



Global Maternal Health (GMatH) Model Overview

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IDM Annual Symposium

May 24, 2023

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Funding:

Z.J.W. and S.J.G. received support from the John D. and Catherine T. MacArthur Foundation (grant no. 10-97002-000-INP). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.



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

Received: 15 June 2022

Accepted: 15 March 2023

Published online: 20 April 2023

Check for updates

Zachary J. Ward¹✉, Rifat Atun^{2,3,4}, Gary King⁵,
Brenda Sequeira Dmello⁶ & Sue J. Goldie^{1,3,4,7}

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.



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

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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

- 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
- 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

Demographics

Population size, age structure; Lifetables; Urbanization; Education; Injury-related Deaths; Migration

Population-Level Trends



Demographics

Population size, age structure; Lifetables; Urbanization; Education; Injury-related Deaths; Migration

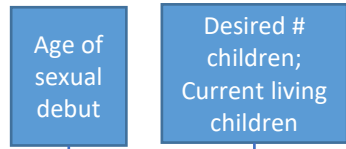
Population-Level Trends



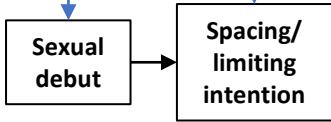
Individual-Level Reproductive Lifecycle

Biology

Family Planning Behaviour



Events



Obstetric Complications

Health System

Clinical Interventions

Demographics

Population size, age structure; Lifetables; Urbanization; Education; Injury-related Deaths; Migration

Population-Level Trends

Individual-Level Reproductive Lifecycle

Biology

Natural fecundity; Lactational amenorrhea
Sex ratio – primary; Twinning rates

Family Planning Behaviour

Age of sexual debut

Desired # children; Current living children

Contraception
Unmet need; Method mix; Failure rate; Duration of use

Events

Sexual debut

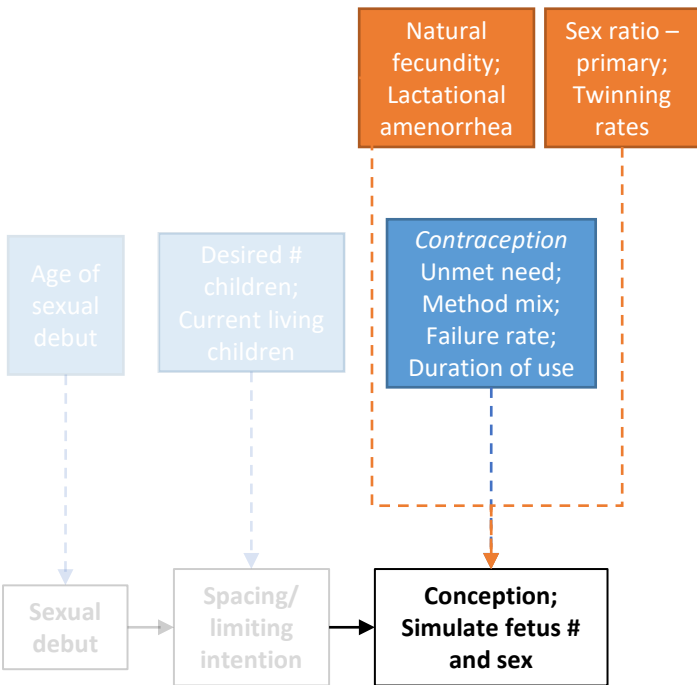
Spacing/limiting intention

Conception; Simulate fetus # and sex

Obstetric Complications

Health System

Clinical Interventions



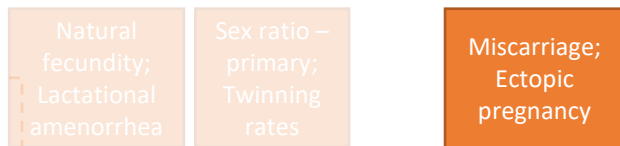
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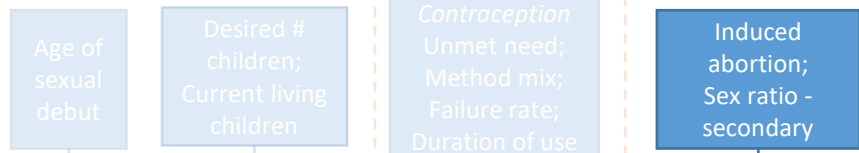
Population-Level Trends

Individual-Level Reproductive Lifecycle

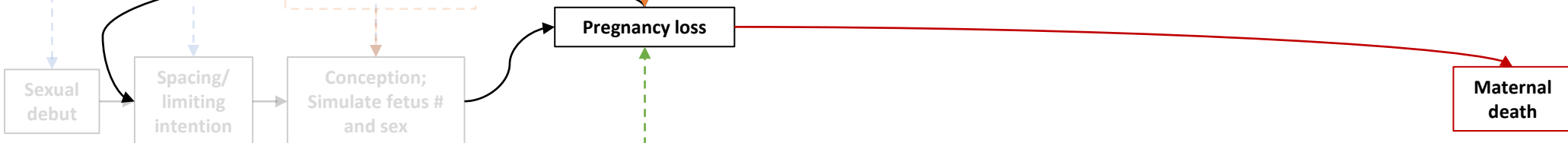
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Family Planning Behaviour



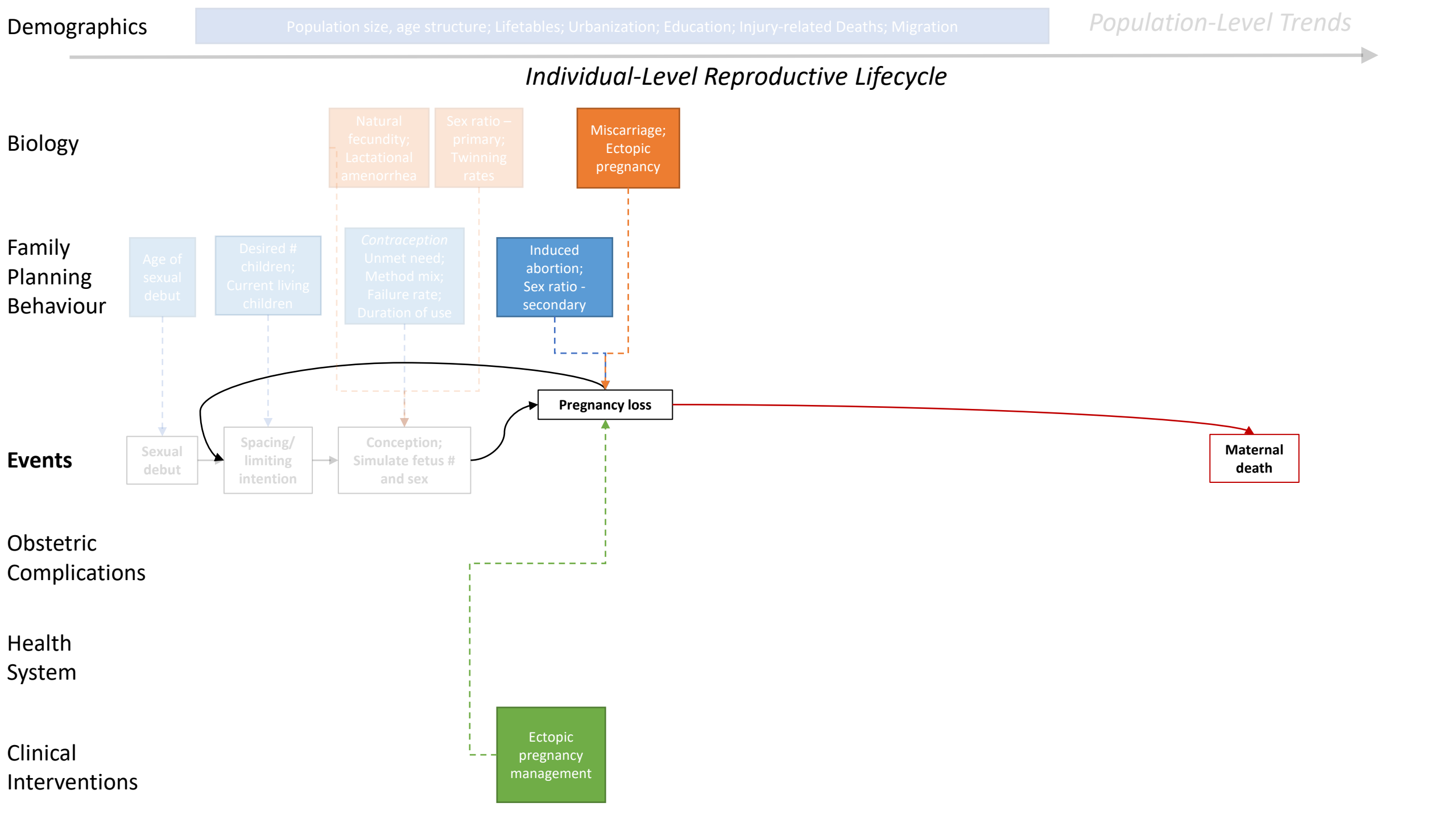
Events



Obstetric Complications

Health System

Clinical Interventions



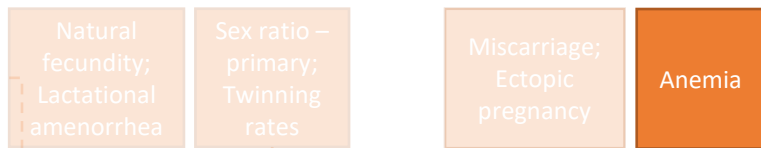
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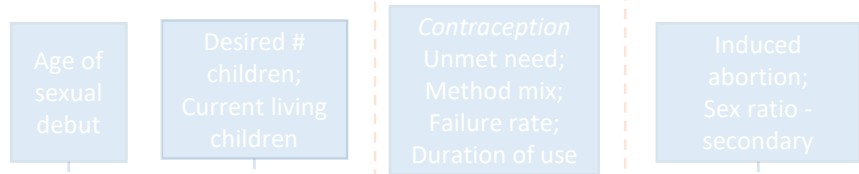
Population-Level Trends

Individual-Level Reproductive Lifecycle

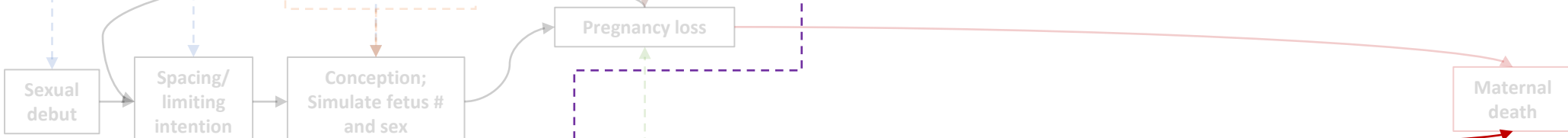
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Family Planning Behaviour



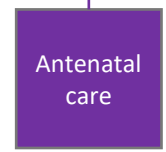
Events



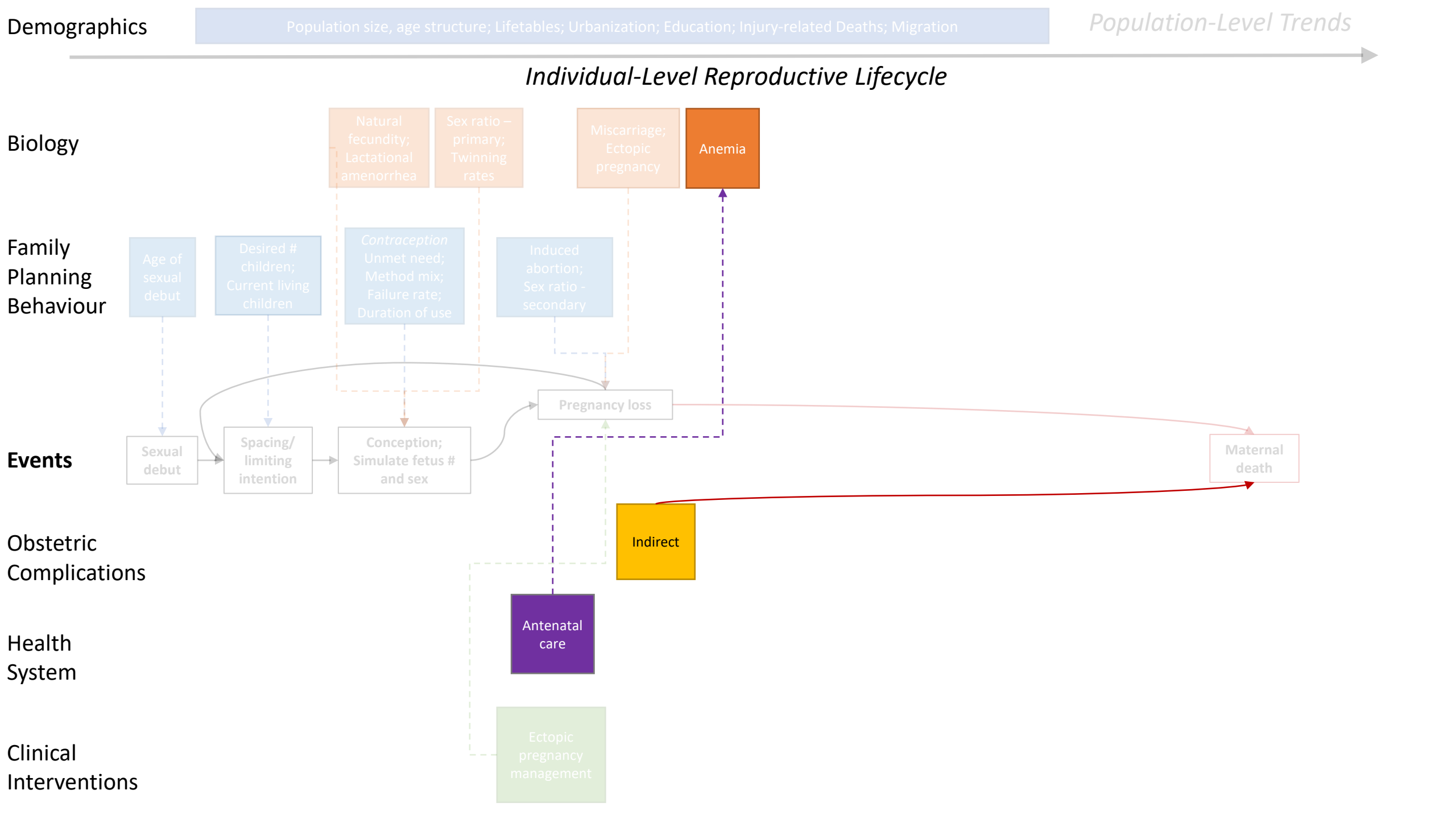
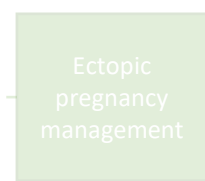
Obstetric Complications



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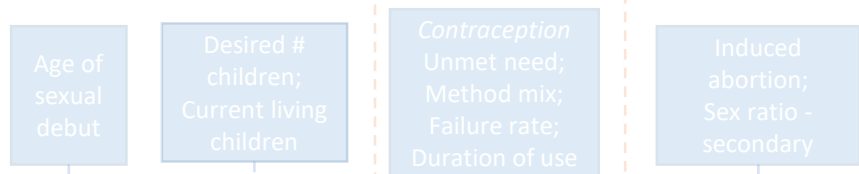
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Individual-Level Reproductive Lifecycle

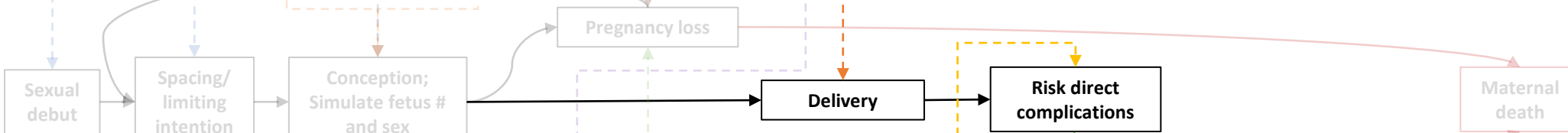
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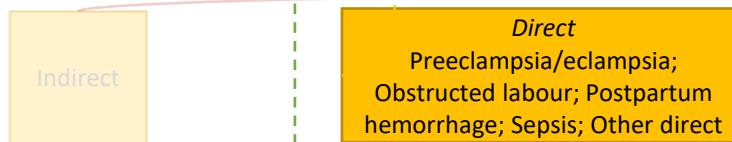
Family Planning Behaviour



Events



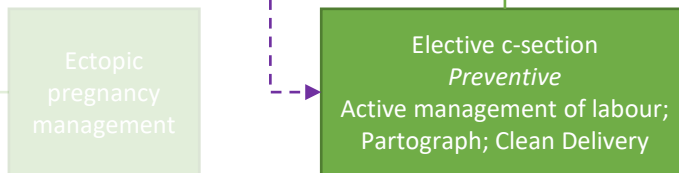
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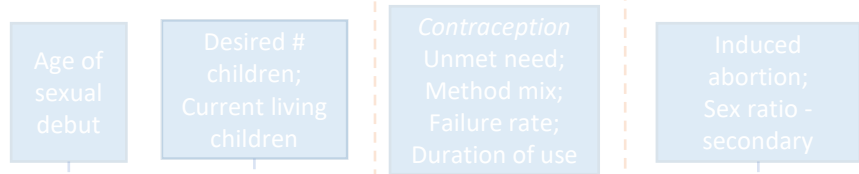
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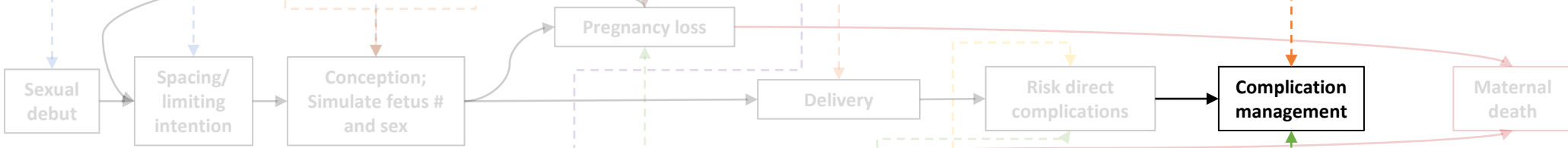
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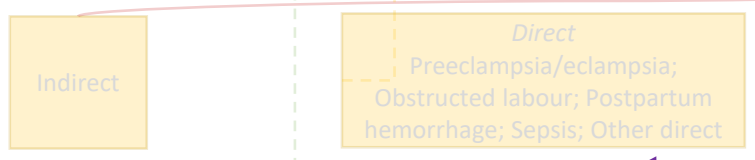
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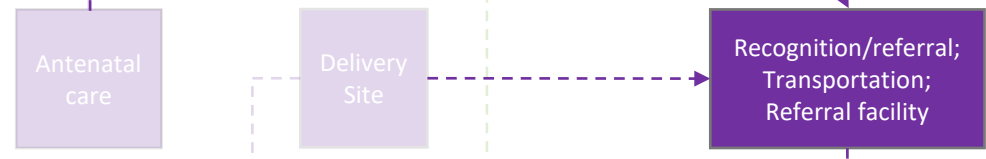
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Obstetric Complications



Health System



Clinical Interventions



Demographics

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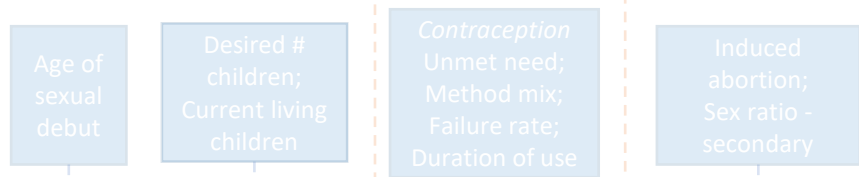
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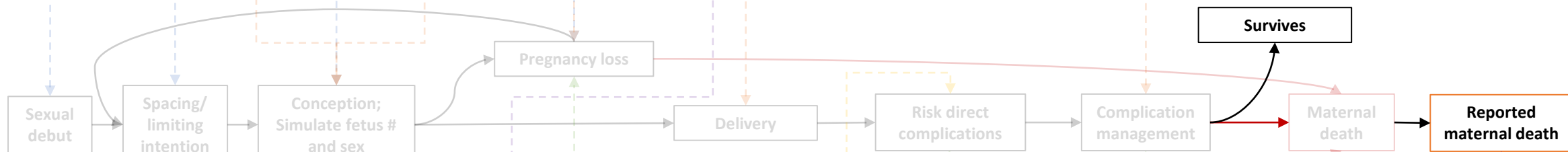
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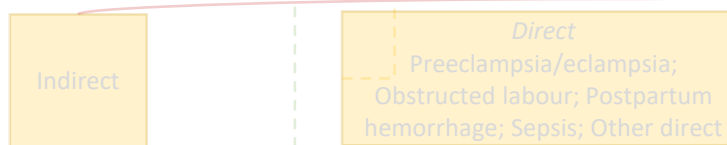
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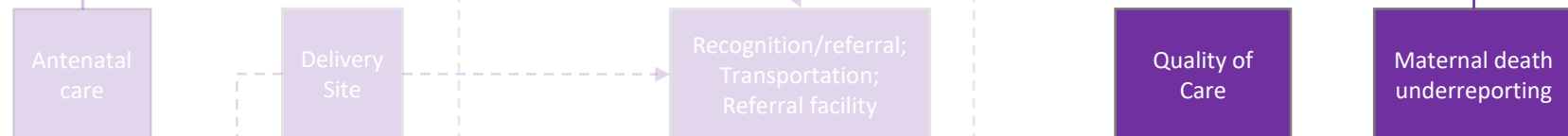
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Population-Level Trends

Individual-Level Reproductive Lifecycle

Biology

Natural fecundity; Lactational amenorrhea

Sex ratio – primary; Twinning rates

Miscarriage; Ectopic pregnancy

Anemia

Month of delivery; Stillbirth risk

Age of menopause

Family Planning Behaviour

Age of sexual debut

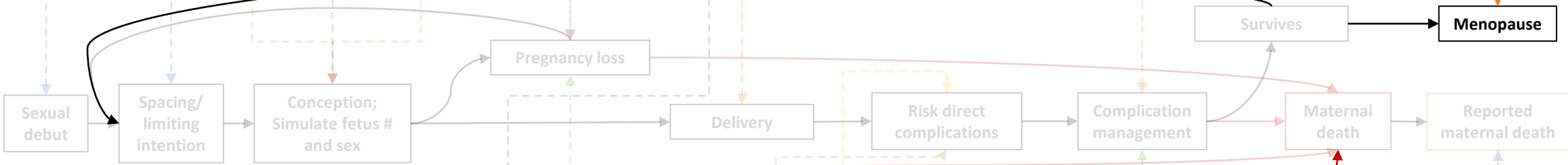
Desired # children; Current living children

Contraception
Unmet need; Method mix; Failure rate; Duration of use

Induced abortion; Sex ratio - secondary

Breastfeeding

Events



Obstetric Complications

Indirect

Direct
Preeclampsia/eclampsia; Obstructed labour; Postpartum hemorrhage; Sepsis; Other direct

Late maternal deaths

Health System

Antenatal care

Delivery Site

Recognition/referral; Transportation; Referral facility

Quality of Care

Maternal death underreporting

Clinical Interventions

Ectopic pregnancy management

Elective c-section
Preventive
Active management of labour; Partograph; Clean Delivery

Curative
Hypertension management; Assisted delivery; Hemorrhage management; Antibiotics

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

[Home](#)[Model Inputs](#)[Datasets and Definitions](#)[Model Calibration](#)

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

Model development was supported by the John D. and Catherine T. MacArthur Foundation, 10-97002-000-INP (PI: Sue J. Goldie).



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

Indicator	Training Set (1990-2015): # Countries (# Estimates)	Testing Set (2016-2020): # Countries (# Estimates)	Data Source
<i>Fertility Indicators</i>			
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
<i>Process Indicators</i>			
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
<i>Mortality Indicators</i>			
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 ratio, pregnancy-related mortality ratio)	22 (96)	3 (8)	Country-specific sources
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

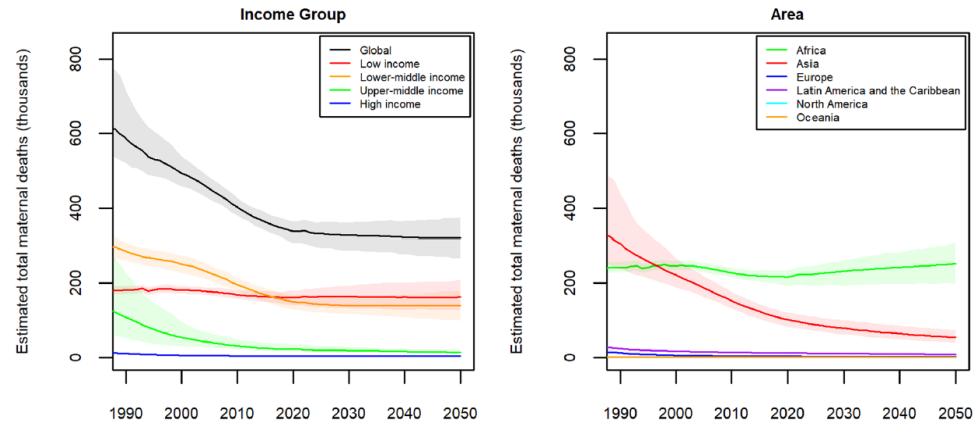
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Posterior Predictive Checks

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



B. MMR

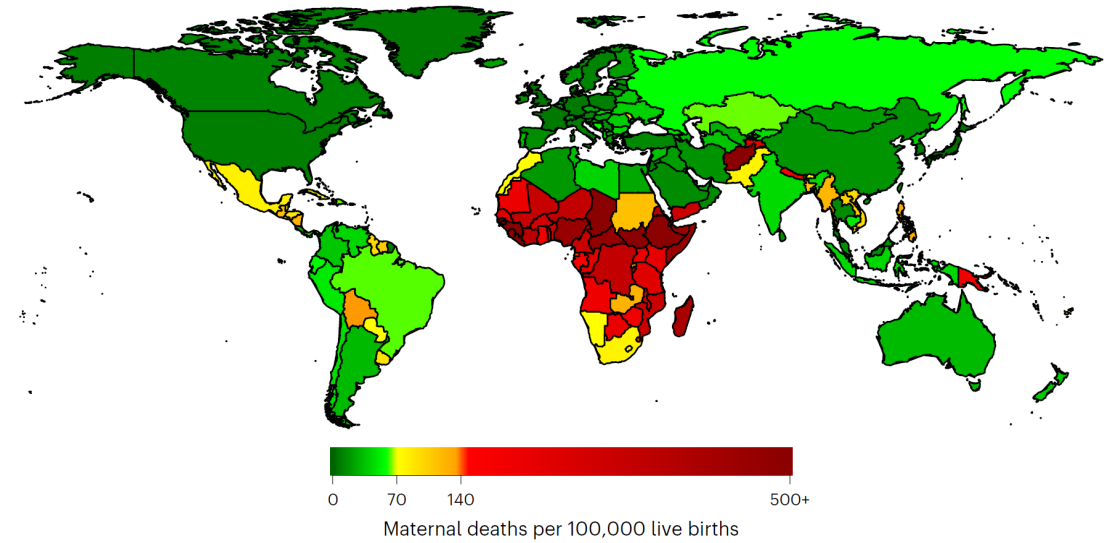
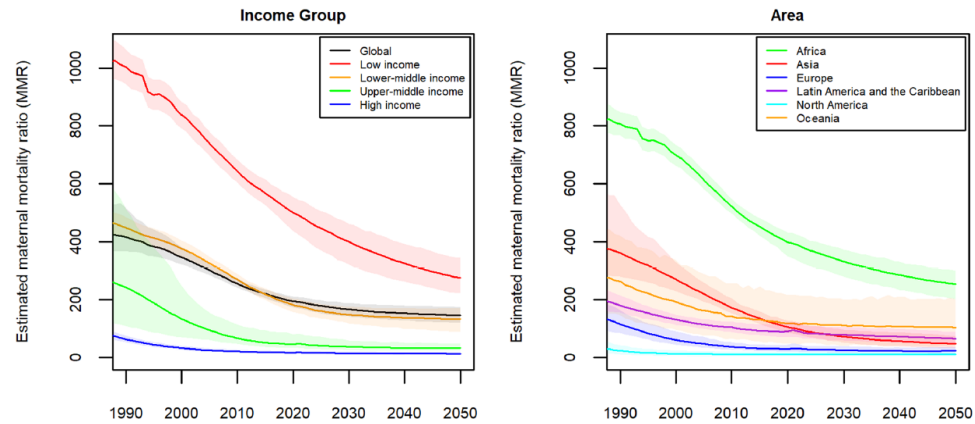
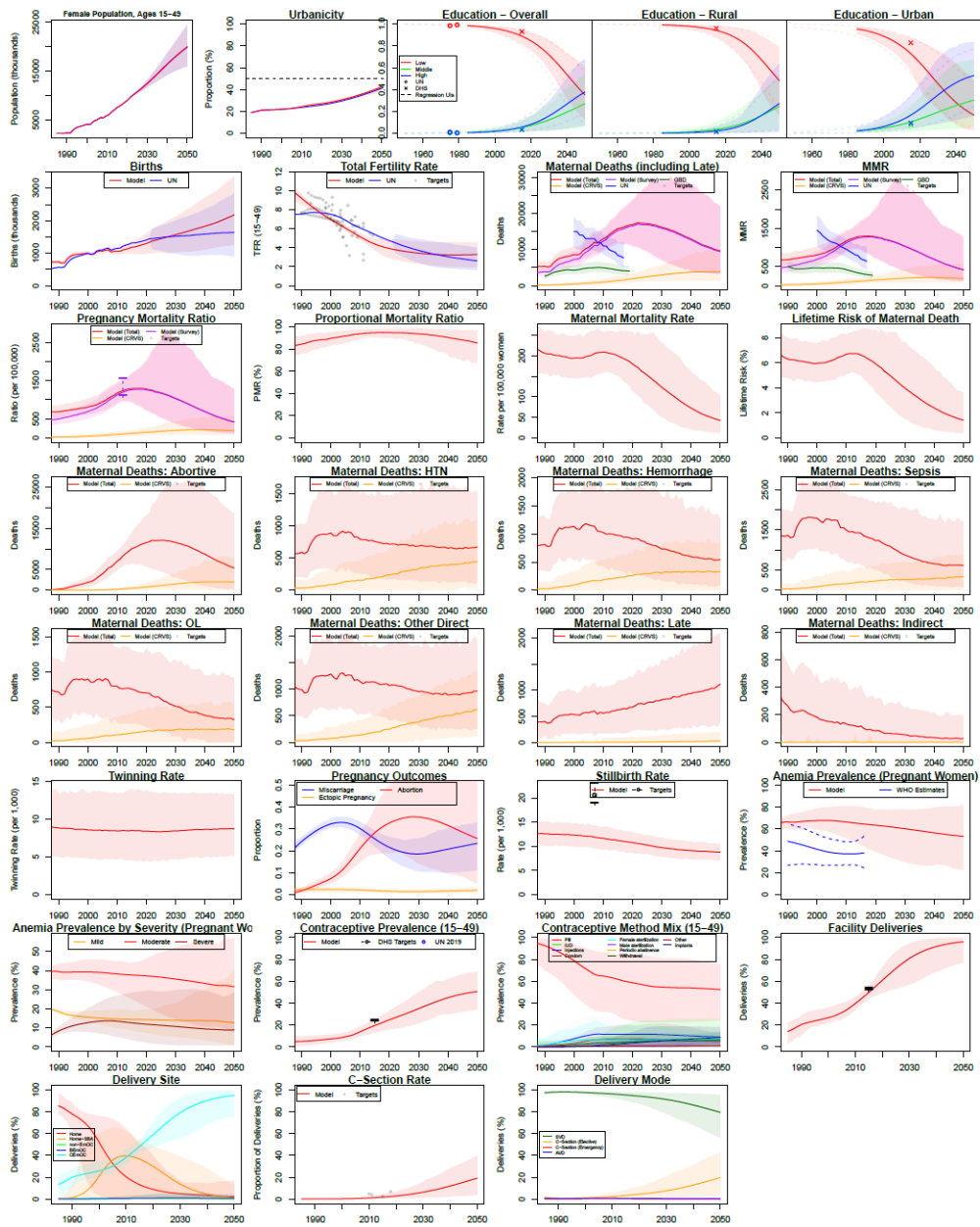


Fig. 2 | Projected MMR by country in 2030. Mean projected MMR (maternal deaths per 100,000 live births) by country in 2030.

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

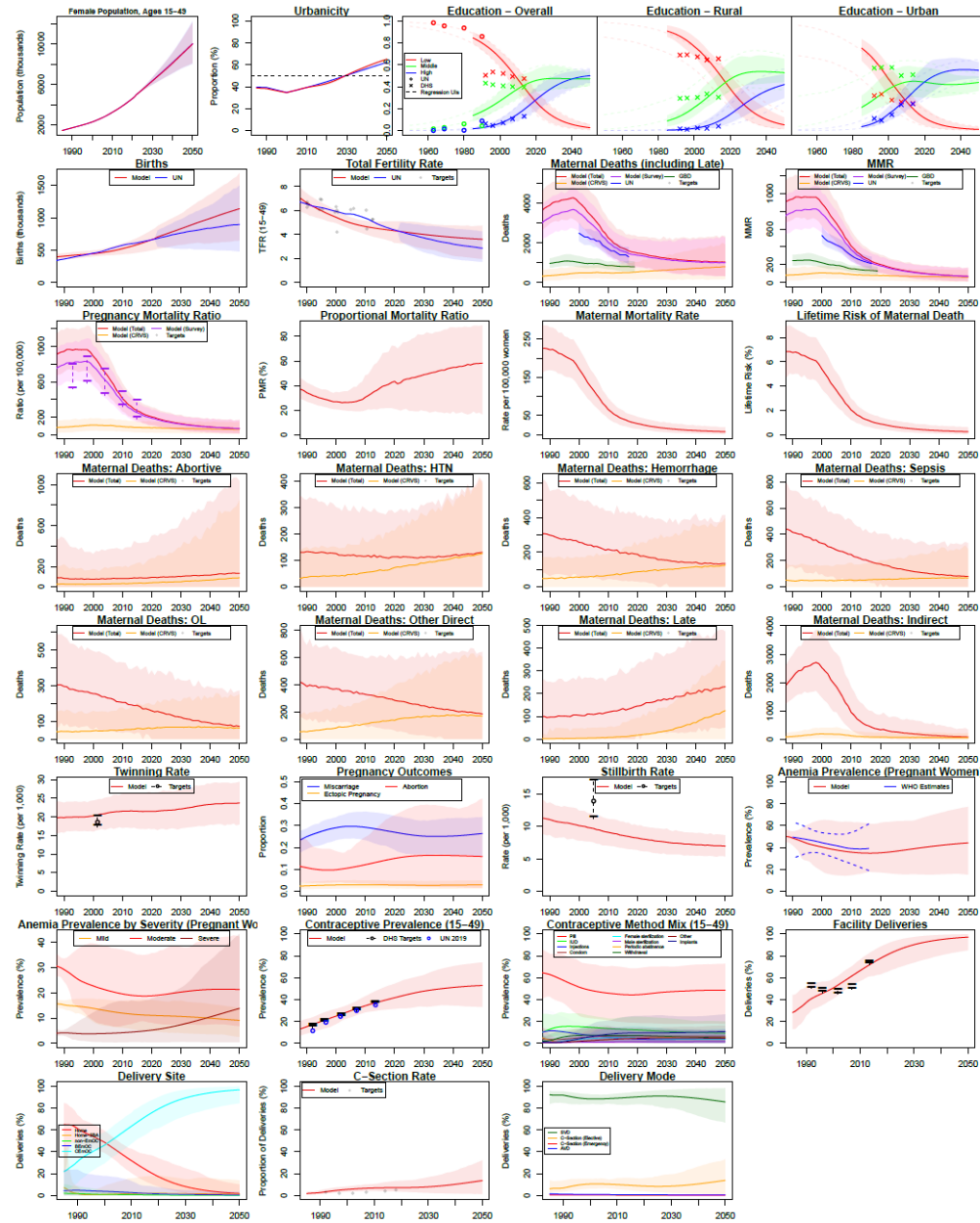
Afghanistan

ISO Code: AFG
 Region: Southern Asia
 Area: Asia
 Income Group: Low income



Zambia

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



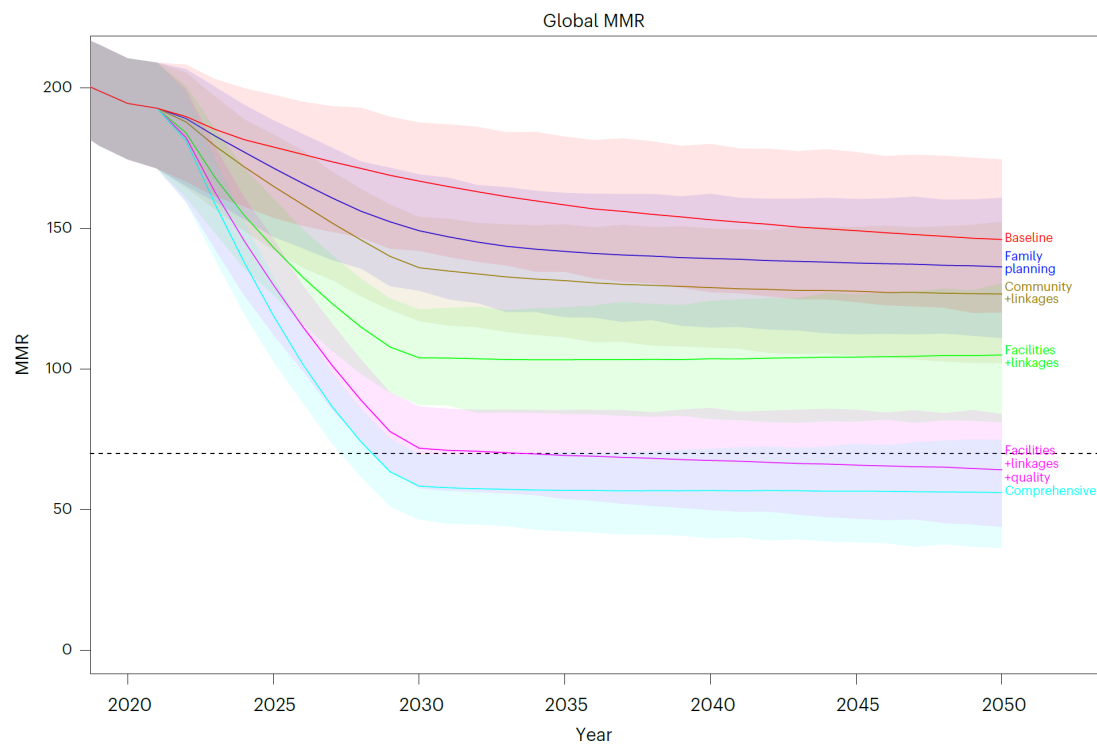
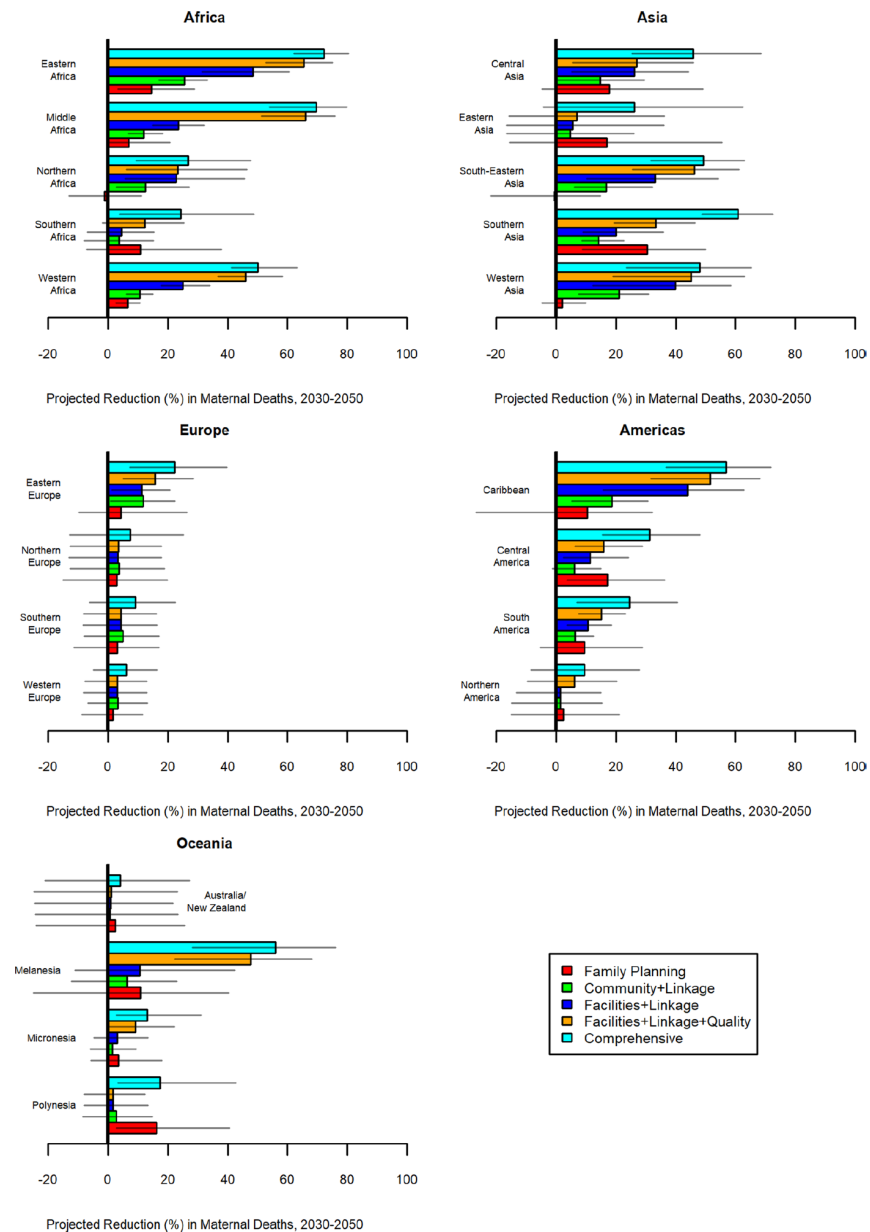


Fig. 1 | Projected global MMR according to an integrated strategy. The lines indicate the means, the shaded regions indicate the 95% UIs and the dashed line indicates the SDG target 3.1 of a global MMR of 70 by 2030.



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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