

Global Maternal Health (GMatH) Model Overview

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Article

Simulation-based estimates and projections of global, regional and country-level maternal mortality by cause, 1990–2050

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Check for updates

Maternal mortality is a major global health challenge. Although progress has been made globally in reducing maternal deaths, measurement remains challenging given the many causes and frequent underreporting of maternal deaths. We developed the Global Maternal Health microsimulation model for women in 200 countries and territories, accounting for individual fertility preferences and clinical histories. Demographic, epidemiologic, clinical and health system data were synthesized from multiple sources, including the medical literature, Civil Registration Vital Statistics systems and Demographic and Health Survey data. We calibrated the model to empirical data from 1990 to 2015 and assessed the predictive accuracy of our model using indicators from 2016 to 2020. We projected maternal health indicators from 1990 to 2050 for each country and estimate that between 1990 and 2020 annual global maternal deaths declined by over 40% from 587,500 (95% uncertainty intervals (UI) 520,600–714,000) to 337,600 (95% UI 307,900–364,100), and are projected to decrease to 327,400 (95% UI 287,800–360,700) in 2030 and 320,200 (95% UI 267,100–374,600) in 2050. The global maternal mortality ratio is projected to decline to 167 (95% UI 142–188) in 2030, with 58 countries above 140, suggesting that on current trends, maternal mortality Sustainable Development Goal targets are unlikely to be met. Building on the development of our structural model, future research can identify context-specific policy interventions that could allow countries to accelerate reductions in maternal deaths.

Ward ZJ, Atun R, King G, Sequeira Dmello B, Goldie SJ. Simulation-based estimates and projections of global, regional and country-level maternal mortality by cause, 1990-2050. *Nat Med* 2023.

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Article

https://doi.org/10.1038/s41591-023-02311-w

A simulation-based comparative effectiveness analysis of policies to improve global maternal health outcomes

Received: 15 June 2022

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The Sustainable Development Goals include a target to reduce the global maternal mortality ratio (MMR) to less than 70 maternal deaths per 100,000 live births by 2030, with no individual country exceeding 140. However, on current trends the goals are unlikely to be met. We used the empirically calibrated Global Maternal Health microsimulation model, which simulates individual women in 200 countries and territories to evaluate the impact of different interventions and strategies from 2022 to 2030. Although individual interventions yielded fairly small reductions in maternal mortality, integrated strategies were more effective. A strategy to simultaneously increase facility births, improve the availability of clinical services and quality of care at facilities, and improve linkages to care would yield a projected global MMR of 72 (95% uncertainty interval (UI) = 58–87) in 2030. A comprehensive strategy adding family planning and community-based interventions would have an even larger impact, with a projected MMR of 58 (95% UI = 46-70). Although integrated strategies consisting of multiple interventions will probably be needed to achieve substantial reductions in maternal mortality, the relative priority of different interventions varies by setting. Our regional and country-level estimates can help guide priority setting in specific contexts to accelerate improvements in maternal health.

Ward ZJ, Atun R, King G, Sequeira Dmello B, Goldie SJ. A simulation-based comparative effectiveness analysis of policies to improve global maternal health outcomes. *Nat Med* 2023.

Maternal Mortality Estimation

Measurement of maternal mortality is fraught with difficulty:

- Inadequate data collection and absence of vital registration systems in many countries
- Relatively rare: large samples are needed for stable estimates
- Difficult to identify: not a single diagnosis but composite of many distinct conditions, each with their own pathophysiology
- Underreporting: many maternal deaths are missed, especially in early pregnancy and from complications of induced abortion

Aggregate vs Structural Models

- Aggregate models: based solely on previous trends of the outcome of interest
 - Estimate cross-sectional country-level association between aggregate factors and levels of maternal mortality
 - Gross domestic product (GDP) the largest driver of trends
- Structural models: based on a defined system of causal components and their relationships
 - Can offer more robust estimates for complex systems
 - Synthesize data on various factors from multiple sources
 - Use information on related processes/outcomes observed with more certainty to estimate ultimate outcomes of interest
 - Causal structure allow for counterfactual scenarios to be run
 - Estimate potential impact of interventions

Model Overview



Global Maternal Health (GMatH) microsimulation model

- Simulates the reproductive histories of individual women in 200 countries and territories
 - 6 subgroups of urban/rural and maternal education (low/medium/high)
 within each country -> account for impact of demographic trends
 - Individual-level heterogeneity in family planning preferences and history of maternal complications

Model Overview



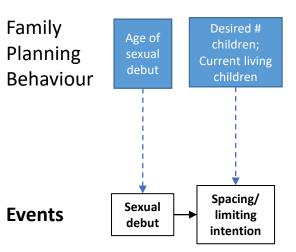
Global Maternal Health (GMatH) microsimulation model

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- Causal framework

- Simulate 'natural history' (i.e. in the absence of any intervention) of various reproductive processes
- Also explicitly model coverage levels and impact of relevant clinical and health system interventions
- Allows counterfactual outcomes to be estimated by varying the coverage levels and/or impact of the modelled interventions

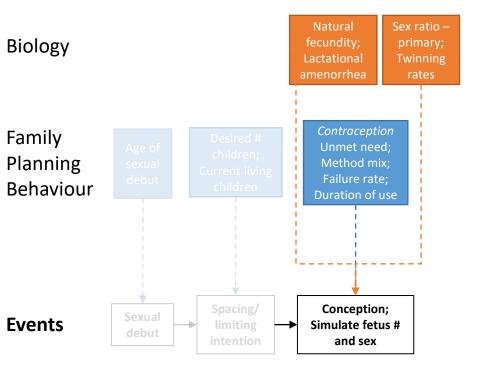
Biology



Obstetric Complications

Health System

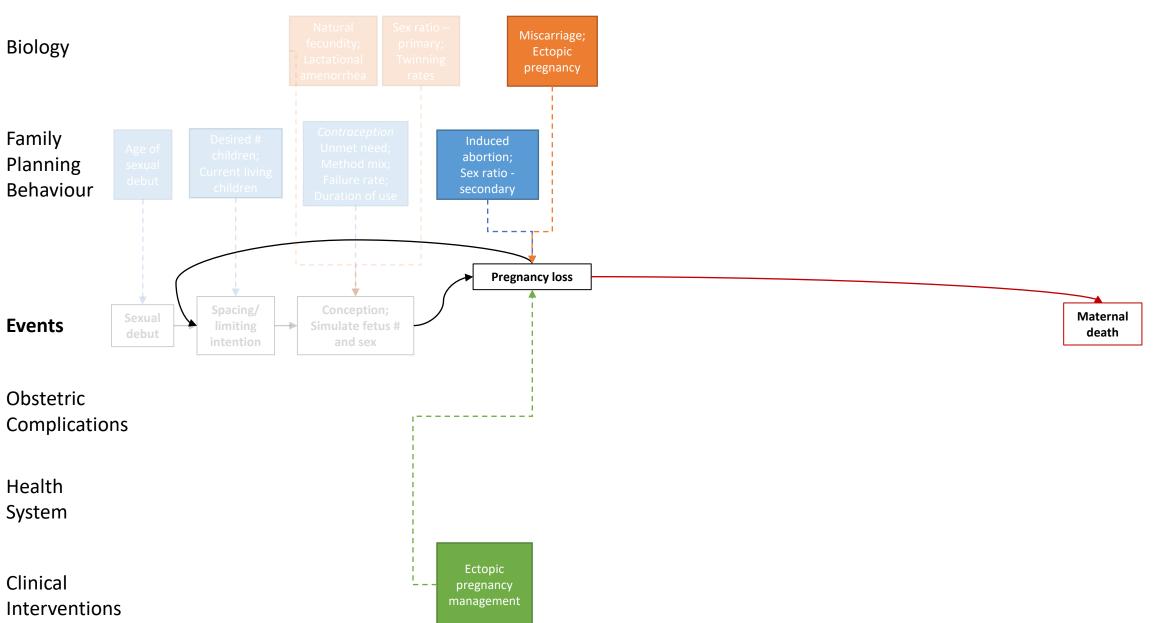
Clinical Interventions

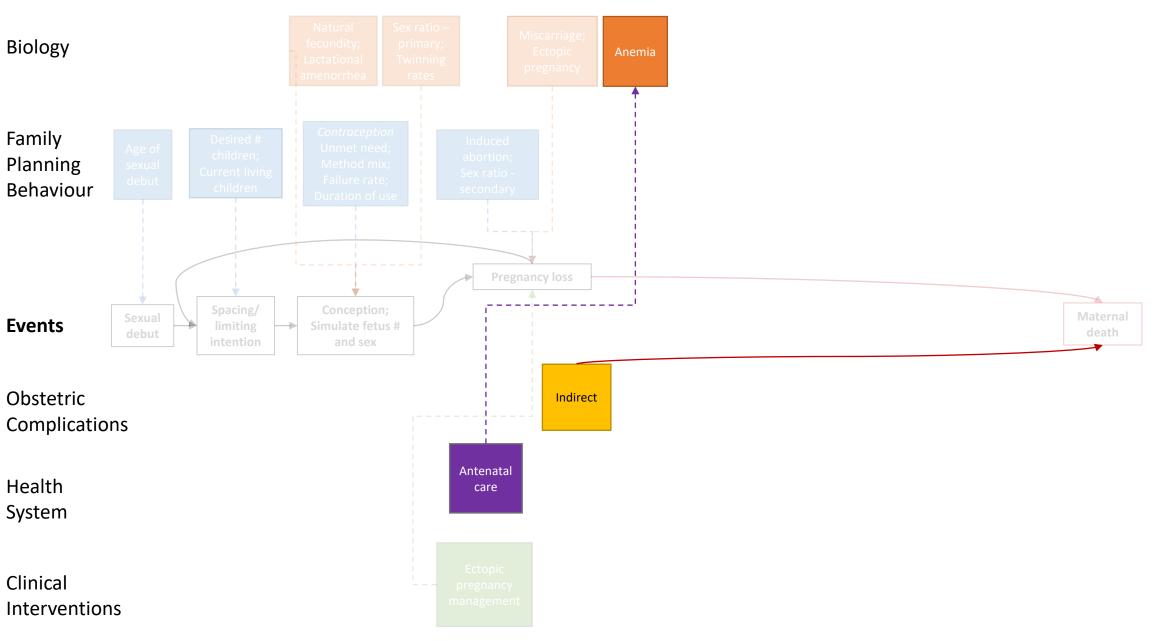


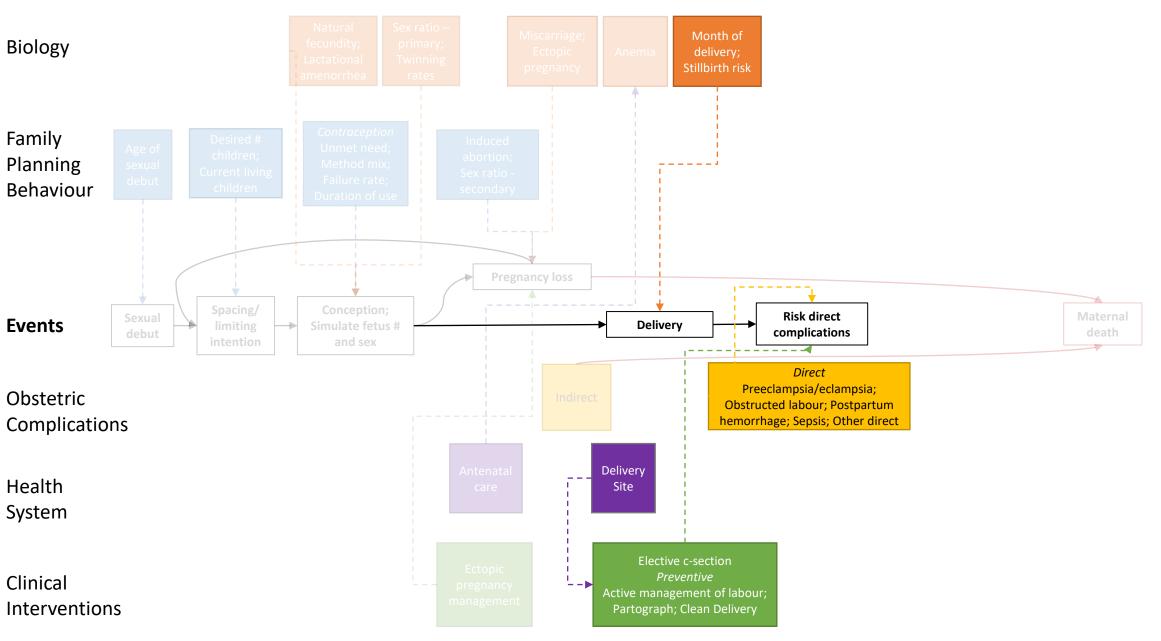
Obstetric Complications

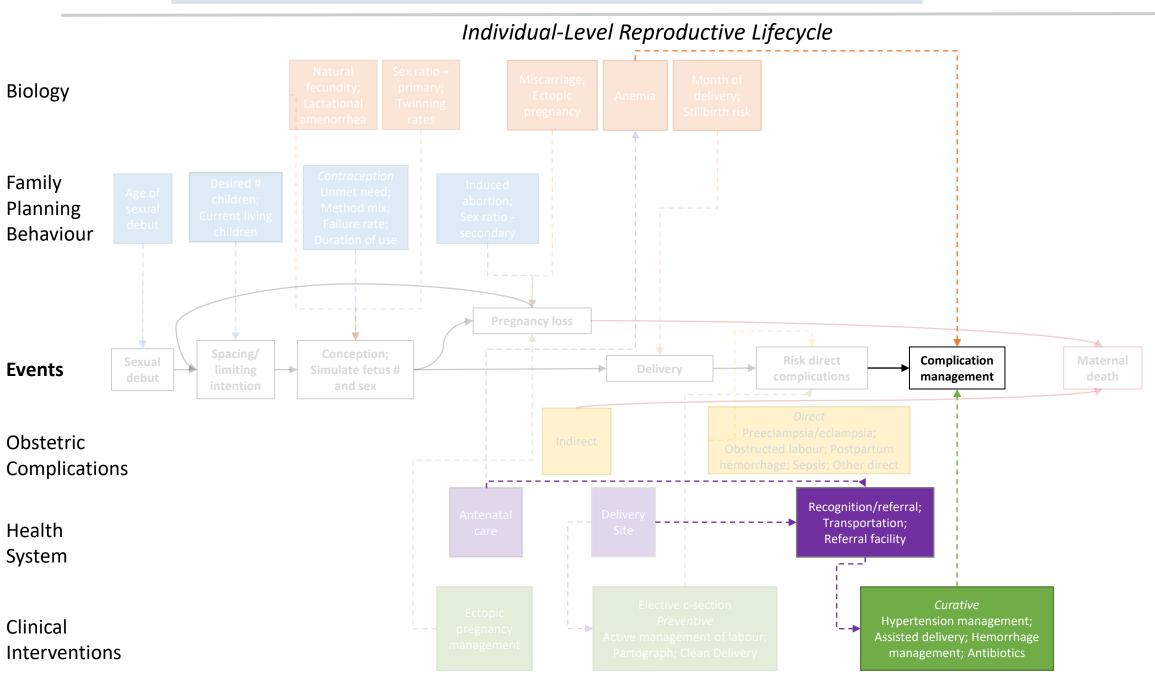
Health System

Clinical Interventions

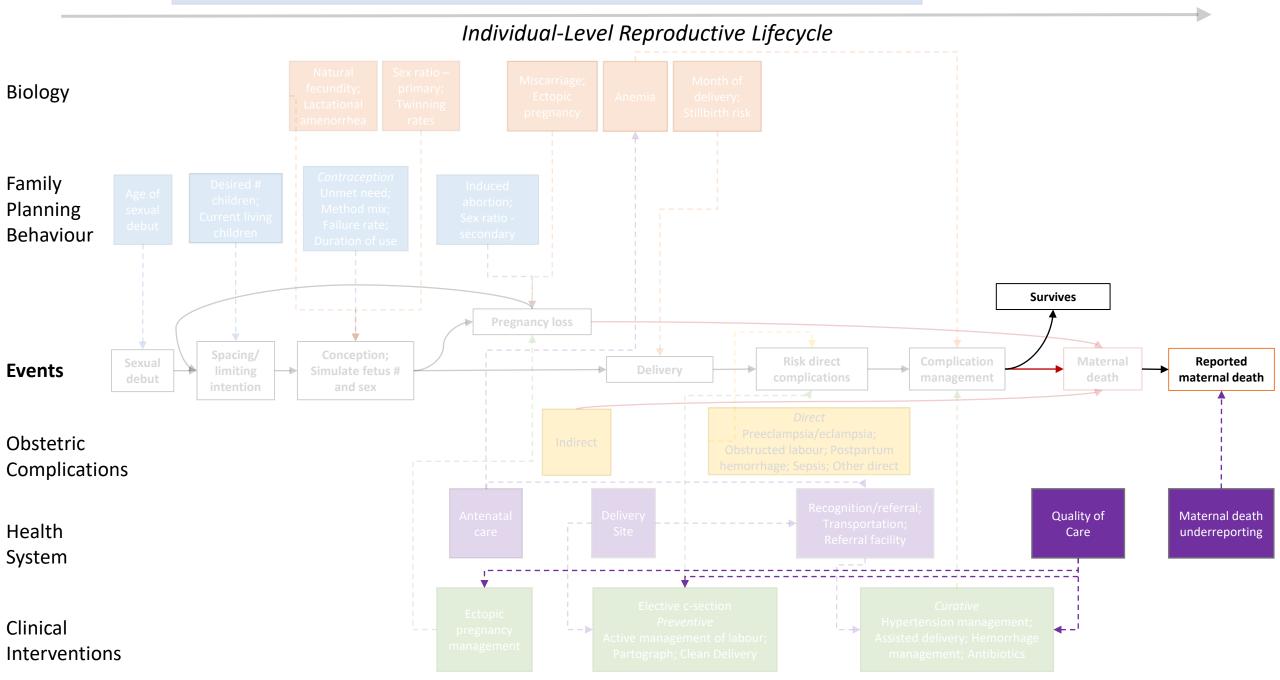




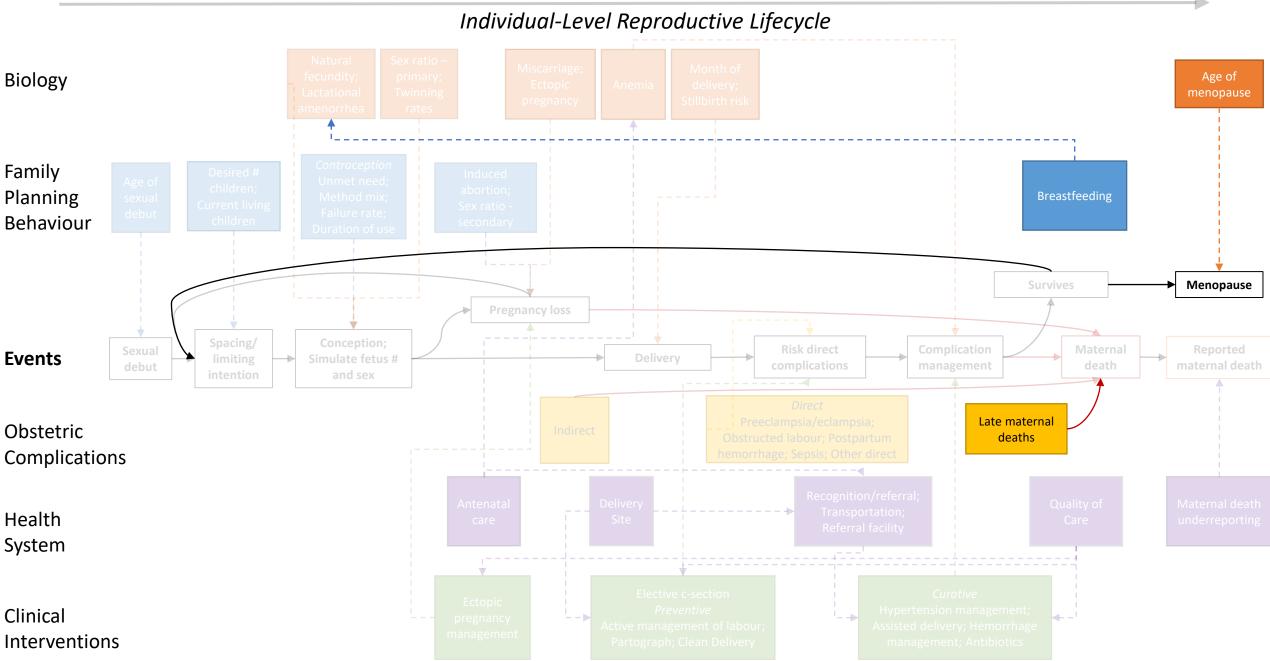




Demographics



Demographics



Model Parameter Inputs

- ~ 50 parameter groups
- Hierarchical modelling approach with up to five levels: global, country income group, area [i.e. continent], region, and country
 - Many parameters vary by subgroup (urban/rural + education)
- Synthesized the best available epidemiologic and clinical evidence from various sources: randomized clinical trials, observational studies, meta-analyses, expert opinion, census data, and primary survey data
 - Individual-level Demographic and Health Survey (DHS) data for over 4.6 million women from 322 surveys in 83 countries

~450,000 parameters

Model Documentation





Model Inputs -





GMatH (Global Maternal Health) Model Model Overview

The Global Maternal Health (GMatH) microsimulation model simulates the reproductive histories of individual women in 200 countries and territories, accounting for heterogeneity in education and urban/rural location, family planning preferences, and history of maternal complications. The structural nature of the model allows for more robust estimates of maternal mortality to be made, and provides a causal framework in which counterfactual scenarios can be modelled to evaluate the impact of different policies aimed at improving maternal health.

- Model Inputs: To develop the model we synthesized the best available epidemiologic and clinical evidence from various sources, including
 randomized clinical trials, observational studies, meta-analyses, expert opinion, census data, and primary survey data, and explicitly
 accounted for uncertainty in all of these inputs.
- Datasets and Definitions: More information on the datasets used in the model and the calculated maternal health indicators is available
 here.
- . Model Calibration: We calibrated the model to empirical data on a range of maternal health indicators.

Acknowledgements

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GMatH (Global Maternal Health) Model - Last updated: 28 November 2022

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Calibration Targets

Calibrated to empirical primary data (no modelled estimates)

Fit to data from 1990-2015, reserving 2016-2020 estimates a test set

	Training Set (1990-	Testing Set (2016-	
	2015): # Countries (#	2020): # Countries (#	
Indicator	Estimates)	Estimates)	Data Source
Fertility Indicators			
Total fertility rate (TFR) (age 15-49)	186 (6,633)	120 (249)	UN World Fertility data
Contraceptive prevalence (age 15-49	74 (235)	20 (21)	DHS data
Twinning rate	107 (107)	0 (0)	Smits 2011, Pison 2015
Process Indicators			
Anemia prevalence (by severity)	48 (291)	16 (48)	DHS data
Stillbirth rate	93 (656)	0 (0)	Blencowe 2016
Facility delivery %	121 (286)	84 (85)	DHS data, WHO GHO database
C-section rate	161 (479)	60 (69)	UNICEF Maternal and Newborn Health Coverage Database
Spontaneous/operative vaginal delivery %	24 (48)	0 (0)	WHO Global Survey on Maternal and Perinatal Health
Mortality Indicators			
Maternal deaths (total) (CRVS data)	123 (2,311)	70 (117)	WHO Mortality Database
Maternal deaths by cause (CRVS data)	114 (11,216)	69 (928)	WHO Mortality Database
Pregnancy-related mortality ratio	56 (137)	0 (0)	DHS data
Miscellaneous (maternal deaths, maternal mortality	22 (96)	3 (8)	Country-specific sources
	22.405	1 525	
ratio, pregnancy-related mortality ratio) TOTAL	22,495	1,525	, .

Calibration Targets

Calibrated to empirical primary data (no modelled estimates)

Fit to data from 1990-2015, reserving 2016-2020 estimates a test set

Computationally intensive model!

- Multi-threaded simulation (6 cores) ~ 20 mins
- 'Relay' simulated annealing
 - Best-fitting hyperparameters are passed to next search chain

Indicator	Training Set (1990- 2015): # Countries (# Estimates)	Testing Set (2016- 2020): # Countries (# Estimates)	Data Source				
Fertility Indicators							
Total fertility rate (TFR) (age 15-49)	186 (6,633)	120 (249)	UN World Fertility data				
Twinning rate	107 (107)	0 (0)	Smits 2011, Pison 2015				
Process Indicators							
Anemia prevalence (by severity)	48 (291)	16 (48)	DHS data				
Facility delivery %	121 (286)	84 (85)	DHS data, WHO GHO database				
Spontaneous/operative vaginal delivery %	24 (48)	0 (0)	WHO Global Survey on Maternal and Perinatal Health				
Maternal deaths (total) (CRVS data)	123 (2,311)	70 (117)	WHO Mortality Database				
Pregnancy-related mortality ratio	56 (137)	0 (0)	DHS data				
TOTAL	22,495	1,525					

Posterior Predictive Checks

Maternal mortality indicators

- Training Set (1990-2015):
 - Coverage probability: 96.0%
 - Mean absolute error by cause: **10.6** deaths

- Testing Set (2016-2020):
 - Coverage probability: 96.0%
 - Mean absolute error by cause: **10.5** deaths

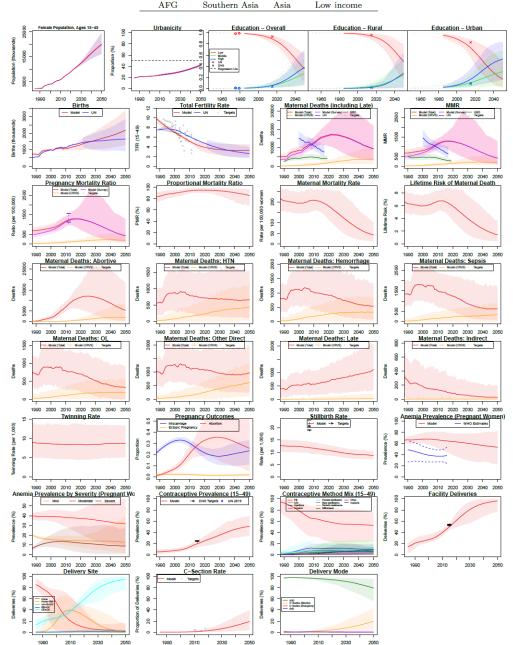
A. Maternal deaths **Income Group** Africa Asia Europe Latin America and the Caribbear 800 s (thousands) Low income Lower-middle income Upper-middle income High income Oceania 900 1990 2000 2010 2020 2030 2040 2050 1990 2000 2010 2020 2030 2040 2050 B. MMR Income Group Africa Asia 1000 nortality ratio (MMR) Low income Lower-middle incom Upper-middle income North America Oceania 009 1990 2000 2010 2020 2030 2040 2050 1990 2000 2010 2020 2030 2040 2050

500+ Maternal deaths per 100,000 live births

Fig. 2 | Projected MMR by country in 2030. Mean projected MMR (maternal deaths per 100,000 live births) by country in 2030.

 $\textbf{Extended Data Fig. 2} \ | \textbf{Estimated maternal deaths and MMR by area} \ and \ \textbf{country income group, 1990-2050.} \ \textbf{A}. \ \textbf{Maternal Deaths.} \ \textbf{B}. \ \textbf{Maternal mortality ratio} \ \textbf{A}. \ \textbf$ $(maternal\ deaths\ per\ 100,000\ live\ births).\ Lines\ represent\ means.\ Shaded\ areas\ indicate\ 95\%\ uncertainty\ intervals.$





Zambia

ISO Code	Region	Area	Income Group
ZMB	Eastern Africa	Africa	Lower middle income

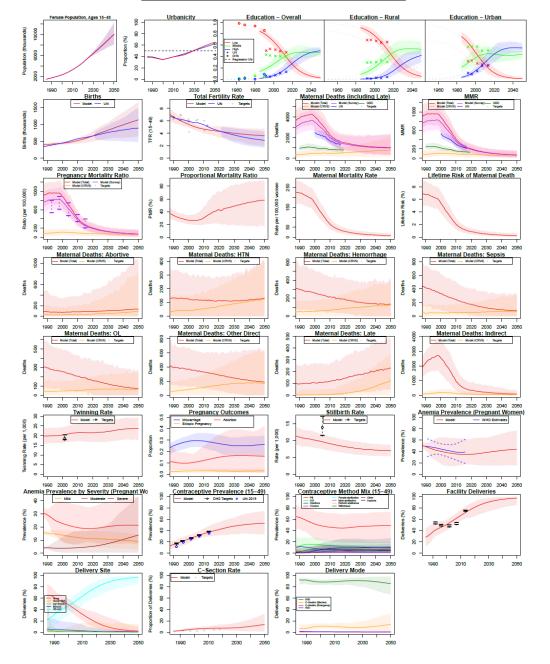


Table 2 | Maternal health policy interventions

Intervention	Description	Modeled implementation	Estimated global mean (95% UI), 2022	2030 target (minimum coverage)
Family planning interven	tions			
Contraception	Reduce unmet need through availability and access to contraception for spacing and limiting	Reduce unmet need for contraception. No change in the methods used or desired family size	Met need: 40.3% (30.6-48.4%)	Met need: 80%
Medical abortion	Reduce mortality due to 'unsafe' abortion through availability and access to 'safe' medical abortion	Increase proportion of abortions that are 'safe'. No change in probability of abortion	89.2% (83.8–93.5%)	95%
Community-based interv	rentions			
ANC	Improve health status (for example, anemia) during pregnancy and knowledge of complication danger signs	Increase probability and number of ANC visits	P _{any} : 66.8% (47.4–78.4%) No. of visits any: 5.3 (3.8–6.5)	P _{any} : 95% No. of visits any: at least 4
deliveries (SBA-home) to trained SBA for home births and use of basic interventions by SBA Facility-based interventions Facility births Increase proportion of women that give birth in medical facilities instead of at home,		Increase proportion of home births attended by an SBA, as well as use of clean birth kits to reduce sepsis, and management of moderate hemorrhage. No change in SBA referral probabilities	SBA: 37.1% (27.7-52.9%) Clean delivery: 58.4% (50.4-65.4%) Hemorrhage management: 8.7% (4.6-13.6%)	SBA: 80% Clean delivery: 90% Hemorrhage management: 50%
Facility-based intervention	ons			
Facility births	that give birth in medical	Increase proportion of facility births. No change in distribution of facility levels	83.0% (80.5–86.0%)	99%
Availability of clinical serv	ices			
Non-EmOC services	Improve availability of basic interventions at non-EmOC facilities	Improve availability of clean delivery, active management of the third stage of labor (AMTSL), partograph, assisted delivery for moderate obstructed labor, treatment of moderate pregnancy-related hypertension, moderate hemorrhage and sepsis at non-EmOC facilities. No change in quality of care	Clean delivery: 77.6% (67.8–86.2%) AMTSL: 76.6% (667–86.4%) Partograph: 50.5% (341,722.2%) Assisted delivery: 53.4% (46.5–59.5%) Hypertension management: 32.3% (217–43.5%) Hemorrhage management: 54.6% (47.3–62.7%) Sepsis management: 79.0% (72.2–86.3%)	90%
example, anemia) during pregnancy and knowledge of complication danger signs SBAs for home deliveries (SBA-home) Facility-based interventions Facility births Increase proportion of women that give birth in medical facilities instead of at home, where they will have access to varying levels of obstetrical care depending on the level of the facility of clinical services Non-EmOC services Improve availability of basic interventions at non-EmOC		Improve availability of clean delivery, AMTSL, partograph, assisted delivery for moderate obstructed labor, treatment of ectopic pregnancy, moderate pregnancy-related hypertension, moderate hemorrhage and sepsis at BEmOC facilities. No change in quality of care	Clean delivery: 93.2% (87.5-97.2%) AMTSL: 92.6% (85.3-95.8%) Partograph: 83.2% (75.8-93.0%) Assisted delivery: 66.4% (61.5-72.0%) Ectopic pregnancy management: 92.2% (86.1-96.0%) Hypertension management: 66.2% (59.3-73.1%) Hemorrhage management: 78.9% (74.3-92.2%) Sepsis management: 89.8% (86.6-93.4%)	95%
	of comprehensive set of interventions at CEmOC	Improve availability of clean delivery, AMTSL, partograph, assisted delivery for moderate-to-severe obstructed labor, treatment of ectopic pregnancy, moderate-to-severe pregnancy-related hypertension, moderate-to-severe hemorrhage and sepsis at CEmOC facilities. No change in quality of care	Clean delivery: 97.6% (95.4-98.9%) AMTSL: 96.5% (94.7-98.1%) Partograph: 90.5% (871-93.7%) Assisted delivery: 96.4% (91.8-97.7%) Ectopic pregnancy management: 96.8% (92.9-99.0%) Hypertension management: 92.4% (88.8-95.0%) Hemorrhage management: 94.3% (92.4-96.1%) Sepsis management: 97.5% (95.4-98.8%)	99%
System-relevant interver	ntions			
Quality of care	that women receive at health	Improve complication recognition and quality of care at facilities. No change in availability of clinical services	Non-EmOC: 47.6% (42.9-55.7%) BEMOC: 85.9% (79.1-92.8%) CEMOC: 93.3% (92.3-94.2%)	Non-EmOC: 90% BEmOC: 95% CEmOC: 99%

Table 2 (continued)| Maternal health policy interventions

Intervention	Description	Modeled implementation	Estimated global mean (95% UI), 2022	2030 target (minimum coverage)	
Linkages to care					
Referral	Improve recognition and referral of pregnancy complications to health facilities	Increase referral of complications from SBA-home, non-EmOC and BEmOC	SBA-home: 73.5% (71.1-76.2%) Non-EmoC: 92.8% (90.4-94.5%) BEMOC: 96.6% (95.4-97.8%)	SBA-home: 90% Non-EmOC: 95% BEmOC: 99%	
Transportation	Improve availability of timely transportation for women seeking emergency care at a health facility	Increase transportation from home, SBA-home, non-EmOC and BEmOC	Home: 24.0% (20.0-28.2%) SBA-home: 61.1% (49.2-71.2%) Non-EmOC: 94.2% (91.4-95.8%) BEMOC: 97.7% (96.3-99.0%)	Home: 80% SBA-home: 85% Non-EmOC: 97% BEmOC: 99%	
Targeted transfers	Improve targeting of referrals to facilities that are a higher level than the current delivery site, as opposed to transferring a woman to another facility of the same level (that is, horizontal transfer)	Reduce horizontal transfers	Non-EmOC: 3.8% (2.7-5.0%) BEmOC: 42.4% (36.4-51.2%)	Non-EmOC: 1% BEmOC: 10%	

Estimated global means (and 95% UIs) for 2022 are weighted by population (calculated across countries and demographic subgroups). The 2030 targets are informed by the 2022 estimated means among high-income countries.

Table 3 | Integrated strategies to reduce maternal mortality

		Family planning		Community- based		Facility-based			System-relevant				
Strategy	Description	Contra- ception	Medical abortion	ANC	SBA- home	Facility births	Non-EmOC services		CEmOC services	Referral	Transpor- tation	Targeted transfers	
Family planning	Improve the ability of women to achieve their fertility preferences	Х	X										
Community+ linkages	Improve community-based pregnancy care and referral pathway for emergency care at health facilities			X	X					X	Х	X	
Facilities+ linkages	Increase facility births, improve availability of clinical interventions at health facilities, and improve referral pathway for emergency care at health facilities					Х	X	Х	Х	X	X	X	
Facilities+ linkages+ quality	Increase facility births, improve availability of clinical interventions at health facilities, and improve referral pathway and quality of care at health facilities					X	Х	Х	Х	Х	X	X	X
Comprehensive	Improve family planning, community-based, facility-based and system-relevant aspects of maternal health	х	Х	X	X	Х	Х	х	х	Х	Х	X	X

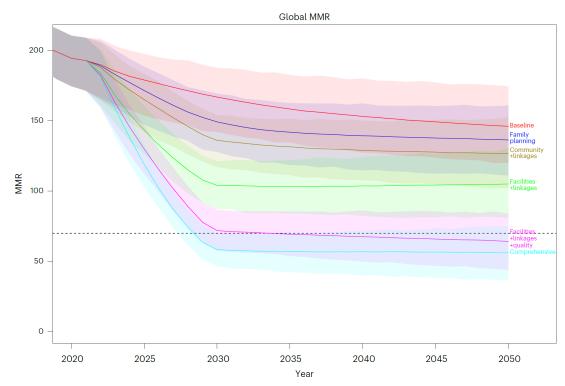
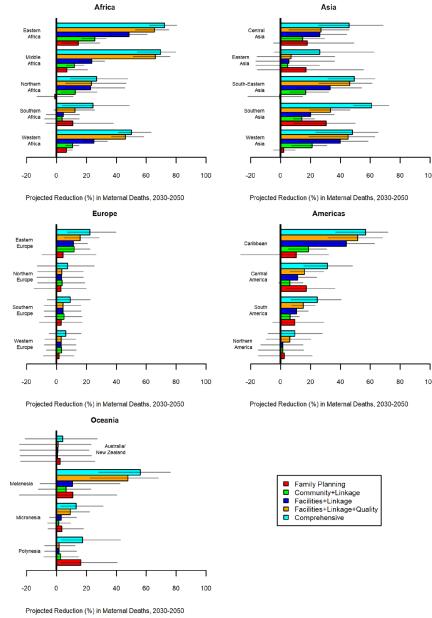


Fig. 1| Projected global MMR according to an integrated strategy. The lines indicate the means, the shaded regions indicate the 95% UIs and the dashed line indicates the SDG target 3.1 of a global MMR of 70 by 2030.



Extended Data Fig. 2 | **Projected Reduction in Maternal Deaths 2030–2050 by Region and Integrated Strategy.** Reduction is mean percent reduction in projected maternal deaths in 2030–2050 (cumulative) compared to Baseline

projections. Horizontal lines indicate 95% uncertainty intervals, calculated as the 2.5 and 97.5 percentiles of the simulation results.

Questions?



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