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Global, regional, and national burden of maternal disorders, 1990–2021: a systematic analysis from the global burden of disease study 2021

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Abstract

Background Maternal morbidity and mortality, encompassing pregnancy-related complications and obstetric disorders, pose a persistent global health challenge with significant multigenerational consequences. As the second leading cause of disability-adjusted life years (DALYs) among women of reproductive age globally, these conditions exert profound impacts on perinatal outcomes and intergenerational health equity. The Global Burden of Disease Study (GBD), recognized as the most comprehensive epidemiological surveillance system, provides critical evidence for optimizing maternal health policies through systematic quantification of disease burden patterns. This multinational study employs GBD 2021 data to conduct a spatiotemporal analysis of maternal disorder burden across 21 GBD regions and 204 countries and territories from 1990 to 2021, utilizing standardized metrics including DALYs, prevalence rates, and mortality incidence.

Methods This population-based multinational investigation employed systematically collected epidemiological evidence from the Global Burden of Diseases (GBD), Injuries, and Risk Factors Study 2021, with data acquisition was conducted through the standardized Global Health Data Exchange platform (https://vizhub.healthdata.org/gbd-results/.GBD Results Tool; data retrieval date: November 11, 2024). We systematically analyzed temporal trends in maternal disorder burden from 1990 to 2021 using a standardized analytical framework stratified across three dimensions: age cohorts (10–54 years), 21 GBD-defined geographical regions, and socio-demographic index (SDI) quintiles—a composite metric integrating income, education, and fertility rates. The burden quantification employed five core metrics: (1) Disability-adjusted life years (DALYs): Integrating years of life lost (YLLs) and years lived with disability (YLDs). (2) Mortality counts: Absolute maternal deaths by etiology. (3) Estimated annual percentage change (EAPC). (4) Age-standardized mortality rate (ASMR). (5) Age-standardized DALYs rate (ASDR): Adjusted using the GBD reference

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population structure. All estimates reported with 95% uncertainty interval (UI) derived from 1,000 Bayesian posterior draws.

Results Quantitative analysis of the Global Burden of Disease (GBD) 2021 dataset reveals significant advancements in maternal health metrics. Between 1990 and 2021, maternal mortality decreased by 60% (age-standardized mortality rate [ASMR]: 12.45 to 4.87 per 100,000), with disability-adjusted life years (DALYs) declining by 43.5% (age-standardized DALY rate [ASDR]: 780.8 to 315.3 per 100,000). The estimated annual percentage change (EAPC) for mortality (-3.1%, 95% CI: -3.2 to -2.99) and DALYs (-3.0%, 95% CI: -3.1 to -2.89) underscores sustained global progress. Maternal abortion and miscarriage (-4.67% EAPC), Maternal hemorrhage (-4.06% EAPC), and Maternal obstructed labor and uterine rupture (-3.68% EAPC) drove maternal mortality reductions. Maternal mortality peaked at ages 20–24 globally, with variations in high-income regions (peaks at 25–34 years). Hemorrhage dominated in sub-Saharan Africa, whereas high-income regions prioritized hypertensive disorder management. The highest maternal mortality remained in low-SDI regions, with a substantial 63% decrease (51.85 to 19.44 per 100,000), while high-SDI regions showed minimal changes. Disease burden from hemorrhage, hypertensive disorders, and abortion declined significantly, while ectopic pregnancy saw stagnation. Regional trends revealed substantial improvements in Southern Asia, while Sub-Saharan Africa remained challenged.

Conclusions The significant decline in global maternal mortality and DALYs over the past three decades highlights the progress made in improving maternal health. However, the persistent disparities across regions and SDI levels underscore the need for targeted interventions. The findings emphasize the importance of continued surveillance and monitoring of maternal health indicators to guide policy and resource allocation. Strengthening the healthcare systems, particularly in low-SDI regions, is crucial to further reduce the burden of maternal disorders.

Keywords Maternal disorders, Global burden of disease study, Incidence, Maternal mortality, Disability-adjusted life years

Introduction

Maternal disorders, including postpartum hemorrhage, hypertensive disorders, and infections, represent a substantial global health burden, emphasizing the critical importance of maternal health within the broader context of public health [1–3]. Maternal complications not only pose a direct threat to the health of the mother but also have far-reaching impacts on the newborn, as well as on the emotional, psychological, and socio-economic well-being of the family. Maternal health is a cornerstone of global public health and is intrinsically linked to social development and the pursuit of gender equality [4, 5].

Maternal and child health, as well as the reduction of maternal mortality, have long been global health priorities and were integral to the United Nations Millennium Development Goals [6]. Leveraging its extensive data collection, standardized methodologies, and rigorous analytical approaches, the Global Burden of Disease (GBD) study provides a critical resource for monitoring advancements towards achieving the health-related United Nations Sustainable Development Goal (SDG) [7]. Its systematic assessments enable policymakers, researchers, and global health stakeholders to track trends, identify disparities, and inform evidence-based interventions aimed at improving population health outcomes. Despite notable progress in reducing the burden of maternal and newborn disorders globally, maternal health challenges remain substantial [8]. A critical prerequisite for further reductions in maternal mortality is a comprehensive understanding of the underlying causes of maternal deaths, which is essential to inform effective policy development and health program implementation [9–11]. Between 1990 and 2021, the world witnessed rapid socio-economic transformations, continued urbanization, notable healthcare advancements, and significant changes in fertility patterns. These shifts have undoubtedly reshaped the landscape of maternal health. However, the persistent and substantial disparities that still exist underscore the deep-rooted systemic inequities within global healthcare systems.

According to estimates by the World Health Organization (WHO), approximately 15% of all pregnant women experience severe obstetric complications each year, including obstetric hemorrhage, maternal sepsis, other maternal infections, hypertensive disorders, obstructed labor, uterine rupture, abortion, and miscarriage [12–14]. Maternal disorders, particularly obstetric hemorrhage, hypertensive diseases, and pregnancy-related infections, collectively account for 75% of global maternal mortality. Disturbingly, 94% of these deaths occur in low-resource settings, where access to quality healthcare is severely limited [15]. The United Nations Sustainable Development Goal (SDG 3.1) has set a clear and ambitious target: to reduce maternal mortality ratios (MMRs) to less than 70 per 100,000 live births by 2030. Despite progress in some countries, maternal mortality remains alarmingly high in many low-income nations, particularly in conflict-affected regions. South Asia, for example, accounts

for a fifth of global maternal deaths, and the maternal mortality rate in the region is disproportionately high [16–18]. These disparities highlight the urgent need for in-depth, long-term assessments of the disease burden. Such analyses may help inform policy adjustments and support the development of more targeted interventions to address this critical issue.

The consequences of maternal morbidity extend far beyond the loss of life, imposing multi-dimensional burdens on households and economies. Maternal complications, particularly conditions like postpartum hemorrhage, place a heavy economic burden on families. These costs can deplete family savings, force borrowing or asset sales, and exacerbate poverty, thereby creating a vicious cycle that deepens income inequality. This, in turn, affects health, human capital, and income distribution across both current and future generations [19]. Therefore, maternal health is both a determinant and a consequence of economic vulnerability, underscoring its vital role in social and economic well-being.

To address these complex and persistent challenges, this study uses the GBD 2021 dataset, which encompasses data from 204 countries and subnational units. We employ validated Bayesian models [20] and geospatial analysis techniques to map the burden of maternal diseases from 1990 to 2021 across multiple dimensions, including mortality, disability-adjusted life years (DALYs), and socioeconomic gradients. Through this approach, we aim to quantify the evolving impact of major maternal health issues. Our ultimate goal is to utilize the GBD 2021 data to explore the maternal disease burden, identify priority regions for targeted resource allocation, accurately assess progress towards SDG 3.1, and provide a methodological framework that can disentangle the complex interactions between demographic transitions, healthcare access, and maternal health outcomes. By doing so, we aim to contribute to the development of more effective and evidence-based strategies to improve global maternal health.

Methods

Data sources

Data on the burden of maternal disorders from 1990 to 2021 were sourced from the GBD 2021 dataset, available through the Global Health Data Exchange (GHDE) GBD Results Tool. The GBD study is led by the Institute for Health Metrics and Evaluation (IHME) [21]. This dataset integrates health data from 21 GBD regions and 204 countries, offering a comprehensive overview of health-related metrics across diverse global populations [22–24]. The GBD study provides a fundamental data framework that includes a comprehensive categorization of maternal disorders and accurate burden estimates.

Definitions The analysis was conducted with careful consideration across multiple dimensions. Data were stratified by age group, creating distinct cohorts to identify age-specific patterns. Geographically, 21 regions were considered to provide a comprehensive understanding of regional disparities. The Socio-Demographic Index (SDI), developed using the Human Development Index (HDI) method [25], was employed as a key measure of socio-economic development. Additionally, the data were stratified into five development-level quintiles. The SDI quantifies a country's or region's level of development based on fertility rate, education level, and per capita income. Ranging from 0 to 1, a higher SDI reflects greater socioeconomic development. The SDI is well-established as a correlate of disease incidence and mortality rates. In this study, countries and regions were classified into five SDI categories (low, low-medium, medium, medium-high, and high), facilitating an examination of how the burden of maternal diseases varied across different socioeconomic contexts [26].

A series of key metrics were calculated to comprehensively assess the burden of maternal diseases. These included incidence rates, which measured the number of new cases of maternal diseases over a specific period; disability-adjusted life years (DALYs), which combine the impact of premature death and years lived with disability due to maternal diseases; mortality rates, which reflect the number of deaths attributed to maternal diseases; and estimated annual percentage change (EAPC), used to analyze the yearly trends in burden. Additionally, age-standardized mortality rates (ASMR) were calculated to adjust for differences in population age structures, enabling fair comparisons across regions and time periods. The age-standardized rate of DALYs (ASDR) was also computed, providing a standardized measure of the overall burden of disability caused by maternal diseases.

Statistical analyses

For statistical analysis and visualization, the R statistical package (version 4.4.2) was employed. This software provided a robust and flexible platform for data manipulation, statistical testing, and the generation of visual representations, ensuring the accuracy and reliability of our results. Through these rigorous analytical methods, we aimed to gain a deeper understanding of the burden of maternal diseases and their associated risk factors, with the goal of providing valuable insights for public health policy-making and intervention strategies.

To assess trends in age-standardized rates (ASR) of maternal diseases mortality, disability-adjusted life years (DALYs), the estimated annual percentage change (EAPC) was calculated. The ASR was computed per 100,000 individuals using the following formula:

$$\mathrm{ASR} = \frac{\sum_{i=1}^{A} a_i w_i}{\sum_{i=1}^{A} w_i} \times 100000$$

Where a_i represents the age-specific rate in the i-th age group, w_i is the number of individuals in the i-th age group within the standard population, and A is the total number of age groups.

The calculation of EAPC was based on a regression model that characterizes the pattern of age-standardized rates over a specified period [27]. The model employed is expressed as:

$$Y = \alpha + \beta X + e$$

Where Y is the natural logarithm of the ASR, X is the calendar year, α is the intercept, β denotes the slope (representing the trend), and e is the error term. The EAPC is calculated as:

$$\mathrm{EAPC} = 100 \times (\exp(\beta) - 1)$$

Representing the annual percentage change. The linear regression model was used to compute the 95% confidence interval (CI) for the EAPC. An ASR is considered to have an increasing trend if both the EAPC and the lower bound of its 95% CI are positive. In contrast, if both the EAPC and the upper bound of its 95% CI are negative, the ASR is considered to have a decreasing trend. If neither condition is satisfied, the age-standardized rate is regarded as stable. Spearman's correlation coefficient was used to assess the associations between the Socio-Demographic Index (SDI) and the age-standardized rates of maternal diseases.

Results

The global impact and temporal trend of maternal disorders

A comprehensive analysis of the global burden of maternal health, based on GBD data up to 2021, highlights trends in maternal mortality and disability-adjusted life years (DALYs). The number of global maternal deaths decreased from 342,498 (95% UI: 310,096, 376,903) in 1990 to 191,152 (95% UI: 161,460, 227,097) in 2021, reflecting an average annual decline of 3.1%. The EAPC for global maternal mortality was −3.1% (95% CI: −3.2 to −2.99). The age-standardized maternal mortality rate dropped from 12.452 per 100,000 (95% UI: 11.262, 13.732) in 1990 to 4.869 per 100,000 (95% UI: 4.112, 5.777) in 2021, representing a reduction of approximately 60% (Supplementary Table 1).

Similarly, the global burden of maternal disorders, measured in DALYs, decreased from 21,798,119 (95% UI: 19,794,770, 23,925,136) in 1990 to 12,314,021 (95% UI: 10,581,000, 14,527,456) in 2021, with an average annual decline of 3.0%. The EAPC for global DALYs was −3.0% (95% CI: −3.1 to −2.89). The age-standardized DALYs rate decreased from 780.791 per 100,000 (95% UI: 709.225, 857.651) to 315.302 per 100,000 (95% UI: 271.076, 371.755) (Supplementary Table 1). These findings underscore a significant global decline in both maternal deaths and DALYs attributable to maternal disorders. This reduction marks a substantial decrease in the global burden of maternal health issues over the past 31 years, indicating a notable improvement in overall health outcomes.

The principal determinants of maternal mortality are multifaceted, involving a range of conditions that significantly threaten maternal health. Key causes of maternal death and disability-adjusted life years (DALYs) associated with maternal disorders include ectopic pregnancy, indirect maternal deaths, late maternal deaths, abortion and miscarriage, maternal deaths aggravated by HIV/AIDS, maternal hemorrhage, hypertensive disorders, obstructed labor and uterine rupture, sepsis, and other infections, as well as other direct maternal disorders. In 1990, the leading causes of maternal death were maternal hemorrhage (114,113 cases, 33.3%), hypertensive disorders (53,894 cases, 15.7%), and abortion/miscarriage (47,506 cases, 13.9%) (Fig. 1A, Supplementary Table 1). By 2021, the number of deaths from these causes had decreased to 46,874, 38,147, and 16,706, respectively, while they remained the three leading causes of death, together accounting for approximately 63% of total maternal deaths (Fig. 1C, Supplementary Table 1).

An analysis of specific causes of maternal death reveals a decline in both mortality and DALYs for most causes, though the rate of decline varies. Maternal mortality and DALYs have shown significant reductions across most causes (Fig. 2A and B). Among the most notable improvements, maternal abortion and miscarriage deaths decreased substantially, from 47,506 to 16,706, and age-standardized death rates dropped from 1.786 to 0.423 per 100,000. The Estimated Annual Percentage Change (EAPC) for this cause was −4.67% (Figs. 1 and 2A6, 2B6). Maternal hemorrhage, another major contributor to maternal mortality, saw deaths decrease from 114,113 to 46,874, with age-standardized death rates falling from 4.129 to 1.198 per 100,000, corresponding to an EAPC of −4.06% (95% CI: −4.24 to −3.87) (Figs. 1 and 2A2, 2B2). Similarly, deaths from obstructed labor and uterine rupture declined from 22,645 to 11,673, with age-standardized death rates dropping from 0.826 to 0.296 per 100,000, yielding an EAPC of −3.68% (95% CI: −3.86 to −3.50) (Figs. 1 and 2A5 and 2B5). However, ectopic pregnancy presents a concerning trend, with deaths increasing slightly from 4,636 to 6,442 and age-standardized death rates remaining stable at 0.17 per 100,000. Despite this small increase, the global EAPC for ectopic pregnancy stands at 0%, indicating a stagnating trend that

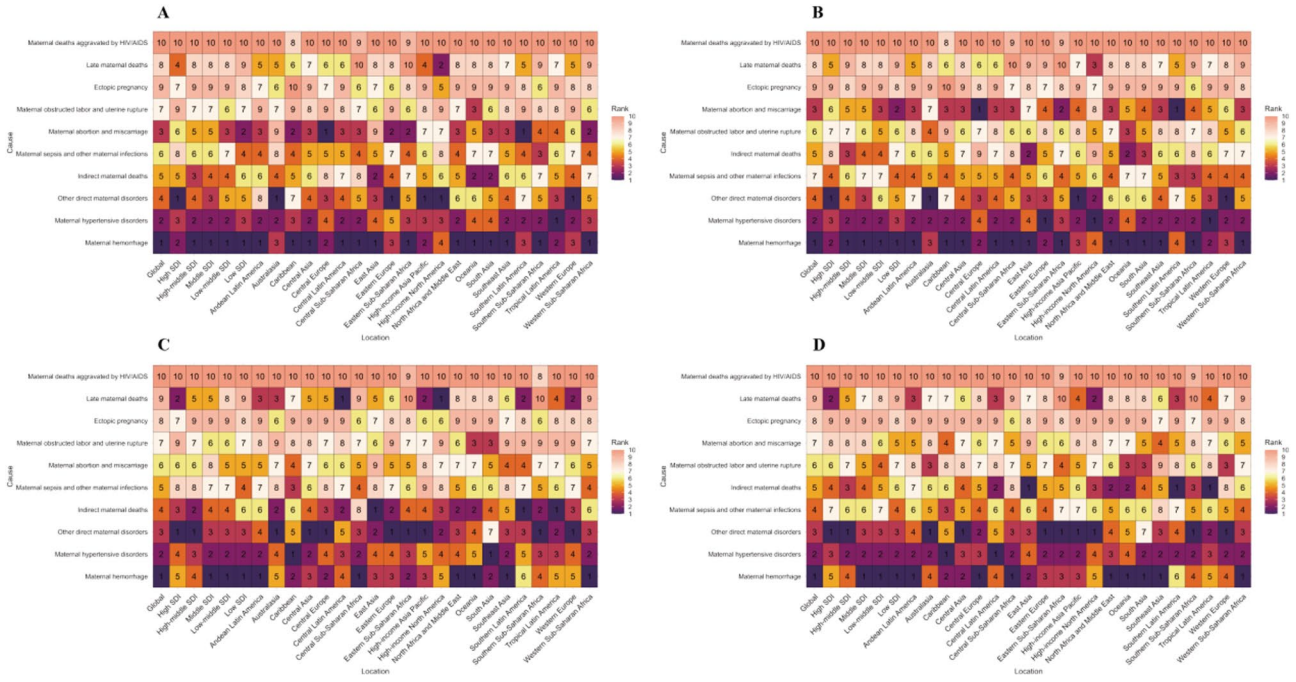

Fig. 1 The global disease burden of maternal disorders deaths and disability-adjusted life-years in 21 regions 1990and 2021. **A** 1990 Deaths. **B** 1990 DALYs. **C** 2021 Deaths. **D** 2021 DALYs

highlights the need for improved early detection and intervention strategies (Fig. 2A7 and 2B7).

Between 1990 and 2021, significant differences in maternal mortality cases and age-standardized death rates were observed across various SDI levels. In 1990, the highest number of deaths and age-standardized death rates were found in regions with low SDI, followed by low-middle SDI, middle SDI, high-middle SDI, and high SDI regions in descending order. By 2021, mortality and DALY rates had decreased across all SDI levels. In low SDI regions, the EAPC for maternal deaths and DALYs was −3.18% (95% CI: −3.37 to −2.98) and −3.13% (95% CI: −3.32 to −2.93), respectively, indicating a significant but slower decline compared to high SDI regions, where the EAPC for maternal mortality and DALYs was close to zero (0.06%, 95% CI: −0.25 to 0.38, and −0.34%, 95% CI: −0.55 to 0.14), suggesting a stable trend in maternal health outcomes (Supplementary Table 1).

Regionally, by 2021, both maternal mortality and DALY rates had declined substantially in sub-Saharan Africa and South Asia, with particularly notable reductions observed in South Asia. However, sub-Saharan Africa and South Asia consistently recorded the highest age-standardized maternal mortality and DALY rates throughout the study period (Fig. 3). In South Asia, the EAPC for maternal deaths and DALYs was −6.34% (95% CI: −6.63 to −6.06) and −6.18% (95% CI: −6.45 to −5.90), respectively, indicating a significant downward trend (Fig. 2A1 and 2B1). Similar declining trends in maternal mortality and DALY rates were observed across most regions, as reflected by the corresponding EAPC estimates (Fig. 2). However, an increase in maternal mortality and DALYs was observed in high-income North America and the Caribbean (Supplementary Fig. 1), primarily driven by rising deaths associated with maternal obstructed labor, uterine rupture, and ectopic pregnancy (Fig. 2A5 and 2A7). These findings highlight that, although maternal health outcomes have generally improved across many regions, substantial regional disparities persist. Some areas have made remarkable progress in reducing maternal mortality and DALY burdens, while others continue to face significant challenges.

The impact of maternal disorders on GBD age and region

Maternal health outcomes exhibit notable regional and age-related variations. Data from the GBD study indicate that, in most regions, the incidence of maternal diseases, along with associated deaths (Fig. 4A) and disability-adjusted life years (DALYs) (Fig. 4B), peaked among women aged 20–24. In 2021, this age group accounted for the highest number of maternal deaths, totaling 36,635 (Supplementary Table 2). However, regions such as Central Europe, Eastern Europe, Central Asia, Southeast Asia, East Asia, Oceania, and high-income countries experience a slightly later peak, with the highest incidence occurring in the 25–29 or 30–34 age groups (Fig. 4). Among age groups, maternal abortion, miscarriage, maternal sepsis, and other infections are common, yet generally result in lower disability and mortality rates. In contrast, maternal hemorrhage and hypertensive

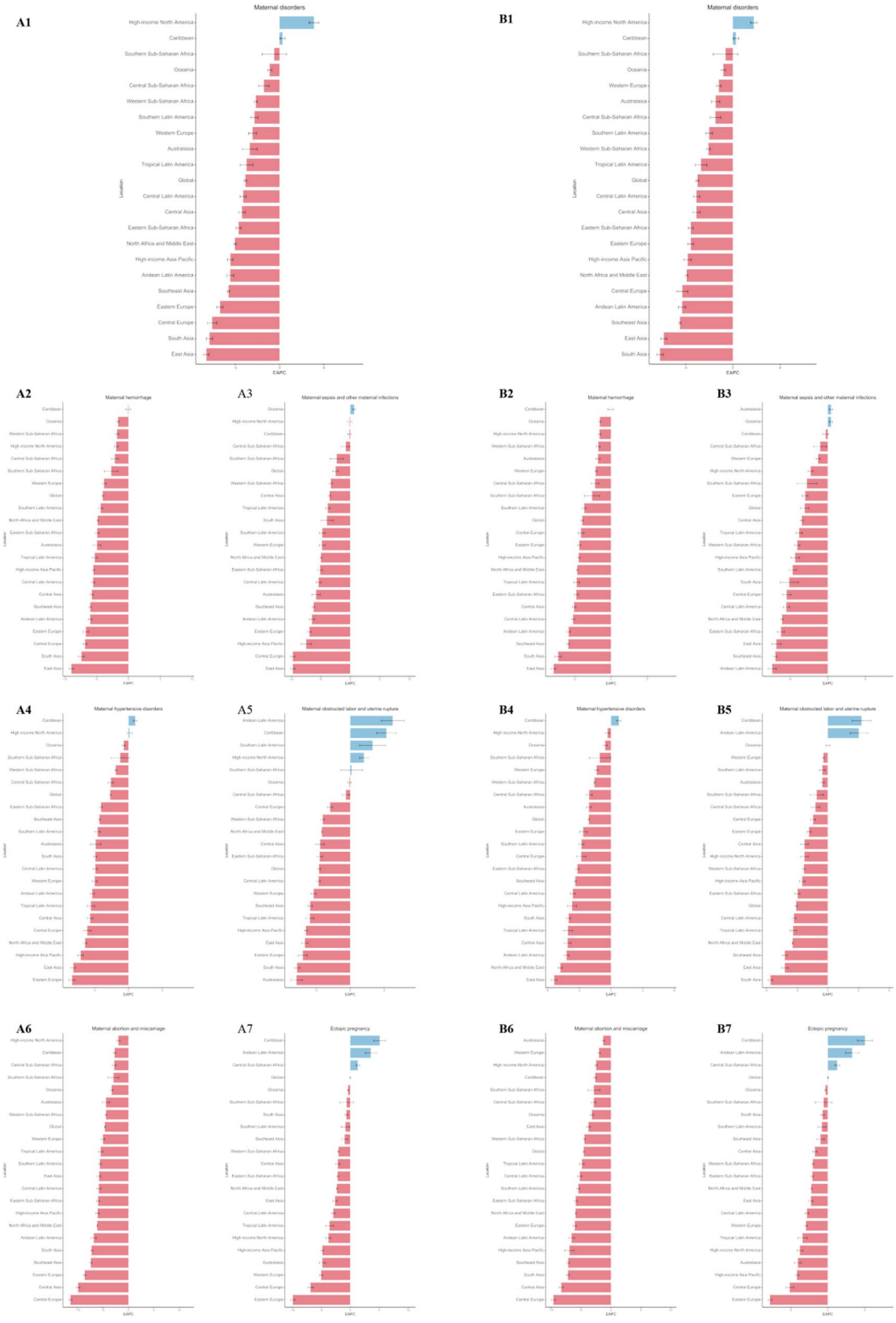

Fig. 2 (See legend on next page.)

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Fig. 2 Age-standardized mortality and DALYs estimated annual percentage changes (EAPCs) from 1990 to 2021 for maternal disorders and their causes, globally and by 21 GBD regions. **A**1-7 Mortality rates EAPCs. **B**1-7 DALYs rates EAPCs. **A**1 Maternal disorders **A**2 Maternal hemorrhage. **A**3 Maternal sepsis and other maternal infections. **A**4 Maternal hypertensive disorders. **A**5 Maternal obstructed labor and uterine rupture. **A**6 Maternal abortion and miscarriage. **A**7 Ectopic pregnancy. **B**1 Maternal disorders **B**2 Maternal hemorrhage. **B**3 Maternal sepsis and other maternal infections. **B**4 Maternal hypertensive disorders. **B**5 Maternal obstructed labor and uterine rupture. **B**6 Maternal abortion and miscarriage. **B**7 Ectopic pregnancy

disorders are the leading causes of maternal deaths and DALYs among women of reproductive age.

Regionally, maternal hemorrhage remains the primary cause of maternal death in sub-Saharan Africa, whereas high-income countries have made substantial progress in controlling hemorrhage, resulting in a steady decline in DALYs. Mortality rates are considerably lower in high-income regions, particularly among women aged 20–24. Further analysis reveals that hypertensive disorders are more prevalent in high-income regions, whereas maternal sepsis and other infections are more common in low-income regions (Figs. 1 and 4).

The impact of maternal disorders on GBD super-region

Temporal trends in age-standardized mortality rates, and DALY rates (ASMR/ASDR) for maternal disorders from 1990 to 2021 are shown in Fig. 5. From 1990 to 2021, most GBD super-regions experienced a decline in age-standardized rates of maternal disorder-related deaths and DALYs. The highest mortality and age-standardized mortality rates were observed in Sub-Saharan Africa (Fig. 5).Trends in age-standardized mortality rates (ASMR) for each disease across regions from 1990 to 2021 are provided in Supplementary Figs. 2 and 3. All six maternal diseases demonstrated a downward trend in almost all regions over this period. However, maternal sepsis and other maternal infections in South Asia showed a slight increase prior to 2000, followed by a subsequent decline (Supplementary Figs. 2 and 3).

The global burden of maternal disorders decreased significantly between 1990 and 2021, with the Sub-Saharan Africa region consistently showing the highest rates in both age-standardized mortality rates, and DALY rates, remaining a major challenge in this and other regions (Fig. 3). Countries in the high-SDI quintile exhibited the lowest age-standardized mortality and DALY rates, with 0.358 (95% UI: 0.307, 0.422) deaths per 100,000 and 28.48 (95% UI: 24.132, 34.119) DALYs per 100,000 people. In contrast, countries in the low-SDI quintile had significantly higher rates, with 19.43 (95% UI: 15.978, 23.865) deaths per 100,000 and 1191.521 (95% UI: 991.615, 1440.071) DALYs per 100,000 (Supplementary Table 1).

Figure 6 illustrates the relationship between age-standardized mortality and DALY rates and the SDI across countries and territories. As SDI increases, the age-standardized mortality rate continues to decrease until it plateaus around an SDI value of approximately 0.70. The age-standardized mortality rates of maternal disorders across regions and countries were strongly negatively correlated with the Socio-demographic Index (SDI) (p-value $< 2.2 \times 10^{-16}$, $r = -0.9229$ and $r = -0.9043$, respectively) (Fig. 6A and C). Similarly, age-standardized DALY rates were also negatively correlated with SDI performance ($r = -0.9227$ and $r = -0.9053$, respectively; $p < 2.2 \times 10^{-16}$)(Fig. 6B and D).

Decomposition analysis of change in death and Age-Period-Cohort (APC) model predictive

Global trends in maternal disease-related mortality were decomposed into three population-level determinants: aging, population growth, and epidemiological changes. Each of the six maternal disease categories was systematically evaluated across these determinants. The horizontal axis quantifies the numerical contribution of each determinant, ranging from − 120,000 to 0, with negative values indicating reductions in mortality attributable to the corresponding factor. The decomposition analysis revealed that epidemiological changes exerted the most substantial influence on mortality reduction, as evidenced by the pronounced negative values. In contrast, population growth partially offset these gains by expanding the size of the at-risk population. The impact of aging displayed significant heterogeneity across specific disease categories. For instance, the effects of aging were more pronounced in maternal hemorrhage and maternal hypertensive disorders than in other maternal diseases (Fig. 7). This results reveal the complex interplay of epidemiological and demographic factors in shaping maternal health outcomes.

The Age-Period-Cohort (APC) model revealed distinct patterns in global maternal mortality, driven by age-specific risks, temporal trends, and generational disparities (Fig. 8). Age effects dominated mortality dynamics, peaking between 20 and 35 years, as shown by the longitudinal age curve. Cross-sectional analyses further confirmed elevated risks in these age groups. Rate ratios (RR) comparing longitudinal and cross-sectional data (Long vs. Cross RR: 0.5–1.5) highlighted age-driven disparities, with minimal deviation from 1.0 in mid-reproductive ages (20–35 years), suggesting stable age effects. Period effects demonstrated a steady decline in mortality post-1990 (fitted temporal trend, Period RR). Cohort effects revealed stark generational contrasts: early cohorts (1940–1960) faced elevated risks (Cohort RR: up to 4.0), while later cohorts (1980–2000) showed marked risk reductions (Cohort RR: ~1.0). Local drift

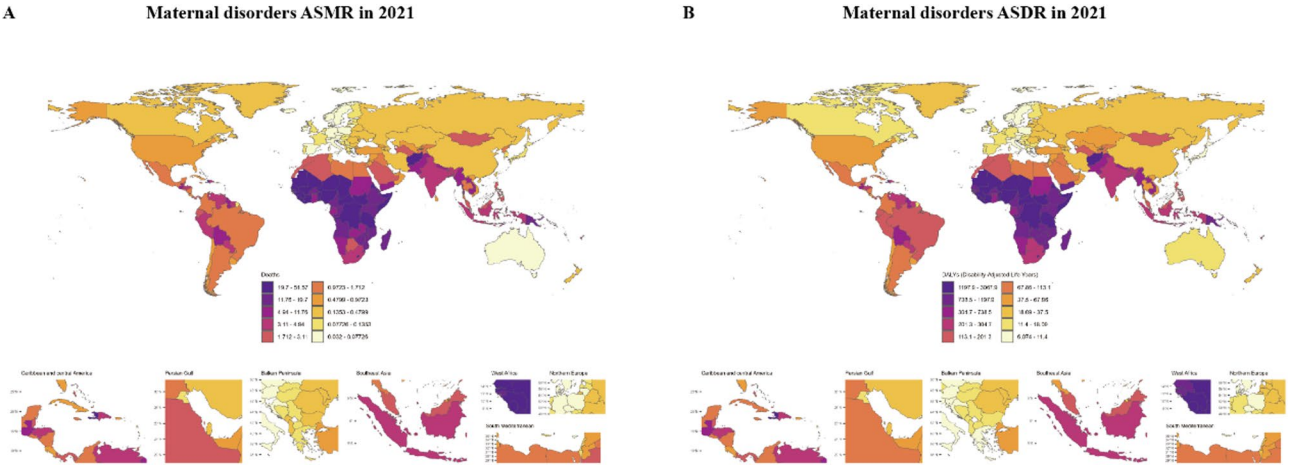

Fig. 3 Global maps of ASMR/ASDR per 100,000 population by maternal disorders in 2021. **A** Maternal disorders ASMR in 2021. **B** Maternal disorders ASDR in 2021. ASMR, age-standardized Mortality rate. ASDR, age-standardized DALY rate. DALYs, disability-adjusted life years

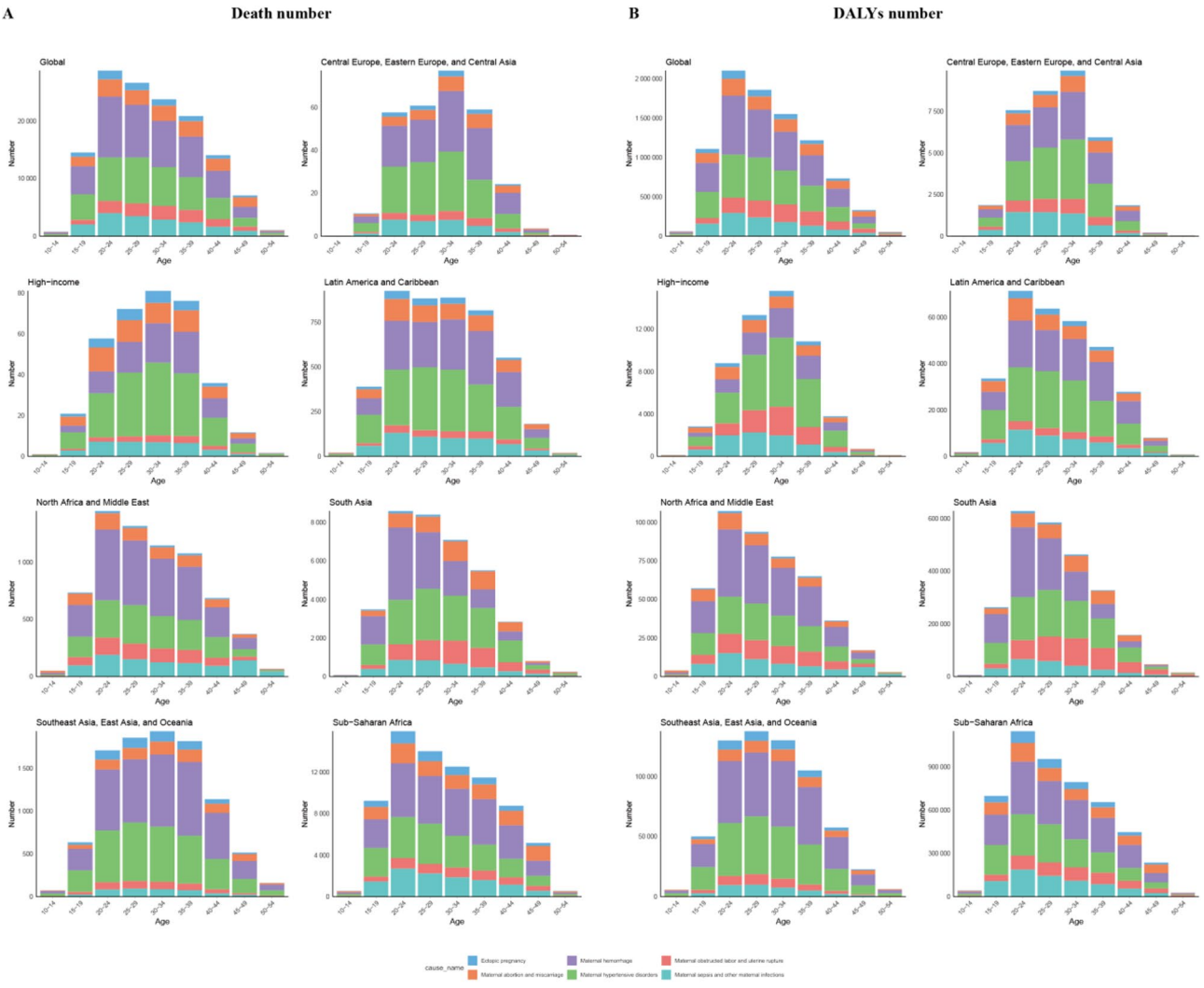

Fig. 4 The distribution of maternal disorder deaths and disability-adjusted life years (DALYs) by age group in 2021 by 7 super-regions **A** Death number. **B** DALYs number

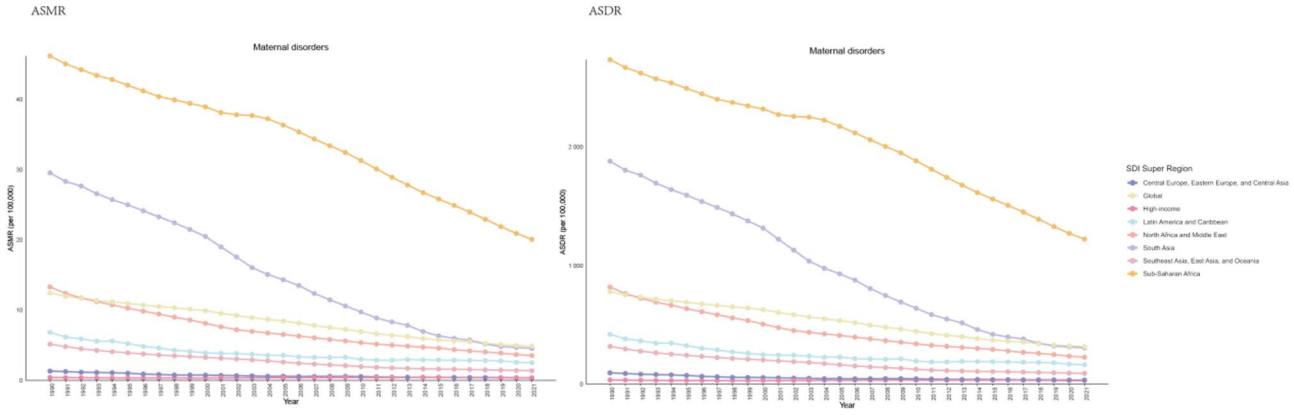

Fig. 5 The age-standardized mortality rate (ASMR) and disability-adjusted life-years rate (ASDR) of maternal disorders in super-region from 1990 to 2021

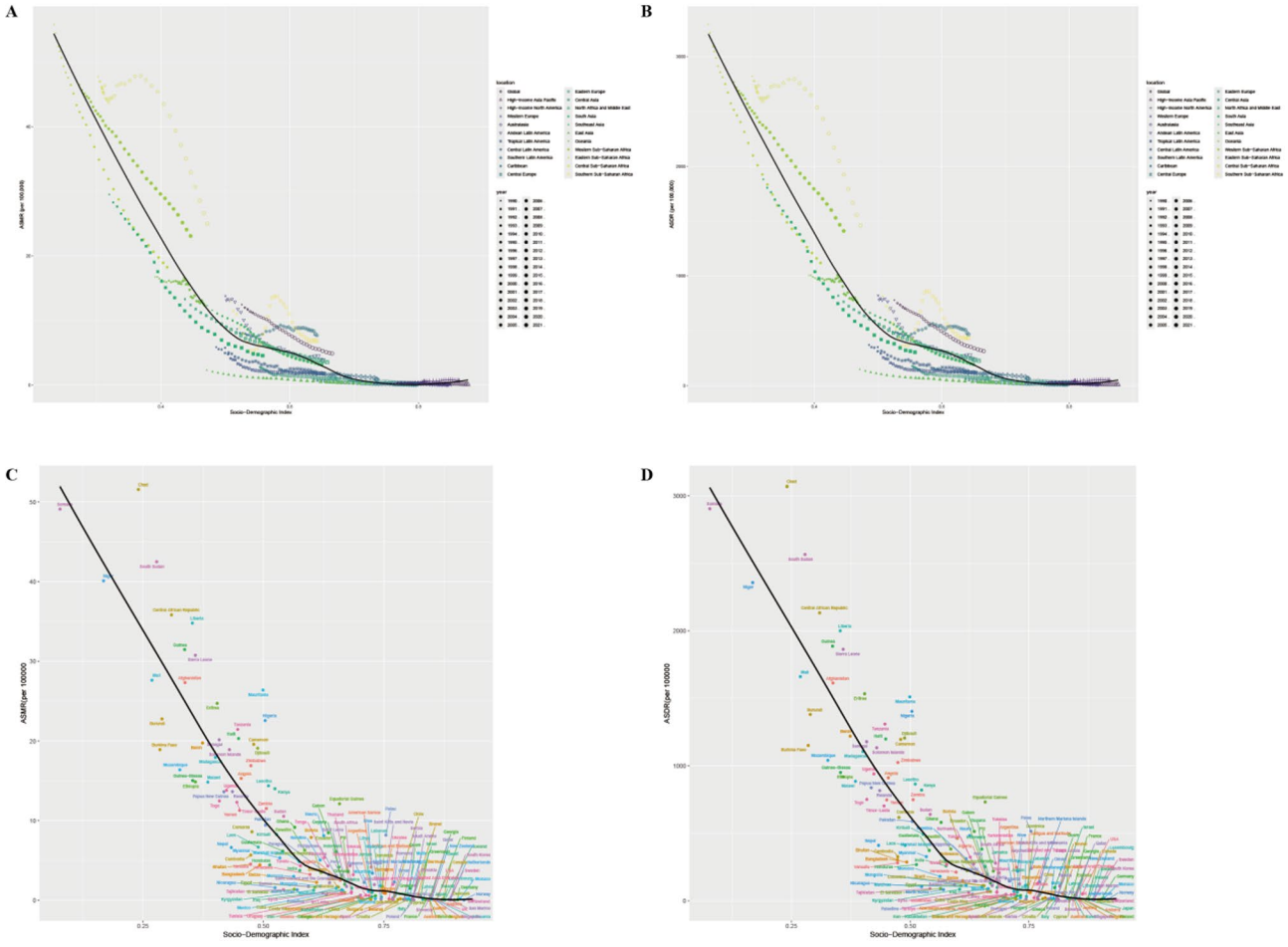

Fig. 6 Age-standardized rates of Mortality and DALYs of maternal disorders, globally and for 21 GBD regions, by SDI (2021), from 1990 to 2021. **A** Age-standardized Mortality rates of maternal disorders by regions (p-value < 2.2e-16, $r = -0.9228596$). **B** Age-standardized ADLYs rates of Maternal disorders by regions p-value < 2.2e-16, $r = -0.922689$). **C** Age-standardized Mortality rates of Maternal disorders by 204 Countries (p-value < 2.2e-16, $r = -0.9043057$). **D** Age-standardized ADLYs rates of Maternal disorders by 204 Countries (p-value < 2.2e-16, $r = -0.9052738$)

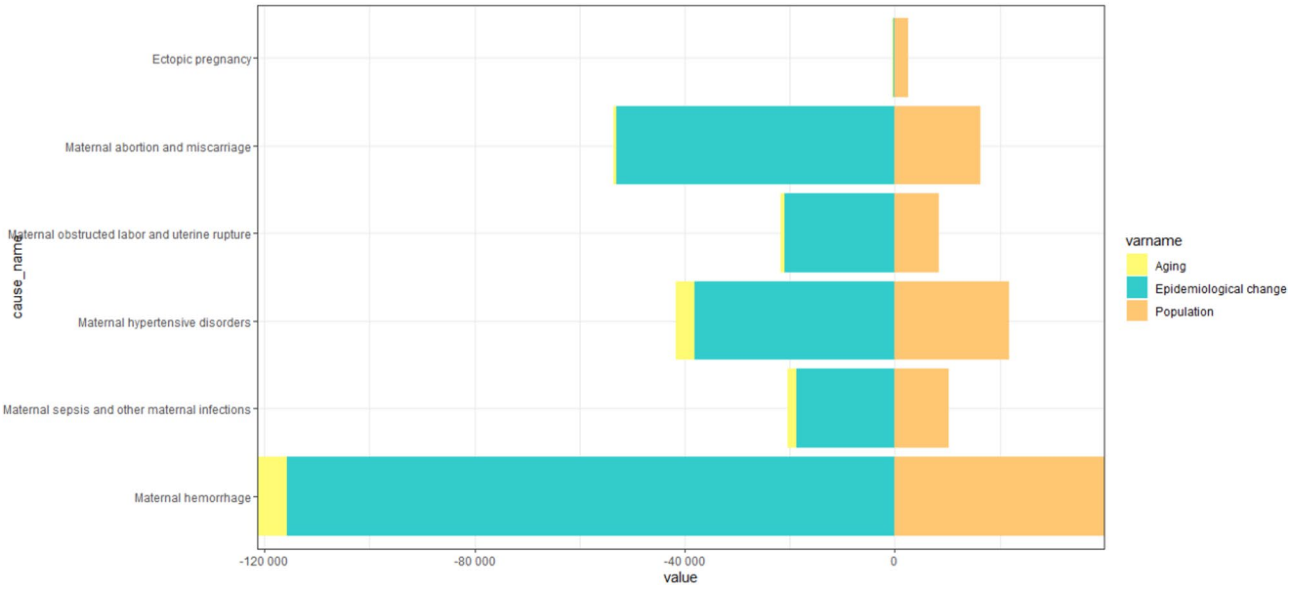

Fig. 7 Change in death of Maternal disorders causers decomposed by three population-level determinants: Aging, Population and Epidemiological change at the global level

analyses quantified annual mortality reductions (−2.0% to −4.0%), with slower declines observed in adolescent groups (10–20 years). In summary, the APC framework delineated maternal mortality as a product of interacting age, period, and cohort forces.

Discussion

This study, based on GBD data, reveals significant trends in the global maternal disease burden from 1990 to 2021. Global maternal mortality and disability-adjusted life years (DALYs) decreased at annual rates of 3.1% and 3.0%, respectively, with age-standardized mortality and DALY rates dropping by approximately 60% and 59.6%. The global number of maternal deaths decreased from 342,498 in 1990 to 191,152 in 2021. However, a study reported in 2012 estimated that 287,000 maternal deaths occurred worldwide in 2010 [28], suggesting that the past decade has seen a rapid decline in maternal mortality. Improvements in maternal health safety could be attributed to advancements in medical technologies (e.g., cesarean sections and treatments for postpartum hemorrhage), improvements in public health measures (e.g., widespread use of prenatal care), and increased attention to maternal health.

Despite these overall improvements, the persistently stable mortality rate of ectopic pregnancy remains a significant concern. As a life-threatening condition characterized by implantation of the fertilized egg outside the uterine cavity, most commonly in the fallopian tube, ectopic pregnancy continues to pose challenges despite advances in medical management [29]. The limited efficacy of current interventions, such as methotrexate therapy and surgical management, may be partly attributed to delayed symptom recognition and untimely referrals from primary care, which are key contributors to adverse outcomes. Moreover, disparities in healthcare resource distribution, particularly the lack of minimally invasive surgical capacity in remote areas, further exacerbate the risk. Addressing ectopic pregnancy mortality requires a comprehensive strategy incorporating public education to promote early symptom recognition, enhanced training for primary care providers in hCG testing and ultrasound diagnostics, the establishment of efficient referral pathways for timely access to specialized care, and structured post-treatment follow-up to prevent recurrence [30, 31].

Our findings highlight substantial disparities in maternal mortality trends across different SDI levels from 1990 to 2021. In low-SDI regions, the EAPC for maternal deaths and DALYs was −3.18% and −3.13%, respectively, indicating meaningful but relatively slower progress compared to higher-SDI regions. In contrast, high-SDI regions exhibited minimal changes (EAPC for maternal deaths 0.06%; DALYs −0.34%), suggesting that maternal health outcomes have plateaued at low levels of mortality in these settings, likely reflecting well-established healthcare systems with comprehensive obstetric care and robust maternal health programs. Notably, the decline in sub-Saharan Africa has been particularly slow, which may be attributed to persistent regional vulnerabilities [32]. In these regions, where education levels are low and economic opportunities for women are limited, pregnancies among adolescents are frequently associated with increased risks due to the physical immaturity of the

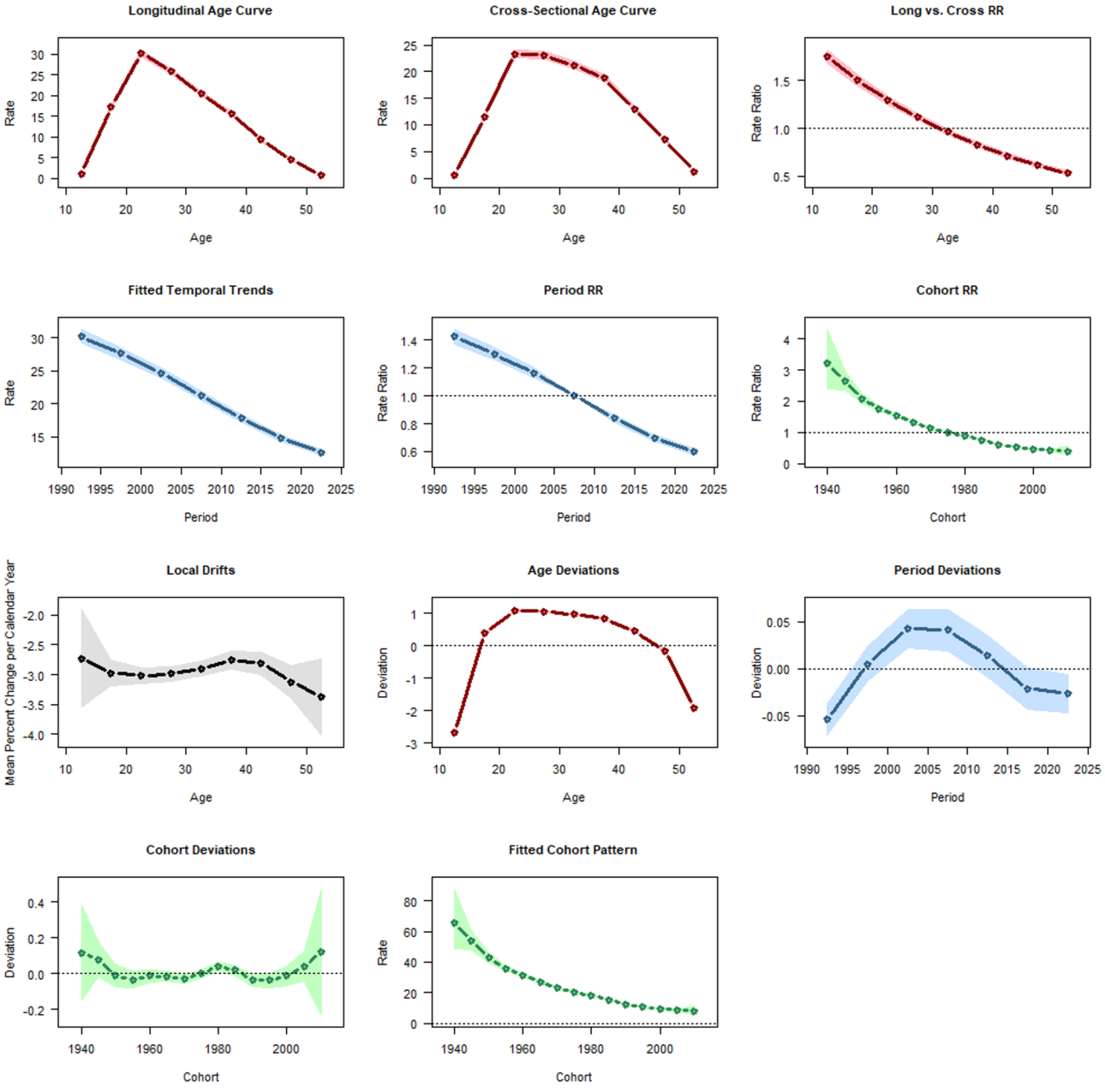

Fig. 8 Visualizing the Complexity of Global Maternal Mortality Through an Age-Period-Cohort (APC) Model

mother and inadequate prenatal care. Early marriage is prevalent, and adolescent women who become pregnant are often from low-income families and may be malnourished before conception. Malnutrition during pregnancy among these young women exacerbates the risks associated with maternal health [33]. To further reduce maternal mortality, in the regions of lower SDI, where resources are often limited, the focus should be on cost-effective and high-impact interventions. For example, scaling up midwife training programs and implementing emergency obstetric transfusion protocols can substantially reduce maternal mortality rates and enhancing the intensity and scope of women's education, and prioritizing reproductive health in development policies and funding, with a particular focus on safeguarding the rights and well-being of pregnant women, adolescents, and infants. Furthermore, this study also reveals that maternal mortality in High-income North America and the Caribbean has shown a slight upward trend, primarily driven by increases in maternal deaths caused by hypertensive disorders and obstructed labor/uterine rupture. Although high-income regions typically have abundant healthcare resources, disparities in access to high-quality maternal and child health services remain, particularly

for ethnic minorities and low-income groups. The higher prevalence of chronic conditions such as hypertension and diabetes among pregnant women in these groups further contributes to the increased maternal mortality risk [34]. For the regions with higher SDI, efforts should focus on narrowing disparities in education, income, and healthcare resource distribution within populations. Additionally, integrating new medical technologies, advancing personalized medicine, and expanding access to mental health services can address emerging healthcare challenges.

On the other hand, the primary causes of maternal mortality include obstetric hemorrhage, hypertensive disorders of pregnancy, and miscarriage. Although the mortality associated with these conditions has significantly decreased, they continue to account for approximately 63% of total maternal deaths globally. Maternal diseases, including those leading to death and disability-adjusted life years (DALYs), typically peak among women aged 20–24 years. However, in high-income countries and regions such as Central and Eastern Europe, Southeast Asia, and East Asia, the peak age for maternal mortality has shifted to 25–29 years or 30–34 years, reflecting the influence of reproductive patterns and healthcare accessibility on maternal health outcomes. Decomposition analysis of changes in maternal mortality reveals that aging has a more pronounced effect on deaths from maternal hemorrhage and hypertensive disorders compared to other causes, suggesting a shift in fertility patterns and structural demographic changes [35–37]. Furthermore, there are notable regional differences in the distribution of causes. In sub-Saharan Africa, obstetric hemorrhage remains the leading cause of maternal death, while high-income countries have significantly reduced these deaths through the implementation of effective healthcare measures. Across age groups, maternal abortion, miscarriage, maternal sepsis, and other infections are prevalent but generally result in lower mortality and DALYs. In contrast, maternal hemorrhage and hypertensive disorders are the leading causes of maternal deaths and DALYs among women of reproductive age. This finding aligns with previous reports, highlighting that maternal hemorrhage continues to be a major area of concern for global policy and economic restructuring in maternal health and safety [38]. In high-income regions, hypertensive disorders of pregnancy are more common, while low-income regions experience higher rates of maternal sepsis and other infections. These disparities reflect differences in healthcare access, medical resources, and maternal nutrition, highlighting the urgent need for increased investment in low-SDI regions. Such investments should prioritize infrastructure development, optimized resource allocation, and educational initiatives aimed at strengthening the healthcare workforce and ultimately improving maternal health outcomes.

However, several limitations of this study should be acknowledged. First, due to systemic and infrastructural deficiencies, the number of cases reported from less developed countries in the GBD study may be underestimated. These deficiencies include the absence of robust surveillance systems, a shortage of qualified healthcare professionals, and the lack of data from non-institutional deliveries. Such limitations may lead to underdiagnosis, misreporting of causes of death, missing records, and other related issues, thereby compromising the completeness and accuracy of the data [39, 40]. Furthermore, GBD estimates heavily rely on modeled data, which inherently involve assumptions related to data quality, healthcare access, and disease prevalence. These estimations may not fully reflect the actual disease burden in low-resource settings and may introduce systematic biases that affect the validity and reliability of our findings [41]. Therefore, these potential biases and their possible impacts on the results should be carefully considered when interpreting our study.

In conclusion, our study demonstrated a clear association between the SDI and the maternal disease burden. Maternal mortality and disability-adjusted life years (DALYs) are lower in high-SDI countries, with a significant decline in both as SDI increases. However, once SDI surpasses a threshold of approximately 0.70, further improvements in maternal health outcomes plateau. Policymakers should focus on bolstering investments in low-SDI regions, particularly in strengthening maternal health management systems, expanding prenatal care coverage, and enhancing risk management during delivery. Additionally, fostering regional cooperation, including technical support, training, and material donations from high-SDI regions, is crucial for improving maternal health security in low-SDI regions.

Conclusion

While significant progress has been made in improving global maternal health, regional and age-related disparities remain. We recommend that future strategies prioritize these differences, implementing targeted interventions, especially in low-SDI regions and high-risk age groups. Through regional cooperation and multifaceted support, it is possible to achieve a more balanced improvement in global maternal health outcomes.

Abbreviations

ASR	Age-Standardized Rates
ASMR	Age-Standardized Mortality Rate
ASDR	Age-Standardized DALYs Rate
CI	Confidence Interval
DALYs	Disability-Adjusted Life Years
EAPC	Estimated Annual Percentage Change
GBD	Global Burden of Disease

SDI Socio-Demographic Index
UI Uncertainty Interval

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions
Jie Huang and Yuanyuan Man designed and drafted the manuscript. Zan Shi and Xiaojie Fu contributed to data curation. Wenhao Shi and Xiaoling Liang conducted the investigation and data acquisition. Jie Huang and Xiaoling Liang verified the underlying data. All authors contributed to the article and approved the final submitted version.

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Data availability
Data is provided within the manuscript and supplementary information files, all data used in this study can be freely accessed at the Global Health Data Exchange GBD 2021 website (https://ghdx.healthdata.org/gbd-2021).

Declarations

Ethics approval and consent to participate
For the Global Burden of Disease (GBD) studies, the institutional review board approved a waiver of informed consent, as the study utilized publicly accessible data that contained no confidential or personally identifiable patient information.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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