Excess maternal deaths and maternal mortality ratios during the COVID-19 pandemic period: a global country-level counterfactual modelling study

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Abstract

Background: Maternal mortality remains uneven globally, and the COVID-19 pandemic disrupted maternal health services through direct infection-related risks and indirect health-system pathways. We estimated country-level deviations in maternal deaths and maternal mortality ratios (MMR) during 2020–2023 relative to pre-pandemic trends.
Methods: We used WHO/UN MMEIG model-based country-level estimates of maternal deaths and MMR from 2000–2019 to fit an ensemble n-sub-epidemic forecasting model. We generated no-pandemic counterfactual projections for 2020–2023 and compared them with WHO/UN MMEIG estimates for the same years. Excess was defined as the positive difference between the WHO/UN MMEIG estimate and the counterfactual prediction; uncertainty was quantified using bootstrap-based prediction intervals.
Results: Globally, estimated cumulative excess maternal deaths were 68,489 (95% UI 34,706–147,118) during 2020–2023, and the aggregate excess MMR was 10,154 (95% UI 4,568–23,744). The largest regional excess death burdens were observed in the South-East Asia Region, Eastern Mediterranean Region, and African Region. Among the eight illustrative high-burden countries, Afghanistan and Somalia had statistically detectable excess maternal deaths, with totals of 2,335 (95% UI 1,148–4,350) and 1,815 (639–3,401), respectively. Liberia had a positive median estimate of 265 excess maternal deaths, but its interval included zero (0–990). Nigeria, Chad, and South Sudan had median totals of zero, although uncertainty intervals indicated that nonzero excess could not be excluded in Chad and South Sudan.
Conclusion: Pandemic-period WHO/UN MMEIG estimates deviated heterogeneously from pre-pandemic counterfactual trends. These findings should be interpreted as modeled excess relative to a no-pandemic baseline and may reflect pandemic-related disruptions together with other contemporaneous health-system, political, and social shocks, rather than directly observed deaths or causal effects attributable solely to COVID-19.

Keywords and phrases: Maternal mortality; Maternal mortality ratio; Excess maternal deaths; COVID-19 pandemic; Counterfactual modeling; Health-system disruption.

Key Messages

What is already known on this topic

Maternal mortality remains highly unequal globally, and the COVID-19 pandemic disrupted essential maternal and newborn health services in many settings. Existing evidence has documented direct infection-related risks in pregnancy and indirect health-system disruptions, but global country-level counterfactual estimates of pandemic-period deviations from pre-pandemic maternal mortality trends remain limited.

What this study adds

Using WHO/UN MMEIG model-based estimates and an ensemble n-sub-epidemic forecasting framework calibrated to 2000–2019 trends, this study estimated 68,489 cumulative excess maternal deaths globally during 2020–2023. The largest regional excess death burdens were observed in the South-East Asia, Eastern Mediterranean and African Regions. The study also estimated an aggregate excess MMR of 10,154, defined as the sum of country-level annual excess MMR deviations across 2020–2023.

How this study might affect research, practice or policy

These findings support the need for pandemic preparedness plans that protect essential obstetric and newborn care while also addressing barriers to care-seeking through risk communication, community engagement and other demand-side interventions. Core services that should be protected include antenatal care, skilled birth attendance, emergency obstetric referral systems, blood supply, essential medicines and postnatal care. They also highlight the importance of stronger maternal mortality surveillance and counterfactual monitoring frameworks to detect health-system shocks, interpret uncertainty and track inequalities during future public-health emergencies.

1 Introduction

Despite advances in technology and healthcare in the 21st century, maternal mortality remains a major global health challenge characterized by profound and persistent inequalities across regions and income levels [6,27]. According to WHO/UN Maternal Mortality Estimation Inter-Agency Group (MMEIG) estimates, there were approximately 260,000 maternal deaths globally in 2023, corresponding to a maternal mortality ratio (MMR) of 197 deaths per 100,000 live births, or approximately one maternal death every two minutes worldwide [50,51]. Although global MMR declined by approximately 40% between 2000 and 2023, progress has been highly uneven, with low- and lower-middle-income countries accounting for approximately 92% of all maternal deaths [50,51]. Thus, global progress masks persistent inequities across countries, regions, and income groups. These disparities reflect not only barriers to access, but also gaps in health-system quality, resilience, and equity [28,44,49].

Substantial improvements in maternal mortality were achieved during the Millennium Development Goal (MDG) era, followed by a marked deceleration in progress after the introduction of the Sustainable Development Goals (SDGs) [6,51]. SDG 3.1 aims to reduce the global maternal mortality ratio to fewer than 70 deaths per 100,000 live births by 2030 [51]. The initial years following SDG implementation showed modest improvement, with global MMR declining from 228 in 2015 to 207 in 2019. However, this pace of decline remains insufficient to achieve the 2030 target without accelerated and sustained interventions, particularly in high-burden settings [6,46]. The persistence of preventable maternal deaths highlights the need to address systemic barriers within health systems, including access to facility-based care, workforce capacity, referral systems, equitable service delivery, and other contributors to maternal mortality, such as unsafe abortion [28,39,44,49,52].

This already vulnerable landscape was further disrupted by the COVID-19 pandemic, which placed unprecedented strain on health systems worldwide [32,48]. Several studies have documented reductions in maternal health-service utilization, interruptions in antenatal, intrapartum, and postnatal care, and adverse maternal and perinatal outcomes during the pandemic [13,22,38,40]. The pandemic prompted widespread reallocation of health resources toward COVID-19 response efforts, contributing to shortages of healthcare personnel, medical supplies, intensive care capacity, essential medicines, blood products, and referral capacity, all of which are critical for safe pregnancy and childbirth [10, 19, 32, 48]. These systemic strains created multiple indirect pathways to mortality. Early modeling studies estimated that, across 118 low- and middle-income countries, disruptions to essential maternal and child health services could result in approximately 12,200 to 56,700 additional maternal deaths over a six-month period, depending on the severity of service reductions [36]. Subsequent empirical studies using facility and administrative data in low- and middle-income countries documented disruptions to maternal and child health-service utilization, with effects varying across countries, services, and time [3, 9]. A systematic review and meta-analysis also reported worsened maternal and perinatal outcomes during the pandemic, including increases in maternal deaths and stillbirths [13]. Fear of infection, mobility restrictions, and disruptions to routine services further reduced utilization of antenatal, intrapartum, and postnatal care, particularly in low-resource settings, where declines in institutional deliveries and skilled birth attendance were reported [4, 26, 30, 32, 36].

Beyond health-system disruptions, SARS-CoV-2 infection presented a direct clinical threat during pregnancy. Pregnant individuals with COVID-19 have been reported to face higher risks of severe disease, intensive care admission, and adverse maternal and neonatal outcomes than relevant comparator groups [8, 42]. Thus, pandemic-period maternal mortality may reflect both direct infection-related risks and indirect effects mediated through disruptions to essential maternal health services, health-system strain, delays in care-seeking, and changes in access to timely obstetric care.

The arrival of COVID-19 vaccines in late 2020 marked an important turning point in pandemic response, but public-health guidance for vaccination in pregnancy varied substantially across countries [53]. This variation may have shaped vulnerability among pregnant populations, particularly in settings where health-system capacity and maternal-health services were already constrained. Because vaccination was not directly evaluated in the present analysis, pregnancy-vaccination policy is interpreted here as contextual background rather than as a modeled exposure.

The impact of COVID-19 on maternal health has been examined in several country-specific and regional studies, documenting disruptions to service utilization and adverse maternal outcomes [4,8,26,30,36]. Recent global analyses have estimated maternal mortality trends through 2023 and examined mortality from COVID-19 infection among pregnant women [18]. However, global country-level counterfactual estimates of excess maternal deaths and excess MMR relative to pre-pandemic WHO/UN MMEIG trends remain limited. This gap is critical because maternal mortality was already on a downward trajectory prior to 2020. To assess deviations during the pandemic period, it is therefore important to compare WHO/UN MMEIG estimates for 2020–2023 against a counterfactual no-pandemic baseline that accounts for these pre-existing trends, rather than simply comparing annual estimates with previous years.

Excess-mortality frameworks have been widely used to estimate the direct and indirect mortality burden of the COVID-19 pandemic by comparing observed or estimated deaths with expected deaths under pre-pandemic conditions [33, 43]. However, their application to maternal mortality at the global country level remains limited. In this study, we address this gap by applying an ensemble n-sub-epidemic modeling framework to generate counterfactual projections of maternal mortality under a no-pandemic scenario, building on prior applications of this approach to forecasting and excess-mortality estimation in other disease contexts [14, 15, 16, 24]. Using WHO/UN MMEIG maternal mortality estimates from 2000 to 2019, we forecast expected maternal deaths and MMR for 2020–2023 and compare these projections with WHO/UN MMEIG estimates for the same period to quantify excess maternal mortality during the COVID-19 pandemic period.

We therefore estimate deviations of WHO/UN MMEIG model-based pandemic-period maternal mortality estimates from counterfactual projections calibrated to pre-pandemic WHO/UN MMEIG trends. These deviations should be interpreted as excess relative to a modeled no-pandemic baseline, not as directly observed deaths or causal effects attributable solely to COVID-19.

The primary objective of this study is to estimate global and country-level deviations in maternal deaths and MMR during 2020–2023 relative to counterfactual projections calibrated to pre-pandemic WHO/UN MMEIG trends and applied consistently across countries. By identifying where and to what extent maternal mortality exceeded expected levels, this analysis informs the Ending Preventable Maternal Mortality agenda and highlights the importance of strengthening health-system resilience and maternal mortality surveillance [44, 46]. These findings underscore the need for policies that explicitly protect essential maternal and newborn health services during future global health emergencies and address persistent inequalities in access to quality care across countries and regions.

2 Data

2.1 Data source and definitions

This study used publicly available country-level estimates from *Trends in Maternal Mortality 2000–2023: Estimates by WHO, UNICEF, UNFPA, World Bank Group, and UN DESA/Population Division* [51]. Throughout this study, we refer to these data as WHO/UN Maternal Mortality Estimation Inter-Agency Group (MMEIG) estimates. The source report provides internationally comparable global, regional, and country-level estimates of maternal mortality for 195 countries and territories. The associated country-level data include annual model-based estimates of the number of maternal deaths and the maternal mortality ratio (MMR).

A maternal death was defined according to the WHO/UN MMEIG definition as the death of a woman[1] while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of pregnancy, from any cause related to or aggravated by pregnancy or its management, but not from accidental or incidental causes [51]. The MMR was defined as the number of maternal deaths per 100,000 live births in a given year [51]. Maternal deaths and MMR were analyzed as complementary outcomes: maternal deaths measure the absolute mortality burden, whereas MMR measures the risk of maternal death relative to the number of live births.

2.2 WHO/UN MMEIG estimation process

The WHO/UN MMEIG estimates are derived through a harmonized estimation process that integrates data from multiple sources, including civil registration and vital statistics (CRVS) systems, population-based surveys, censuses, and specialized maternal mortality studies [51]. Because data completeness and cause-of-death classification vary substantially across countries, statistical modeling is used to adjust for underreporting, misclassification, and data-source differences, and to generate internationally comparable estimates across settings and over time [7, 34, 51]. The Bayesian maternal mortality estimation model used by WHO/UN MMEIG incorporates data-driven country trends while accounting for variation in data quality and source-specific reporting issues [7]. Official country consultations are conducted as part of the estimation process to review preliminary estimates and incorporate additional country-specific information when available [51]. As a result, WHO/UN MMEIG estimates may differ from nationally reported figures but are designed to support cross-country comparability.

2.3 Pandemic-period estimates and analysis window

For the pandemic period, the WHO/UN MMEIG estimates should be interpreted as model-based estimates rather than raw observed maternal death counts. In the 2025 WHO/UN MMEIG report, 2020–2022 were treated as COVID years and estimated using a modified COVID BMat model setup, whereas 2023 was not treated as a COVID year and was estimated using the default BMat framework [51]. We therefore define 2020–2023 as the pandemic-period analysis window for this study, while recognizing that 2023 was handled differently in the WHO/UN MMEIG estimation process.

Pre-pandemic WHO/UN MMEIG estimates from 2000 to 2019 were used for model calibration, and WHO/UN MMEIG estimates from 2020 to 2023 were used for comparison with counterfactual projections. The 2000–2019 calibration window was selected to focus on contemporary pre-pandemic maternal mortality trends and to avoid using pandemic-period information in model fitting. Excess maternal deaths and excess MMR were derived by comparing WHO/UN MMEIG estimates for 2020–2023 with model-based forecasts generated from pre-pandemic trends. Thus, our analysis compares model-based WHO/UN MMEIG pandemic-period estimates with model-based counterfactual projections calibrated to pre-pandemic WHO/UN MMEIG trends, rather than comparing forecasts with raw surveillance counts.

[1]We retain the terminology used in the WHO/UN MMEIG definition of maternal death. We recognize that not all people who become pregnant identify as women; throughout this study, the term is used to maintain consistency with the source data and official definition.

2.4 Study population and country groupings

This analysis included all countries and territories in the WHO/UN MMEIG source dataset with available maternal death and MMR estimates for the study period. Countries were grouped by WHO region, including the African Region, the Region of the Americas, the Eastern Mediterranean Region, the European Region, the South-East Asia Region, and the Western Pacific Region. Results were generated for all countries included in the analytic dataset, with country-level outputs provided in the Supplementary Material.

Because the analysis relied exclusively on publicly available, aggregated country-level estimates and did not involve individual-level human participant data, ethical approval was not required.

2.5 Illustrative high-burden settings

For descriptive line-graph visualizations, we selected eight illustrative high-burden settings: Afghanistan, South Sudan, Chad, Nigeria, Guinea-Bissau, Liberia, Somalia, and Lesotho. Seven of these countries were among the nine countries classified by the WHO/UN MMEIG report as having "very high" MMR in 2023 [51], while Lesotho was included as an additional high-burden setting to illustrate heterogeneity in pandemic-period maternal mortality trajectories. This selection was made for visualization only and did not affect the global analysis, model fitting, or country inclusion criteria.

Descriptive maternal death and MMR trajectories in the eight illustrative high-burden settings showed that pre-pandemic trajectories were heterogeneous across countries, with some settings exhibiting long-run declines and others showing non-monotonic patterns before 2020. These descriptive patterns motivate the use of flexible country-specific counterfactual models while emphasizing that all countries in the analytic dataset were modeled using the same procedure. Formal counterfactual forecasts and excess mortality estimates are reported in Section 4.

3 Methodology

In this section, we present our modeling framework and approach for estimating excess maternal mortality and excess MMR during the COVID-19 pandemic-period analysis window. Our analysis builds on a series of recent counterfactual forecasting studies that estimated pandemic-period excess burden by calibrating models to pre-pandemic trends, projecting expected outcomes under a no-pandemic scenario, and comparing those projections with observed or reported pandemic-period estimates. Closely related applications include global excess tuberculosis mortality, U.S. excess tuberculosis incidence, excess mortality among people living with HIV/AIDS, and excess drug overdose mortality during the COVID-19 pandemic [5, 20, 24, 25].

In this study, we define the pandemic-period analysis window as 2020–2023. These are the years for which WHO/UN MMEIG maternal mortality estimates were compared with counterfactual no-pandemic projections generated from pre-pandemic trends. As noted in the Data section, the WHO/UN MMEIG report treats 2020–2022 as COVID years in its modified COVID BMat model setup, whereas 2023 was estimated using the default BMat framework [51].

We used two separate datasets: one containing annual maternal death estimates and another containing annual MMR estimates. To focus on contemporary pre-pandemic maternal mortality trends and avoid using pandemic-period information in model fitting, we calibrated our models using WHO/UN MMEIG estimates from 2000 to 2019 [7, 51]. We then forecast both maternal deaths and MMR for 2020–2023 under a counterfactual no-pandemic scenario. By comparing these forecasts with WHO/UN MMEIG estimates for 2020–2023, we estimated excess maternal deaths and excess MMR during the pandemic-period analysis window.

To capture the multi-phase nature of maternal mortality trends, we model each country's maternal mortality trajectory as a sum of up to n sub-epidemic components, each governed by a generalized logistic growth curve. This approach provides a flexible yet parsimonious representation of nonlinear temporal trends in maternal mortality, allowing the model to adapt to changes in trajectory while avoiding overfitting, particularly given the relatively short annual time series. This method is applied independently to the maternal deaths estimates and the MMR estimates. The dynamics of the ith latent sub-epidemic component are described by

$$\frac{dC_i(t)}{dt} = A_i(t) r_i C_i^{p_i}(t) \left(1 - \frac{C_i(t)}{K_{0i}}\right), \quad i = 1, \ldots, n, \tag{1}$$

where $C_i(t)$ represents the ith latent component of the fitted maternal mortality trajectory, r_i denotes the growth rate, p_i is the scaling-of-growth parameter, and K_{0i} is the saturation level of the ith component, enabling flexible approximation of temporal patterns in the WHO/UN MMEIG estimates. The onset timing of the ith sub-epidemic is controlled by an indicator function A_i which is given by:

$$A_i(t) = \begin{cases} 1 & \text{if } C_{i-1}(t) > C_{thr} \\ 0 & \text{otherwise} \end{cases}, \quad i = 2, \ldots, n, \tag{2}$$

where $A_1(t) = 1$ for the first sub-epidemic and C_{thr} is the threshold. Therefore, sub-epidemic i triggers as soon as $C_{i-1} > C_{thr}$.The initial value is given by $C_1(0)$, which is initialized using the first value of the fitted WHO/UN MMEIG time series. The values of C_{thr} are obtained by equally discretizing the cumulative sum of the smoothed signal into as many levels as there are data points.

We use the corrected Akaike Information Criterion (AICc) to select the top-ranked sub-epidemic models:

$$\text{AICc} = -2\log(\text{likelihood}) + 2m + \frac{2m(m+1)}{n_d - m - 1}, \tag{3}$$

where m is the total number of model parameters, and n_d is the number of data points.

In this study, we utilize the SubEpiPredict toolbox for fitting and forecasting both maternal mortality and MMR trajectories using the ensemble n-sub-epidemic modeling framework. For each value of the threshold parameter C_{thr}, we consider two model structures: one with $n = 1$ sub-epidemic (i.e., $m = 3$ parameters) and another with $n = 2$ sub-epidemics (i.e., $m = 6$ parameters). Model parameters are estimated using the nonlinear least squares (NLS) method. During the modeling process, we select the top-ranked model within the n-sub-epidemic framework based on the AICc values.

For parameter estimation, we employ the MultiStart optimization method with 30 different initial guesses to ensure robustness. We perform 300 bootstrap resampling iterations to assess the accuracy of the 95% PI and provide uncertainty quantification. We generate forecasts using both normal and Poisson error structures, with final selection based on the model that yields the 95% PI that best captures the data during the calibration phase.

The counterfactual projections generated from pre-pandemic WHO/UN MMEIG estimates from 2000–2019 are intended to characterize deviations from recent historical maternal mortality trends under a no-pandemic scenario, rather than to support causal attribution of excess maternal mortality to COVID-19.

3.1 Excess Maternal Deaths

Let $Y = \{y_{2020}, y_{2021}, y_{2022}, y_{2023}\}$ denote the WHO/UN MMEIG maternal death estimates for the pandemic period. The forecasted maternal deaths for each year are denoted by $\hat{Y} = \{\hat{y}_{2020}, \hat{y}_{2021}, \hat{y}_{2022}, \hat{y}_{2023}\}$, with lower and upper bounds denoted by L_j and U_j, where $j = \{2020, 2021, 2022, 2023\}$. We estimate the number of excess maternal deaths, E_{MD}, with lower $E_{MD_{LB_j}}$ and upper bounds $E_{MD_{UB_j}}$, as follows:

$$E_{MD_j} = \max\{0, y_j - \hat{y}_j\}, \quad E_{MD_{LB_j}} = \max\{0, y_j - U_j\}, \quad E_{MD_{UB_j}} = \max\{0, y_j - L_j\}. \tag{4}$$

In this study, excess mortality is defined as the positive deviation between the WHO/UN MMEIG estimate and the expected counterfactual value, $\max(0, y_j - \hat{y}_j)$. Negative differences are set to zero because the aim of this analysis is to quantify the additional mortality burden during the pandemic rather than net deviations around the baseline trend. Allowing both positive and negative excess values would create greater ambiguity in interpretation, since each could reflect either a true change in maternal mortality or an artifact of model uncertainty and data limitations. In settings with incomplete vital registration systems, lower WHO/UN MMEIG estimates may also reflect underreporting, misclassification, delays in death registration, or uncertainty in the underlying estimation process rather than true reductions in maternal mortality. Therefore, restricting excess mortality to positive deviations provides a more cautious and interpretable measure of pandemic-related burden. This definition is also consistent with our previous modeling study on excess tuberculosis mortality during the COVID-19 pandemic period, where the same approach produced estimates aligned with independent WHO assessments [24].

The total number of excess maternal deaths is calculated as:

$$E_{MD_{total}} = \sum_{j=2020}^{2023} E_{MD_j}, \quad E_{MD_{LB_{total}}} = \sum_{j=2020}^{2023} E_{MD_{LB_j}}, \quad E_{MD_{UB_{total}}} = \sum_{j=2020}^{2023} E_{MD_{UB_j}}. \tag{5}$$

Although prediction intervals are not strictly additive across years due to potential temporal correlations, we sum the yearly excess maternal deaths and their corresponding bounds to approximate the total excess burden over the pandemic period. If pandemic-related disruptions were positively correlated across years, cumulative uncertainty could be larger than suggested by year-specific intervals, particularly in settings where early health-system strain led to persistent workforce shortages, delayed care-seeking, or reduced service capacity in subsequent years. At the same time, each year of the COVID-19 pandemic was characterized by distinct health-system disruptions, service availability, and population-level responses, resulting in differing maternal mortality dynamics across years. Summation therefore provides a practical and interpretable descriptive measure of cumulative excess maternal mortality during the pandemic period. Thus, the summed bounds should be interpreted as an approximate descriptive uncertainty range for cumulative excess burden rather than as a formal prediction interval for the total.

3.2 Excess MMR

Similarly, let $R = \{r_{2020}, r_{2021}, r_{2022}, r_{2023}\}$ denote the WHO/UN MMEIG MMR estimates for the pandemic period. The forecasted MMR for each year is denoted by $\hat{R} = \{\hat{r}_{2020}, \hat{r}_{2021}, \hat{r}_{2022}, \hat{r}_{2023}\}$, with lower and upper bounds denoted by L_j^{MMR} and U_j^{MMR}. We estimate the excess MMR, E_{MMR}, with corresponding bounds as:

$$E_{MMR_j} = \max\{0, r_j - \hat{r}_j\}, \quad E_{MMR_{LB_j}} = \max\{0, r_j - U_j^{MMR}\}, \quad E_{MMR_{UB_j}} = \max\{0, r_j - L_j^{MMR}\}. \tag{6}$$

The total excess MMR over the pandemic period is:

$$\begin{gathered} E_{MMR_{LB_{total}}} = \sum_{j=2020}^{2023} E_{MMR_{LB_j}}, \quad E_{MMR_{UB_{total}}} = \sum_{j=2020}^{2023} E_{MMR_{UB_j}}, \\ E_{MMR_{total}} = \sum_{j=2020}^{2023} E_{MMR_j}. \end{gathered} \tag{7}$$

Although MMR is a rate, we summarize excess MMR across years as the sum of annual deviations to provide a cumulative measure of departure from the expected annual maternal mortality risk during 2020–2023. This quantity should be interpreted as an aggregate excess MMR over the pandemic period, rather than as a rate for a single calendar year.

4 Results

Unless otherwise stated, pandemic-period maternal deaths and MMR values refer to WHO/UN MMEIG model-based estimates, as described in Section 2. We generated country-level counterfactual projections for maternal deaths and MMR for 2020–2023 and compared these projections with WHO/UN MMEIG estimates for the same period. Results are presented first for eight illustrative high-burden countries and then for global and regional patterns. We defined statistically detectable excess as an estimate for which the lower 95% uncertainty bound was greater than zero.

4.1 Counterfactual trajectories in illustrative high-burden countries

Figure 1 compares counterfactual no-pandemic MMR projections with WHO/UN MMEIG MMR estimates during 2020–2023 across the eight illustrative high-burden countries. The trajectories show substantial heterogeneity in pandemic-period deviations from expected maternal mortality trends. In Afghanistan, Somalia, Guinea-Bissau, and Lesotho, WHO/UN MMEIG MMR estimates were generally above the median counterfactual projections during at least part of the pandemic-period analysis window. In Somalia and Guinea-Bissau, these deviations were most apparent in the early pandemic years before converging toward projected trends, whereas Lesotho showed persistent elevation across the period. For Lesotho, this persistent elevation should be interpreted cautiously, as it may partly reflect the country's high HIV burden and the established association between HIV and pregnancy-related mortality, rather than pandemic-period disruption alone [11, 41]. By contrast, WHO/UN MMEIG MMR estimates in Nigeria, Liberia, South Sudan, and Chad were close to or below the median projected trajectories during much of 2020–2023.

Supplementary Figure 75 shows corresponding counterfactual projections for annual maternal deaths. Afghanistan and Somalia showed the clearest positive deviations from projected maternal death trajectories, particularly in 2020 and 2021. Guinea-Bissau, Liberia, and Lesotho also showed positive median deviations in some pandemic years, although uncertainty was substantial. In Nigeria, Chad, and South Sudan, WHO/UN MMEIG maternal death estimates were generally at or below median counterfactual projections during the pandemic-period analysis window. Overall, the trajectory plots indicate that excess patterns for maternal deaths and MMR were broadly related but not identical, reflecting differences in birth volume, population size, baseline mortality levels, and changes in the denominator for MMR.

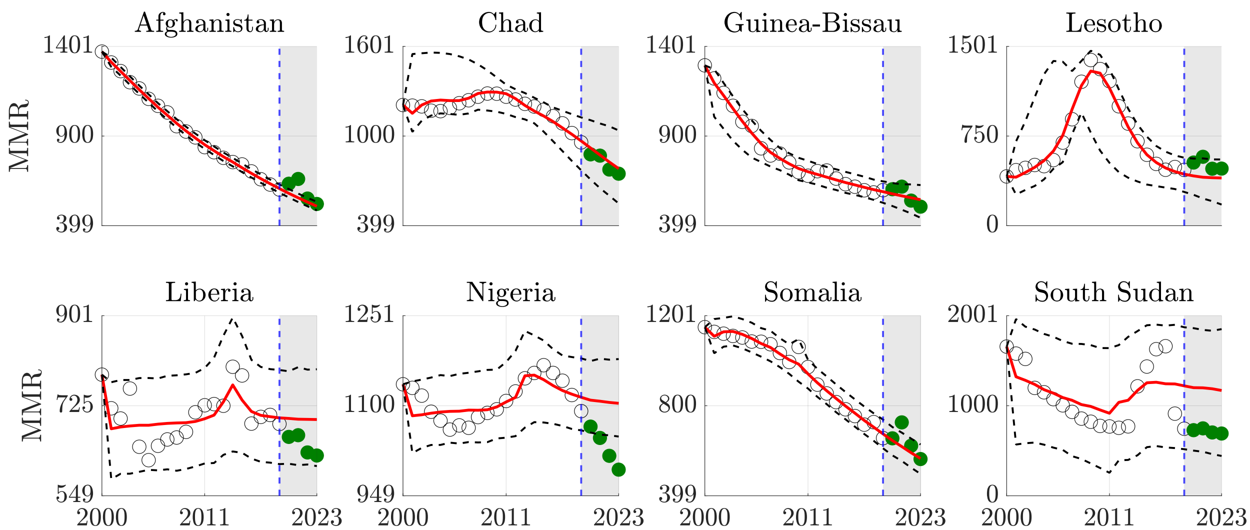


Figure 1: Calibration and forecasting of annual maternal mortality ratio (MMR) from 2000 to 2023 for eight illustrative high-burden countries—Afghanistan, South Sudan, Chad, Nigeria, Guinea-Bissau, Liberia, Somalia, and Lesotho—using an ensemble n-sub-epidemic modeling framework. The model was fitted to pre-pandemic WHO/UN MMEIG estimates from 2000–2019 and used to forecast MMR during 2020–2023 under a counterfactual no-pandemic scenario. Red lines show median model predictions, black dashed lines indicate 95% prediction intervals, hollow black circles represent WHO/UN MMEIG estimates during the calibration period, and green filled circles denote WHO/UN MMEIG estimates during the forecast period.

4.2 Excess MMR in illustrative high-burden countries

Table 1 summarizes estimated annual and cumulative excess MMR from 2020 to 2023 for the eight illustrative high-burden countries. Lesotho had the largest cumulative excess MMR, with an estimated total of 437 deaths per 100,000 live births above the counterfactual trajectory over 2020–2023 (95% UI 14–1192). Afghanistan had the next highest cumulative excess MMR, 192 (111–284), followed by Somalia, 149 (46–412).

These three countries had statistically detectable cumulative excess MMR because their lower uncertainty bounds were greater than zero.

Guinea-Bissau had a positive median cumulative excess MMR of 77, but the uncertainty interval included zero (0–357), indicating that excess MMR was not statistically detectable. Chad, South Sudan, Liberia, and Nigeria had median cumulative excess MMR estimates of zero, although the upper uncertainty bounds were positive for all four countries. South Sudan and Chad had particularly wide upper bounds, 977 and 761, respectively, indicating that nonzero excess MMR could not be ruled out despite median estimates of zero. These findings underscore the importance of distinguishing between a median estimate of zero and evidence that excess can be excluded.

In terms of timing, Afghanistan showed statistically detectable annual excess MMR in 2020 and 2021, followed by smaller estimates with intervals including zero in 2022 and 2023. Somalia showed its largest statistically detectable annual excess MMR in 2021. Lesotho had positive annual median excess MMR across all four years, with the strongest evidence in 2021. Overall, the MMR results suggest that excess risk was heterogeneous in magnitude and timing across high-burden settings.

Country	2020	2021	2022	2023	Total
Afghanistan	54 (30, 76)	105 (82, 129)	20 (0, 43)	13 (0, 36)	192 (111, 284)
Chad	0 (0, 168)	0 (0, 218)	0 (0, 175)	0 (0, 199)	0 (0, 761)
Guinea-Bissau	26 (0, 94)	51 (0, 129)	0 (0, 72)	0 (0, 62)	77 (0, 357)
Lesotho	112 (0, 270)	171 (14, 349)	75 (0, 272)	78 (0, 301)	437 (14, 1192)
Liberia	0 (0, 52)	0 (0, 59)	0 (0, 24)	0 (0, 21)	0 (0, 155)
Nigeria	0 (0, 10)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 10)
Somalia	10 (0, 76)	108 (46, 172)	31 (0, 98)	0 (0, 66)	149 (46, 412)
South Sudan	0 (0, 227)	0 (0, 260)	0 (0, 241)	0 (0, 249)	0 (0, 977)

Table 1: Estimated annual and cumulative excess maternal mortality ratio (MMR) from 2020 to 2023 in eight illustrative high-burden countries. Values are shown as median estimates with 95% uncertainty intervals. Cumulative excess MMR is the sum of annual excess MMR deviations across 2020–2023 and should not be interpreted as a single-year rate.

4.3 Excess maternal deaths in illustrative high-burden countries

Table 2 summarizes estimated annual and cumulative excess maternal deaths from 2020 to 2023 for the eight illustrative high-burden countries. Afghanistan and Somalia accounted for the largest estimated excess maternal death burdens among these countries. Afghanistan had an estimated cumulative excess of 2,335 maternal deaths (95% UI 1,148–4,350), and Somalia had an estimated cumulative excess of 1,815 maternal deaths (639–3,401). Both countries had statistically detectable cumulative excess maternal deaths.

Liberia had a positive median cumulative excess estimate of 265 maternal deaths, but its uncertainty interval included zero (0–990). Guinea-Bissau and Lesotho also had positive median cumulative estimates, 101 (0–316) and 58 (0–295), respectively, but neither was statistically detectable. Nigeria had a cumulative median estimate of zero with an uncertainty interval of 0–0. Chad and South Sudan also had median cumulative estimates of zero, but positive upper bounds indicated that nonzero excess could not be excluded. South Sudan had a particularly wide interval, 0–4,062, reflecting substantial uncertainty.

Annual patterns differed across countries. Afghanistan showed statistically detectable excess maternal deaths in 2020 and 2021, followed by smaller estimates with uncertainty intervals including zero in later years. Somalia showed statistically detectable annual excess maternal deaths in 2021 and 2022. Liberia showed positive median excess deaths in every pandemic year, but each annual interval included zero. These findings show that countries can have positive median excess estimates without meeting the threshold for statistically detectable excess.

Country	2020	2021	2022	2023	Total
Afghanistan	719 (199, 1227)	1469 (949, 1996)	147 (0, 665)	0 (0, 463)	2335 (1148, 4350)
Chad	0 (0, 0)	0 (0, 185)	0 (0, 0)	0 (0, 0)	0 (0, 185)
Guinea-Bissau	30 (0, 74)	53 (0, 101)	14 (0, 71)	4 (0, 70)	101 (0, 316)
Lesotho	18 (0, 85)	40 (0, 109)	0 (0, 50)	0 (0, 51)	58 (0, 295)
Liberia	27 (0, 167)	74 (0, 233)	63 (0, 258)	101 (0, 332)	265 (0, 990)
Nigeria	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Somalia	227 (0, 613)	1004 (609, 1410)	442 (30, 832)	142 (0, 545)	1815 (639, 3401)
South Sudan	0 (0, 833)	0 (0, 1110)	0 (0, 1009)	0 (0, 1110)	0 (0, 4062)

Table 2: Estimated annual and cumulative excess maternal deaths from 2020 to 2023 in eight illustrative high-burden countries. Values are shown as median estimates with 95% uncertainty intervals. Statistically detectable excess was defined as a lower uncertainty bound greater than zero.

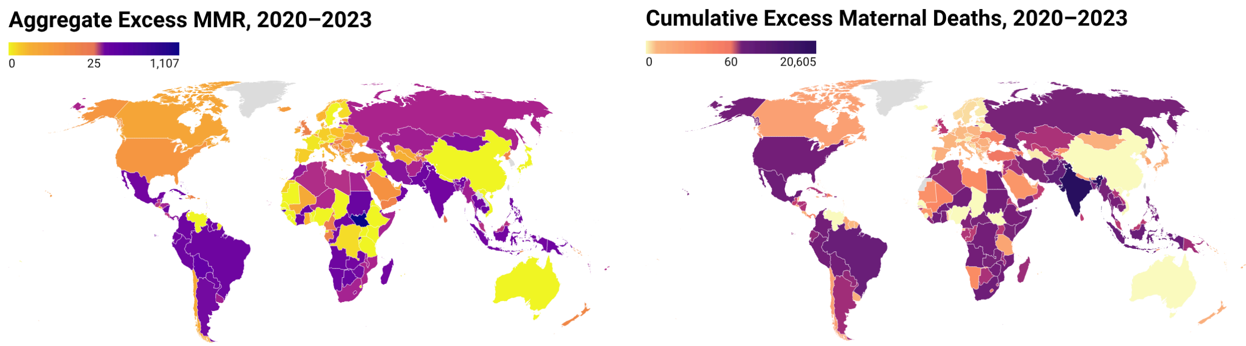
4.4 Global and regional excess maternal mortality

Across all modeled countries and territories, cumulative excess maternal deaths during 2020–2023 were estimated at 68,489 (95% UI 34,706–147,118). The corresponding aggregate excess MMR, calculated as the sum of annual excess MMR deviations across 2020–2023, was 10,154 (95% UI 4,568–23,744). By WHO region, the largest excess maternal death burdens were observed in the South-East Asia Region, Eastern Mediterranean Region, and African Region, whereas the largest aggregate excess MMR values were observed in the African Region, Region of the Americas, and Western Pacific Region. These estimates are summarized in Table 3. Overall, 113 of 195 countries had statistically detectable cumulative excess maternal deaths, and 133 countries had statistically detectable aggregate excess MMR, defined as a lower 95% uncertainty bound greater than zero.

Region	Countries included	Cumulative excess maternal deaths	Aggregate excess MMR	Countries with excess deaths	Countries with excess MMR
Global	195	68,489 (34,706–147,118)	10,154 (4,568–23,744)	113	133
African Region	47	13,789 (2,920–58,232)	3,547 (608–13,308)	15	16
Region of the Americas	36	9,583 (7,334–13,538)	2,658 (1,668–3,858)	23	30
Eastern Mediterranean Region	22	13,886 (5,216–25,751)	1,130 (653–2,129)	19	21
European Region	53	1,210 (606–2,022)	977 (724–1,321)	33	40
South-East Asia Region	11	28,030 (17,669–43,597)	643 (447–1,079)	7	8
Western Pacific Region	26	1,991 (961–3,978)	1,199 (468–2,049)	16	18

Table 3: Global and WHO-region cumulative excess maternal deaths and aggregate excess maternal mortality ratio (MMR) during 2020–2023. Aggregate excess MMR was calculated as the sum of country-level annual excess MMR deviations across 2020–2023 and should not be interpreted as a single-year or population-weighted regional MMR. The columns "Countries with excess deaths" and "Countries with excess MMR" report the number of countries with statistically detectable excess, defined as a lower 95% uncertainty bound greater than zero.

Figure 2 compares the geographic distribution of aggregate excess MMR and cumulative excess maternal deaths during 2020–2023. Higher aggregate excess MMR values were concentrated across parts of sub-Saharan Africa and several countries in Latin America, indicating larger departures from expected maternal mortality risk relative to live births. In contrast, higher cumulative excess maternal death counts were concentrated across much of sub-Saharan Africa and South Asia, reflecting both elevated maternal mortality risk and larger birth cohorts. The two maps are related but not identical: excess MMR reflects risk relative to live births, whereas excess maternal deaths reflect absolute mortality burden.



(a) Aggregate excess MMR

(b) Cumulative excess maternal deaths

Figure 2: Global maps of excess maternal mortality during 2020–2023. Panel (a) shows aggregate excess maternal mortality ratio (MMR), calculated as the sum of annual excess MMR deviations across 2020–2023. Panel (b) shows cumulative excess maternal deaths over the same period. Country-level estimates were derived using an ensemble n-sub-epidemic modeling framework calibrated to pre-pandemic WHO/UN MMEIG estimates from 2000–2019 and projected through 2020–2023 under a counterfactual no-pandemic scenario. Darker shades indicate higher values. Countries not included in the analytic dataset or not mapped are shown in gray. The maps were generated using Datawrapper.

5 Discussion

This study estimated country-level deviations in maternal deaths and maternal mortality ratios (MMR) during the 2020–2023 pandemic-period analysis window relative to counterfactual projections calibrated to pre-pandemic WHO/UN MMEIG trends. The findings show substantial geographic heterogeneity in excess maternal mortality, with positive deviations often concentrated in settings that already had high baseline maternal mortality and structural health-system vulnerabilities. These patterns are consistent with broader evidence that global maternal mortality progress has been uneven and that high-burden countries remain furthest from the SDG 3.1 target [18, 51]. However, the spatial patterns also suggest that excess burden cannot be explained by income level or region alone. Differences across countries may reflect variation in maternal-care systems, the balance between home and facility-based delivery, baseline mortality levels, fertility patterns, data quality, conflict, climate-related shocks, and the extent to which pandemic-related disruptions affected access to timely obstetric care. In fragile health systems, these factors are unlikely to operate independently: conflict and displacement can reduce service availability, climate shocks can disrupt transport and food security, and policy and funding shocks, including donor-policy restrictions and disruptions to externally supported reproductive-health services, can constrain reproductive and maternal health services [31, 35]. Such overlapping pressures may amplify pandemic-related disruptions and make it difficult to isolate the specific contribution of the COVID-19 pandemic from other contemporaneous drivers of maternal mortality.

At the national level, the illustrative high-burden country trajectories show that several settings experienced slowed improvement or temporary reversals during the pandemic years. In some countries, positive deviations were concentrated in 2020 and 2021, suggesting that disruptions to maternal health services may have been most acute during the initial phase of the pandemic. These patterns are plausibly consistent with documented disruptions to essential health services, reduced facility-based care, interruptions to referral pathways, delays in care-seeking due to fear of infection, transport restrictions, shortages of blood and essential medicines, and the reallocation of health-system resources toward COVID-19 response [3, 9, 10, 36, 48]. They are also consistent with evidence that maternal and perinatal outcomes worsened during the pandemic and that SARS-CoV-2 infection posed direct clinical risks during pregnancy [8, 13, 42]. Nevertheless, our framework does not assign causal attribution. The estimated deviations should be interpreted as signals of departure from expected pre-pandemic trends, not as deaths directly caused by COVID-19. This caveat is particularly important for the illustrative high-burden settings, where pandemic-period deviations may have been shaped by overlapping shocks, including conflict, displacement, other infectious disease outbreaks, fragile health systems, disruptions to reproductive health services, and policy shocks affecting access to maternal and reproductive care. These factors may have compounded pandemic-related disruptions and make it difficult to isolate a COVID-19-specific effect.

Several countries did not exhibit statistically detectable excess maternal mortality during the pandemic-period analysis window. In this study, "statistically detectable" refers to excess estimates for which the lower uncertainty bound was greater than zero. The absence of statistically detectable excess should not be interpreted as evidence of no pandemic-related disruption or true improvement in maternal outcomes, particularly in countries with persistently high baseline maternal mortality. In some settings, median excess estimates were zero, whereas in others, such as Liberia in the maternal deaths analysis, the median estimate was positive but the uncertainty interval included zero. These results should therefore be interpreted as uncertain rather than null. Limited civil registration and vital statistics (CRVS) coverage, underreporting, misclassification of maternal deaths, delays in death registration, and pandemic-related disruption to reporting systems may all obscure true deviations from expected maternal mortality [1, 2, 21, 34]. Death-certificate ascertainment and pregnancy-status reporting can also affect maternal mortality measurement, particularly where cause-of-death data are incomplete or inconsistently coded [12, 23]. In countries where WHO/UN MMEIG estimates fell below projected counterfactual trends, these patterns may reflect real continuation of pre-pandemic improvement, model uncertainty, or reporting limitations. This underscores the need for stronger maternal mortality surveillance systems to interpret excess-mortality signals with confidence. However, even strengthened routine surveillance may not fully capture stigmatized or less-visible contributors to maternal mortality, including unsafe abortion, self-harm, and pregnancy-related violence [39, 52].

Interpreting the results also requires attention to the distinct meanings of MMR and absolute maternal deaths. MMR captures maternal mortality risk relative to live births, whereas absolute maternal deaths reflect the total burden on families, communities, and health systems [51]. Because MMR depends on the number of live births, changes in fertility during the pandemic may affect its interpretation differently from absolute maternal deaths. For example, a decline in live births could increase MMR even if the number of maternal deaths remained stable, whereas absolute deaths more directly reflect the total mortality burden. Conversely, countries with large birth cohorts may have high excess maternal death counts even when excess MMR is modest. Considered jointly, these two outcomes provide a more complete picture of pandemic-period maternal mortality than either metric alone.

A key strength of this study is the use of a consistent country-level counterfactual framework to estimate deviations in both maternal deaths and MMR. By applying the same ensemble n-sub-epidemic modeling approach across countries, the analysis provides a comparable set of estimates that complements country-specific studies and broader global maternal mortality assessments [16, 18]. The study also contributes to the wider excess-mortality literature by applying a framework commonly used to assess direct and indirect pandemic mortality burden to a maternal-health outcome [33,43]. This approach is useful because it accounts for pre-existing downward or non-linear maternal mortality trends, rather than relying on simple comparisons between pandemic and immediately preceding years.

Several limitations merit emphasis. First, this analysis relies on WHO/UN MMEIG model-based estimates rather than raw observed maternal death counts. Therefore, the analysis compares one set of model-based pandemic-period estimates with counterfactual forecasts calibrated to pre-pandemic model-based estimates. The results should be interpreted as deviations between WHO/UN MMEIG estimates and modeled no-pandemic projections, not as deviations in directly observed surveillance counts [7, 51]. Second, the estimates inherit uncertainty from the WHO/UN MMEIG estimation process, including uncertainty related to incomplete CRVS coverage, underreporting and misclassification of maternal deaths, source-specific adjustments, and the Bayesian modeling framework used to generate comparable country-year estimates, as described in Section 2.2. They also inherit uncertainty from the counterfactual forecasting model. Unless uncertainty in the WHO/UN MMEIG estimates is fully propagated into the forecasting procedure, the reported intervals may underrepresent the total uncertainty around excess maternal mortality. Third, the counterfactual forecasts assume that pre-pandemic trends would have continued in the absence of the pandemic. This assumption may be less plausible in countries affected by conflict, climate shocks, major health-system reforms, or other contemporaneous disruptions. This limitation is especially relevant for the illustrative high-burden settings emphasized in this study, several of which experienced conflict, displacement, outbreaks of other infectious diseases, or policy and funding shocks during the analysis window. Findings for these countries should therefore be interpreted as hypothesis-generating signals of departure from expected trends, rather than as country-specific estimates of COVID-19-specific effects.

Fourth, the positive-only definition of excess mortality, $\max(0, \text{observed} - \text{expected})$, was used to quantify additional burden during the pandemic period. This definition is useful for summarizing excess burden, but it does not capture signed deviations below the counterfactual baseline. Negative deviations could reflect true continued improvement, changes in fertility, data-quality limitations, or model uncertainty. Future analyses should therefore present signed-deviation sensitivity analyses alongside positive-only excess estimates. Fifth, this study could not distinguish deaths directly attributable to SARS-CoV-2 infection from deaths indirectly associated with health-system disruption, delays in care, or reduced service utilization. Cause-of-death attribution practices also varied across countries, and COVID-19 deaths among pregnant or postpartum individuals may not have been classified consistently as maternal deaths. As with other excess-mortality approaches, the estimates reflect temporal deviations from expected trends and should not be interpreted as causal effects attributable solely to COVID-19 [33].

From a policy perspective, the findings highlight the importance of explicitly protecting essential maternal and newborn health services within emergency preparedness and response plans. Preparedness plans should also include risk communication and community engagement (RCCE) components that provide clear, trusted, and locally adapted information, engage communities in service planning, and address fear, misinformation, stigma, transport challenges, and other obstacles that may prevent timely care-seeking during emergencies [37, 47]. Continuity of antenatal care, skilled birth attendance, emergency obstetric care, referral systems, blood supply, essential medicines, and postnatal care should be treated as core health-system functions during crises, not as services that can be safely deferred [17, 46]. Health-system resilience requires not only surge capacity for emerging threats, but also the ability to maintain routine and emergency care for high-risk populations during periods of disruption [19, 29, 44]. Countries may also benefit from early-warning indicators for maternal service disruption, including declines in antenatal care attendance, institutional deliveries, skilled birth attendance, emergency obstetric referrals, caesarean-section capacity, referral transport capacity, and maternal death notification, as well as shortages of blood and essential medicines [45, 48].

The results also underscore the importance of strengthening maternal death surveillance and response systems. Improved CRVS systems, maternal death notification, confidential enquiry, and routine maternal and perinatal death surveillance and response can help identify preventable deaths, distinguish direct from indirect causes, and guide timely corrective action [1, 2, 45]. Such systems are especially important in settings where model-based international estimates remain necessary because routine data are incomplete or delayed. Investments in surveillance should therefore be viewed not only as measurement improvements, but also as part of health-system preparedness and accountability. At the same time, routine surveillance should be complemented by confidential enquiries, maternal death reviews, and community-informed mechanisms that can better identify neglected or stigmatized contributors to maternal mortality.

In conclusion, the COVID-19 pandemic period was associated with heterogeneous country-level deviations in maternal deaths and MMR relative to modeled pre-pandemic WHO/UN MMEIG trends. Positive excess estimates were most evident in settings with high baseline maternal mortality and pre-existing health-system vulnerabilities, although uncertainty and data limitations remain substantial. These findings should be interpreted as modeled excess relative to a no-pandemic counterfactual baseline, not as directly observed deaths or causal effects attributable solely to COVID-19. Strengthening maternal health services, protecting emergency obstetric care during crises, and improving maternal mortality surveillance are critical to sustaining progress toward SDG 3.1 and preventing avoidable maternal deaths during future public-health emergencies.

Data availability statement

Input data are publicly available from the WHO/UN MMEIG maternal mortality estimates. Derived outputs supporting the main tables and figures are provided in the Supplementary Material.

Code availability

The analysis code and generated outputs supporting this manuscript are available in the repository: `https://github.com/hkarami-GSU/Maternal_Mortality`.

Ethics approval

This study used publicly available, aggregate country-level estimates and did not involve human participants or identifiable private information; institutional review board approval was not required.

Contributors

JHG, HK, and GC conceived and designed the study. HK and JHG curated and analysed the data. HK implemented the modelling and prepared the tables and figures. JHG, HK, and GC drafted the manuscript. HK, HAH, MAD, GMM, and GC contributed to the interpretation of the findings and critically revised the manuscript for important intellectual content. GC supervised the study. All authors reviewed and approved the final manuscript.

AI-use disclosure

Generative AI tools were used to assist with language editing and organization of revision comments. The authors reviewed, verified, and take full responsibility for all manuscript content.

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Competing interests

The authors declare no competing interests.

Patient and public involvement

Patients and the public were not involved in the design, conduct, reporting, or dissemination planning of this modelling study using publicly available aggregate data.

Patient consent for publication

Not required.

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