globally in 2015, the median country-specific MMR was 54 deaths per 100 000 livebirths (IQR 14–229) and country-specific estimates ranged from 3 (80% UI 2–3) in Finland to 1360 (999–1980) in Sierra Leone (figure 2). Among countries with an MMR greater than 100 deaths per 100 000 livebirths in 1990, changes ranged from an increase of 34·0% (80% UI 6·5–91·2) for Guyana, to a decrease of 90·0% (78·9–94·6) for Maldives. The lower bound of the 80% UI exceeded 500 for eight countries (Central African Republic, Chad, Democratic Republic of the Congo, Guinea, Liberia,

For the MMR estimates for all years see <http://www.who.int/reproductivehealth/publications/monitoring/maternal-mortality-2015/en/>

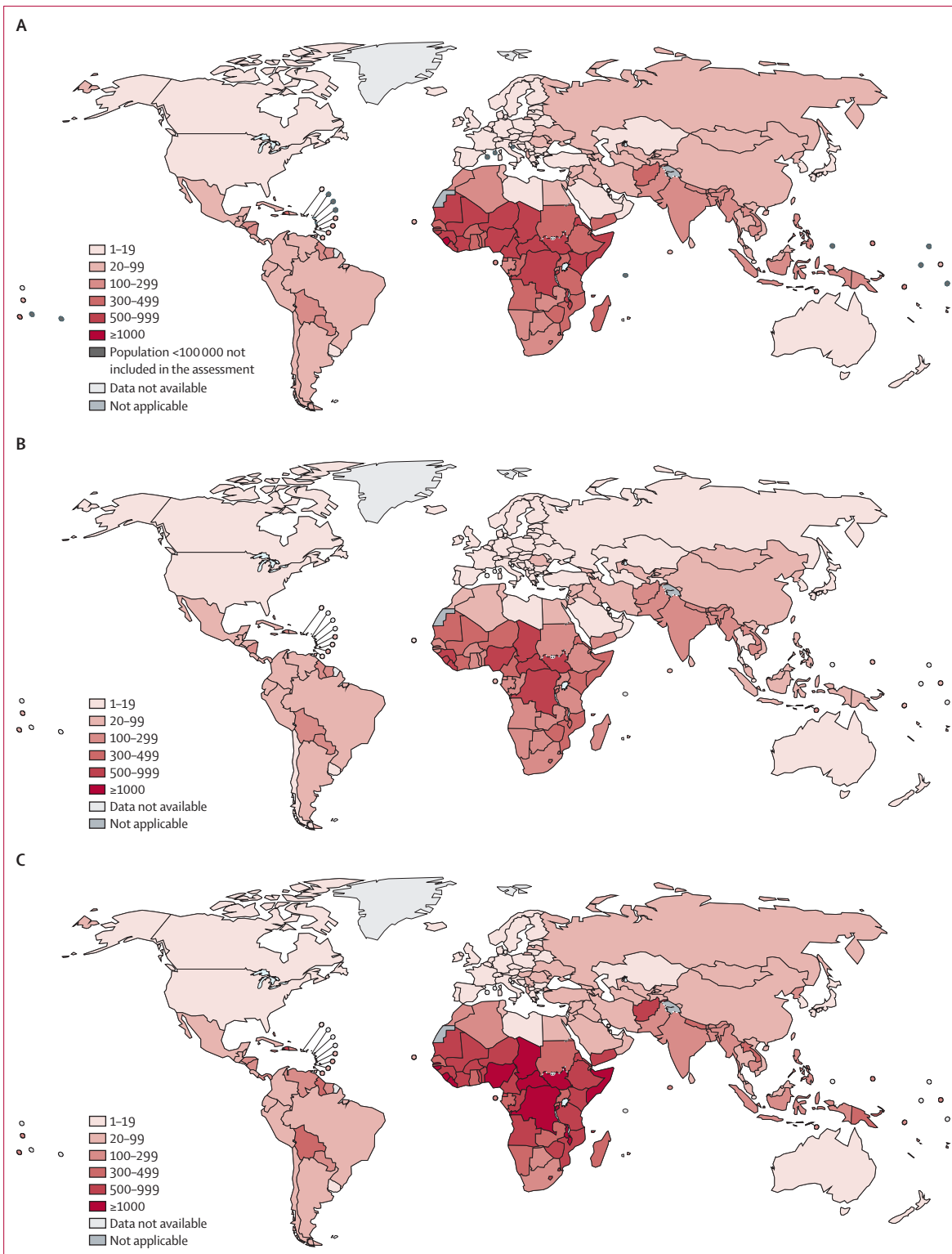


Figure 2: Maternal mortality ratio (per 100 000 livebirths) for 2015
 (A) Point estimates, (B) lower bounds of 80% uncertainty intervals, and (C) upper bounds of 80% uncertainty intervals.

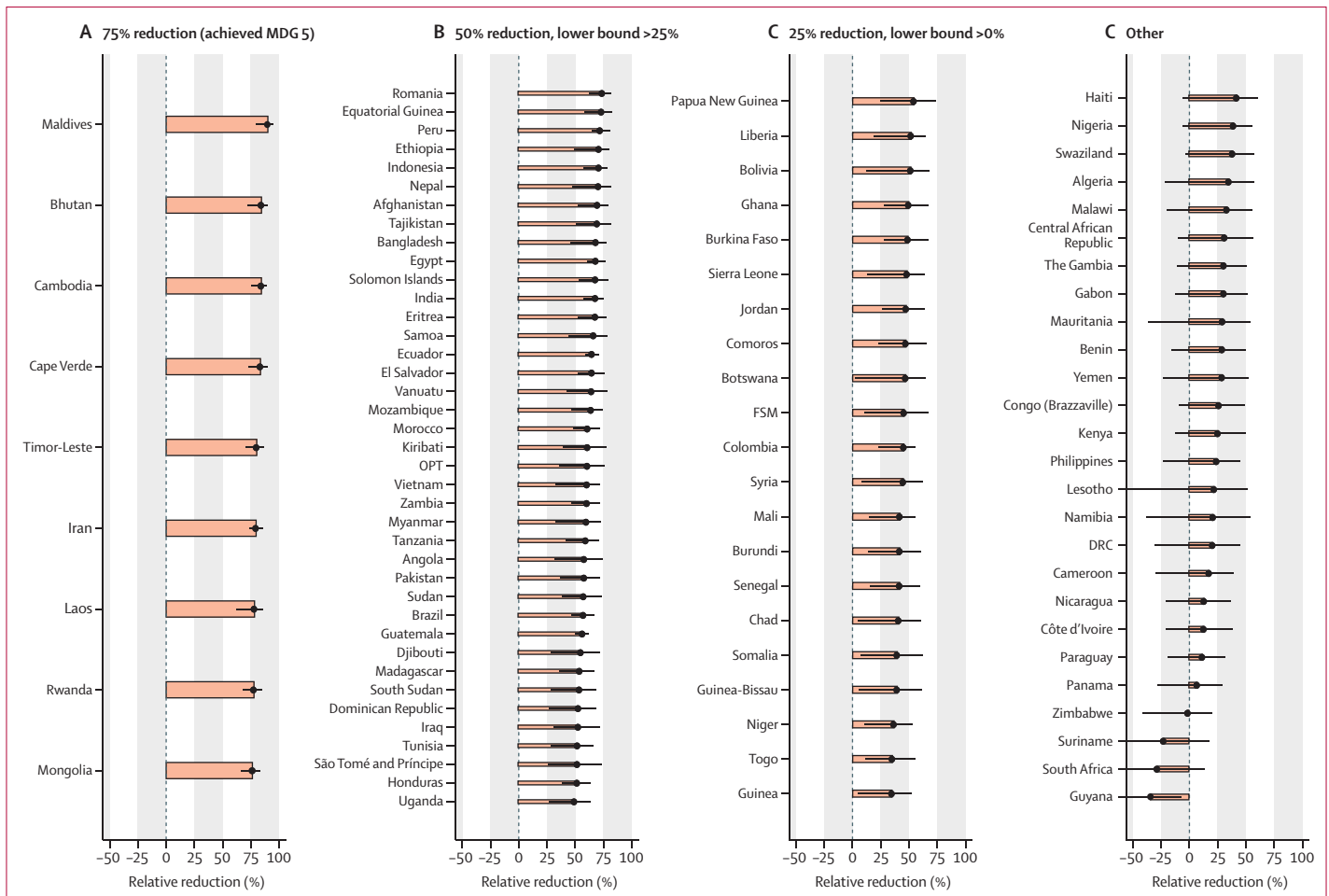


Figure 3: Relative reduction in maternal mortality ratio from 1990 to 2015, for 95 countries with maternal mortality ratio of more than 100 in 1990
 Countries are grouped on the basis of the categories from table 3. Within each category, countries are sorted by relative reduction. Error bars refer to 80% uncertainty intervals. DRC=Democratic Republic of the Congo. OPT=Occupied Palestinian Territory. FSM=Federated States of Micronesia.

Definition	Percent reduction in MMR from 1990 to 2015	
	Point estimate for percentage reduction	Lower bound of 80% UI
1 Probability (reduction is at least 75%) >50%	>75%	NA
2 Probability (reduction is at least 50%) >50% AND Probability (reduction is at least 25%) >90%	>50%	>25%
3 Probability (reduction is at least 25%) >50% AND Probability (reduction is at least 0%) >90%	>25%	>0%
4 Probability (reduction is at least 25%) <50% OR Probability (reduction is at least 0%) <90%	<25%*	<0%*

Categories are defined based on two probability statements regarding minimum relative reductions in the MMR between 1990 and 2015, where the first statement is true with at least 50% chance while the second statement is true with at least a 90% chance. The two columns on the right provide the corresponding criteria based on point estimates and lower bound of 80% UIs for the probability statements in each of the categories to hold true. Note that lower bounds of 80% UIs provide one-sided probability statements that refer to 10% or 90% chance. *One criterion is sufficient. MMR=maternal mortality ratio. UI=uncertainty interval.

Table 3: Categorisation of countries based on evidence for progress in reducing the maternal mortality ratio between 1990 and 2015

Nigeria, Sierra Leone, and South Sudan); thus, the chance that the MMR is less than 500 is less than 10% for these countries. The point estimate for the MMR in 2015 exceeded 500 for an additional 12 countries (Burundi, Cameroon, Côte d'Ivoire, Eritrea, The Gambia, Guinea-Bissau, Kenya, Malawi, Mali, Mauritania, Niger, and Somalia). Ten countries had an MMR of 5 deaths per 100 000 livebirths or less (Austria, Belarus, Czech Republic, Finland, Greece, Iceland, Italy, Kuwait, Poland, and Sweden). Based on the upper bounds of the 80% UI, there is at least a 90% chance that the MMR is less than 5 deaths per 100 000 livebirths for Finland, Greece, and Poland.

For the 95 countries with a high maternal mortality (MMR >100 deaths per 100 000 livebirths) in 1990 (figure 3). The countries are grouped into four categories on the basis of the MMR between 1990 and 2015, to assess whether MDG 5 was achieved (table 3). The greatest relative reduction in MMR occurred in the nine countries in category 1 (Bhutan, Cape Verde, Cambodia, Iran, Laos, Maldives, Mongolia, Rwanda, Timor-Leste), for which the

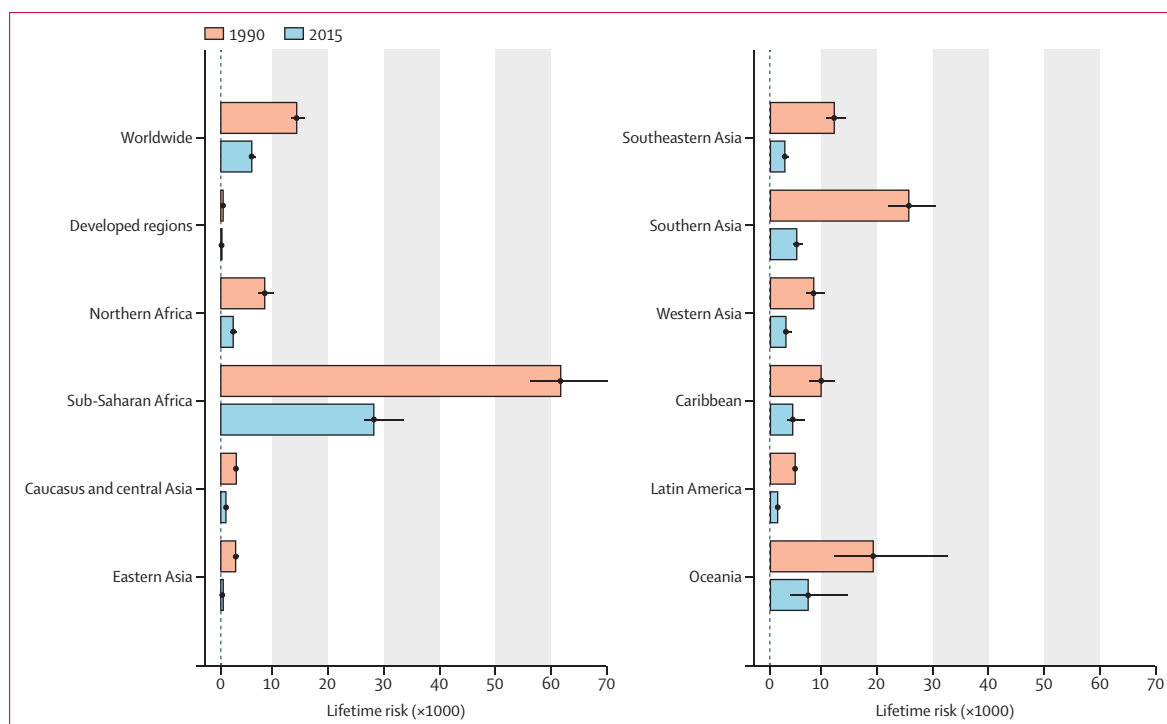


Figure 4: Lifetime risk of maternal death in 1990 and 2015
Number of maternal deaths per 1000 women over their lifetime.

point estimate of the reduction between 1990 and 2015 suggests that the MDG 5 target of a 75% reduction has been met. Of the category 1 countries, the probability of having reached MDG 5 is greater than 90% for Cambodia and Maldives but smaller than 90% for all other countries. The other categories are based on point estimates and the lower bounds of the 80% UIs for the relative decline. It is important to include uncertainty assessments in a categorisation of country progress. For example, in Nigeria, the point estimate for the relative reduction in MMR since 1990 suggests a decrease of 39.6%. However, the lower bound of the 80% UI is -5.0%; thus, the chance that no progress has been made is greater than 10%. Most countries (39 [41%] of 95) are in category 2; for countries in this category, the best estimate suggests that MMR has fallen by at least 50%, and there is at least a 90% chance that the MMR decreased by 25% since 1990. For the 21 countries in category 3, the best estimate suggests that the MMR reduced by at least 25% and there is at least a 90% chance that the MMR has declined. For category 4 countries, the chance that the MMR decreased is less than 90% or the point estimate of the country-specific decline is less than 25% (figure 3).

Globally, lifetime risk of maternal death fell by more than half, from 14 maternal deaths per 1000 women over their lifetimes (80% UI 13–15) in 1990, to 6 (5–6) maternal deaths in 2015 (figure 4), which is equivalent to 1 death per 73 women (66–78) in 1990, and 1 death per 180 women (160–190) in 2015. The largest relative declines occurred in

eastern Asia (84%) and southern Asia (81%). The largest absolute decline occurred in sub-Saharan Africa, where the risk decreased from 1 per 16 women (80% UI 14–18) in 1990, to 1 per 36 women (30–39) in 2015. At the country level, lifetime risks in 2015 ranged from 1 death per 23700 women (18000–32700) in Greece to 1 death per 17 (12–23) in Sierra Leone. Likewise, the global maternal mortality rate decreased from 0.41 deaths per 1000 women (0.38–0.45) in 1990, to 0.17 (0.16–0.19) in 2015, and the rate for individual countries in 2015 ranged from 0.001 deaths per 1000 women (0.001–0.002) in Greece, to 2.0 (1.4–2.9) in Sierra Leone (appendix pp 76–88).

If the global MMR fell to less than 70 deaths per 100000 livebirths by 2030 (the SDG target), there would be 89000 maternal deaths in 2030, and about 2.5 million deaths cumulatively between 2016 and 2030 (table 4). This projection of maternal mortality is substantially lower than the projection of a global MMR of 161 deaths per 100000 livebirths in 2030 based on an annual continuous rate of reduction of 2.9%, which is the median of the country-specific rates for 2000–10. Regional projected MMRs range from 4 maternal deaths per 100000 livebirths to 128 maternal deaths per 100000 livebirths under the SDG scenario, compared with a range of 8–357 maternal deaths per 100000 livebirths under the more conservative projection (table 4).

To meet the SDG target, countries with an MMR below 432 deaths per 100000 livebirths in 2015 will need to achieve an annual continuous rate of reduction of

	Scenario 1			Scenario 2		
	MMR in 2030 (deaths per 100 000 livebirths)	Maternal deaths in 2030	Cumulative maternal deaths	MMR in 2030 (deaths per 100 000 livebirths)	Maternal deaths in 2030	Cumulative maternal deaths
Worldwide	161	223 000	3 878 000	64	89 000	2 508 000
Developed regions	8	990	19 000	4	500	14 000
Northern Africa	43	1700	34 000	21	850	25 000
Sub-Saharan Africa	357	161 000	2 692 000	128	58 000	1 646 000
Caucasus and central Asia	21	320	6500	11	160	4800
Eastern Asia	18	2400	50 000	9	1200	37 000
Southeastern Asia	72	7900	150 000	36	3900	109 000
Southern Asia	115	40 000	778 000	58	20 000	564 000
Western Asia	59	3200	58 000	30	1600	42 000
Caribbean	117	7400	14 000	58	370	11 000
Latin America	39	3600	70 000	20	1800	51 000
Oceania	123	360	6400	61	180	46 000

Regions and developmental status based on MDG classification. Scenario 1 is based on past experience in a typical country (annual rate of reduction of 2.9%) and scenario 2 is based on the Sustainable Development Goal of a global MMR of less than 70 deaths per 100 000 livebirths by 2030, and MMR of less than 140 deaths per 100 000 livebirths for each country. The number of maternal deaths has been rounded as follows: <100 rounded to the nearest 1; 100–999 rounded to nearest 10; 1000–9999 rounded to nearest 100; and >10 000 rounded to nearest 1000. MMR=maternal mortality rate. MDG=Millennium Development Goals.

Table 4: Projections of MMR and maternal deaths for 2030

7.5% for 2016–30, which is beyond the rate of 5.5% that was required to meet MDG 5. Ten countries (Belarus, Cambodia, Estonia, Kazakhstan, Lebanon, Mongolia, Poland, Rwanda, Timor-Leste, Turkey) had point estimates greater than 7.5% in 2000–10. For 30 countries with MMRs greater than 432 deaths per 100 000 livebirths in 2015, even higher annual continuous rates of reduction are needed to reduce the MMR to less than 140 deaths per 100 000 livebirths in 2030.

Discussion

Our study provides a comprehensive analysis of global maternal mortality trends based on the latest data from 171 countries. The maternal mortality ratio has declined substantially between 1990 and 2015, but progress has been much slower than required to meet the MDG 5 target of reducing the MMR by 75% between 1990 and 2015. This global summary masks variation in progress across regions and across countries. Understanding the drivers of progress in reducing maternal mortality—as well as the factors impeding progress—is key to making informed decisions for reducing the MMR in the post-MDG era.

Documenting the successes of individual countries provides practical guidance and inspiration for targeted interventions to reduce maternal mortality (panel 2). Country-specific studies also help to better understand major risk factors and potential solutions in countries with high maternal mortality so that action can be taken.^{17–22} A study in Tanzania²³ suggested that the

distance to a health clinic and quality of care were factors contributing to high maternal mortality. For countries with high HIV prevalence, indirect AIDS maternal deaths have contributed to higher maternal mortality in the past 20 years (appendix pp 103–118). The increase in antiretroviral therapy in these countries will spur progress in maternal mortality.

Continuing or emerging humanitarian crises, or conflict, post-conflict, or disaster situations might also hinder progress in reducing maternal mortality.²⁴ Evidence and analyses of these events are often anecdotal—data on health outcomes in crisis situations is rarely collected. Although providing comprehensive maternal and child health interventions might be unrealistic in countries faced with conflict or natural disaster, targeted actions such as routine obstetric care during crises might be possible and could reduce maternal mortality from preventable causes.²⁵

In 2000, when the MDGs were endorsed, 98 countries had civil registration systems, 37 countries had had nationally representative surveys done in the previous 5–7 years, and few specific reports on maternal mortality existed. To overcome the limitations of a paucity of data, statistical models have been used to assess progress in maternal health. Our model updates the method for estimating maternal mortality, and uses new data corresponding to 3634 country-years of information in 171 countries and updated estimates for covariates and the number of livebirths. Validation exercises suggest that our model was reasonably well calibrated.¹⁰ The appendix (p 121) provides an overview of the differences between UN Maternal Mortality Estimation Inter-Agency Group estimates published in 2014, and our revised estimates, and decomposes differences into those caused by new methods versus those caused by updated inputs.⁹

Despite these improvements, challenges remain regarding the estimation of maternal mortality and our study has some limitations. Estimating maternal mortality is challenging because of limited data availability. For example, for nine of 171 countries with empirical evidence, there were no datapoints from 2005 or later, and for 55 of 171 countries, there was no information since 2010. Moreover, there is substantial uncertainty around observations because of random errors (including sampling or stochastic errors), and uncertainty arising from systematic errors in reporting.

The misclassification of maternal deaths is a great obstacle to accurate measurement of maternal mortality in countries with functioning vital registration systems. Although the addition of a pregnancy check box on International Classification of Diseases coding documents has improved the classification of maternal deaths, they continue to be classified outside of related ICD-10 codes.⁹ Acknowledging these classification difficulties, countries such as Kazakhstan, Mexico, and Cuba have implemented specialised surveillance systems

and administrative protocols to review and correct cause of death assignment before submission to vital statistical departments; thus, eliminating systematic misclassification errors (unpublished data).^{26,27} If implemented in more countries, this strategy would result in more accurate reporting and provide the basis for additional analyses of misclassification that might inform misclassification adjustments for countries without such systems.

Another reporting difficulty relates to the effect of the changing definition and idea of what a maternal death is. During the MDG reporting period, countries with vital registration systems changed from using ICD-9 to ICD-10. Whereas deaths reported by ICD-9 codes cannot be explicitly identified by timing, ICD-10 introduced the concept of late maternal deaths; those that occur 42 days to 1 year after the end of a pregnancy. Since the introduction of these codes (O96 and O97), the number of late maternal deaths and cases of near-miss and maternal morbidity have increased (perhaps because of obstetric transition, in which deaths decrease because of improvements in health care).²⁸ Although improvements in health care probably contribute to this effect, the potential contribution of changes in reporting also warrants further investigation. Such considerations are especially relevant for the release of the 11th revision of the ICD, which is expected in 2018, and will be implemented through the latter half of the SDG monitoring period.

For countries without well-functioning vital registration systems, well-designed research studies and surveillance systems can collect data for cause-specific analyses of mortality to assess the proportion of deaths that have maternal causes.^{7-9,11,29} However, many countries rely on the reporting of pregnancy-related mortality for estimating maternal mortality, which is challenging because limited data are available that enable a detailed analysis of how national pregnancy-related mortality compares to maternal mortality. There is also the challenge of defining and estimating which proportion of pregnancy-related AIDS deaths should be counted as maternal deaths due to the aggravating effect of the pregnancy.⁹ Subnational studies, such as that of the INDEPTH surveillance network, might also provide new insights for estimates.²⁹ The extent of under-reporting or over-reporting of the proportion of pregnancy-related deaths is another uncertain factor. Although previous studies¹² suggested that the proportion of pregnancy-related maternal deaths are under-reported, a more recent study³⁰ in a demographic surveillance site in Senegal showed that the proportion of pregnancy-related deaths was over-reported when using a Demographic Health Survey questionnaire, and that a sibling's survival calendar might provide a better instrument for measuring pregnancy-related mortality. Further studies are needed to test the validity of these findings in other settings. More generally, to improve maternal mortality

Panel 2: Country examples of accelerated declines of maternal mortality

Survey data from Bangladesh from 2001–10,^{17,18} show that maternal health is affected by factors both directly linked and indirectly linked to health services such as improved transportation, access to mobile telephone technology (and thus communication channels for information and social assistance), as well as education and socioeconomic status. An almost doubling in the proportion of girls with at least some secondary education is believed to be empowering, raising their potential to respond effectively to maternal complications and navigate the health-care system.^{17,18} The case of Bangladesh shows the need to look beyond the health-care systems when considering how to enact policies to reduce maternal mortality.

Between 1990 and 2015, both Cambodia and Rwanda had accelerated rates of reduction of maternal mortality. Cambodia reduced maternal mortality, with an annual continuous rate of reduction of 7.4% (80% UI 5.6–8.7), and the rate in Rwanda was 6.0% (4.5–7.4). In Cambodia, access to health care was improved through heavy government investment in transport infrastructure and health facilities, from local free-standing health facilities and health centres to referral and national hospitals. Innovative policies and programme responses for reproductive, maternal, and child health have priorities in Cambodia from the mid-2000s, including operating health centres 24 h per day and adding maternity waiting houses and extended delivery rooms at health centres to make maternity services more accessible. The Cambodian Ministry of Health also increased both the training of midwives and their absorption into the health system through targeted deployment. To further increase the proportion of births attended by a skilled midwife, financial incentives were offered to health-care workers.¹⁹

Rwanda's substantial reductions in maternal mortality have been linked to a range of key policy and programme interventions, including deployment of 45 000 trained community health workers nationwide. Community health workers are incentivised by rewarding them according to improvements on selected indicators, including the proportion of women delivering at health facilities. Rwanda also prioritised community involvement, allowing villages to elect three individuals to serve as their community health workers. Additionally, a comprehensive and community-based health insurance scheme has lowered financial thresholds for accessing maternal and child health services and thus expanded access to poorer populations. Finally, Rwanda has greatly strengthened its data collection system to help set priorities, plan, and allocate resources: all maternal and child health services have been integrated into a national monitoring and evaluation framework, a web-based health management information system has been developed and deployed, and maternal death reviews were scaled up.²⁰

Together, these examples show how the expansion of service coverage and increasing the number of health-care providers, setting standards of care, clarifying when referrals should be made, and training programmes for qualified health providers such as midwives helped to reduce maternal mortality.^{17,21} These examples also show the need to balance quality of care with avoidance of over-medicalisation to reduce maternal mortality.^{21,22}

estimates, future endeavours related to maternal health monitoring should take into account how data are collected and determine mechanisms to standardise data to minimise reporting biases.¹¹

The estimation of maternal mortality depends on the estimation of adult female mortality and the number of births. As such, the challenges and limitations that apply to the estimation of these two indicators should also apply to estimation of maternal mortality.^{13,14} Uncertainty assessments should include the uncertainty in related indicators such as covariates, all-cause deaths, and births. A further limitation is the reliance on predictor covariates

whenever empirical country observations are lacking. Compounding this limitation is the challenge in constructing time series of covariates that are comparable across countries and within countries over time. Doing so for skilled birth attendance is particularly challenging because of difficulties in its definition as well as reporting.^{31–34} Because of the uncertainty in maternal mortality indicators, more attention needs to be given to the presentation and interpretation of UIs. In addition, users of MMR estimates should be warned against post-hoc analyses for countries with limited data, such as correlating the MMR estimates with coverage indicators, given the uncertainty surrounding the MMR estimates and the covariate-driven estimation approach.

Our estimates of MMR differ from those produced by the Global Burden of Disease study 2013 (appendix pp 119, 305–487).³⁵ Globally, for the 183 countries included in our study (excluding Puerto Rico), the Global Burden of Disease study estimated that there were 374 000 maternal deaths in 1990, compared with our estimate of 532 000 (80% UI 496 000–590 000).³⁶ Large differences are present in southern Asia and sub-Saharan Africa. For 2013, the differences are smaller: the Global Burden of Disease study estimates 292 000 maternal deaths compared with 315 000 (80% UI 303 000–356 000) in our study. Differences in MMRs might be due to differences in estimates of all-cause deaths: all-cause mortality estimates are much lower in the Global Burden of Disease study than in our study for most countries in sub-Saharan Africa in 1990, and all-cause mortality in the Global Burden of Disease might be underestimated for those countries that rely largely on Demographic Health Survey sibling histories.³⁷ Other explanations for differences in estimates include differences in the pre-processing of input data (ie, vital registration and Demographic Health Survey data), differences in the estimates of the number of births (the Global Burden of Disease study used estimates from World Population Prospects 2012 whereas we used World Population Prospects 2015), and differences in the models and covariates used for estimating maternal mortality outcomes. More analysis is needed to better understand the contribution of the various differences in modelling to the differences in estimates at the country and regional levels.

As the aim of monitoring in MDG 5 has given way to maternal mortality-related targets for the SDGs, a vision of ending all preventable maternal deaths has emerged.³⁸ Although maternal deaths might still occur in even the best circumstances, every effort should be made to eliminate preventable maternal deaths. The SDG of reducing global maternal mortality to less than 70 deaths per 100 000 livebirths by 2030 works towards this aim.¹¹ Our projections suggest that the achievement of the SDG maternal mortality target would result in 60·1% fewer maternal deaths in 2030, and 1·4 million fewer deaths cumulatively from 2016 to 2030, compared with a projection based on the typical rate of reduction for 2000–10.

Although the SDG target is a worthy aim, individual countries need to do much work to accomplish this ambitious goal in the next 15 years. Continued research on what efforts and innovations have the greatest effect on maternal mortality will help to allocate resources and set priorities. The acceleration in reducing maternal mortality will not be possible without clinical and non-clinical interventions as well as political and policy action, as shown by countries that have already substantially decreased maternal mortality in a short period. Although each country will be different, the Ending Preventable Maternal Mortality Strategy suggests adaptive highly effective interventions to improve women's health, before, during, and after pregnancy.¹¹ Discussions on interventions should be informed by the content and quality of the care provided; efforts are underway to define and delineate what constitutes high-quality care, which would be expected to decrease mortality and morbidity.³⁹ These strategies are complemented by analyses such as the Lives Saved Tool and the One Health Tool, which provide insights into their cost-effectiveness and effect on mortality reduction.^{40,41}

Achievement of the target will also require robust information systems to monitor progress and inform priority-setting, planning, and resource allocation. The importance of high-quality data, specifically on cause of death, to inform decision making and to ultimately reduce maternal mortality is described in the UN Global Strategy for Women's, Children's and Adolescents' Health, which puts data collection at the centre of political attention.^{42,43}

Although the activities and resources needed to accomplish the SDG target might seem overwhelmingly ambitious, ten countries—including Cambodia and Rwanda—have experienced rates of reduction that exceeded those necessary to meet the SDG target. Moreover, a world where millions of preventable maternal deaths continue to occur is not acceptable as an alternative scenario. Hence, the time for action is now.

Contributors

LA and SZ developed the statistical model and analysed the model results. DH and CM provided statistical support and inputs to the model's development. DC, DH, DMF, AG, and A-BM constructed input datasets. LA, DC, DH, and LS wrote the first draft of the report. All authors reviewed results and provided inputs and comments.

UN MMEIG collaborators and technical advisory group

Saifuddin Ahmed (Johns Hopkins University, Baltimore, MD, USA), Mohamed M Ali (World Health Organization, Eastern Mediterranean Regional Office, Cairo, Egypt), Agbessi Amouzou (United Nations Children's Fund, New York, NY, USA), David Brauholtz (independent consultant), Peter Byass (Umeå University, Umeå, Sweden; University of the Witwatersrand, Johannesburg, South Africa), Liliana Carvajal-Velez (United Nations Children's Fund, New York, NY, USA), Victor Gaigbe-Togbe (United Nations Population Division, New York, NY, USA), Patrick Gerland (United Nations Population Division, New York, NY, USA), Edilberto Loaiza (UNFPA, New York, NY, USA), Samuel Mills (World Bank Group, Washington DC, USA), Namuunda Mutombo (African Population and Health Research Center, Nairobi, Kenya), Holly Newby (United Nations Children's Fund, New York, NY, USA), Thomas W Pullum (Demographic Health Survey, Rockville, MD, USA), and Emi Suzuki (World Bank Group, Washington DC, USA).

Declaration of interests

We declare no competing interests.

Acknowledgments

The content of this Article is solely the responsibility of the authors and does not necessarily represent the official views of the institutions to which the authors are affiliated. We thank the numerous survey participants and the staff involved in the collection and publication of the data that we analysed. We also thank country focal points and participants of regional workshops on maternal mortality estimation for their comments and provision of additional data sources. We are grateful to Jeff Eaton, Bilal Barakat, and Emily Peterson for discussion of the study and comments on previous versions of the manuscript, and to Nobuko Mizoguchi for preparing the census input data. We thank Maria Barreix and Karin Stein for assistance with translation and manuscript preparation.

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