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Global temporal trends in maternal hypertensive disorders incidence and mortality from 1990 to 2021 based on the global burden of disease study

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Maternal hypertensive disorders (MHD) remain a significant global health challenge. This study aims to provide a comprehensive analysis of the global burden of MHD from 1990 to 2021, focusing on incidence and mortality trends across different sociodemographic index (SDI) regions and age groups. We utilized Global Burden of Disease (GBD) study methodologies to analyze MHD incidence and mortality. Temporal trends were examined using Joinpoint regression to calculate annual percentage changes and average annual percentage changes with 95% confidence interval (CI). Age-period-cohort models were applied to analyze trends across different age groups, time periods, and birth cohorts, with particular attention to SDI regions. Globally, the age-standardized incidence rate (ASIR) of MHD decreased from 554.35 (95% Uncertainty Interval [UI]: 461.38t o 675.43) per 100,000 in 1990 to 461.94 (95% UI: 392.73 to 551.65) in 2021, with an average annual percent change (AAPC) of − 0.6% (95% CI: −0.67% to − 0.53%). The age-standardized death rate (ASDR) declined from 1.94 (95% UI: 1.71–2.15) per 100,000 in 1990 to 0.97 (95% UI: 0.81–1.18) in 2021 (AAPC − 2.18%; 95% CI: −2.3% to − 2.06%). Low SDI regions faced the highest burden. Age-period-cohort analyses revealed heterogeneous trends across age groups and SDI regions, with younger age groups (particularly ages 15–19 years) showing the most substantial improvements, demonstrated by the steepest declines in both incidence (-1.62% per year) and mortality rates (-2.57% per year). More recent birth cohorts demonstrated greater improvements, with declining risks of both incidence and mortality compared to earlier birth cohorts. Despite global reductions in MHD incidence and mortality over the past three decades, substantial disparities persist across regions and age groups. Targeted interventions, particularly in low SDI regions and among high-risk age groups, are crucial for further reducing the global burden of MHD.

Keywords Maternal hypertensive disorders, Global burden of disease, Joinpoint regression, Age-Period-Cohort analysis

Abbreviations

MHD	Maternal Hypertensive Disorders
SDI	Sociodemographic Index
GBD	Global Burden of Disease
ASIR	Age-Standardized Incidence Rate
UI	Uncertainty Interval
AAPC	Average Annual Percent Change
CI	Confidence Interval
ASDR	Age-Standardized Death Rate

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Maternal hypertensive disorders (MHD), including preeclampsia, eclampsia, and gestational hypertension, are among the most prevalent and severe complications during pregnancy, posing significant risks to maternal and neonatal health worldwide[1]. Affecting approximately 10% of pregnancies globally, MHD remains a leading cause of maternal morbidity and mortality, contributing substantially to the global burden of disease[2,3]. These disorders are closely associated with increased risks of cardiovascular diseases, stroke, and end-organ damage in mothers, while also contributing to adverse fetal outcomes including intrauterine growth restriction, preterm birth, and perinatal death[4–6]. Furthermore, women with a history of MHD face elevated long-term risks of chronic hypertension and cardiovascular complications[7]. Despite concerted global public health efforts over the past three decades, aimed at reducing maternal mortality, the incidence and mortality rates associated with MHD remain troublingly high, particularly in low- and middle-income countries[8].

A detailed analysis of global trends in MHD incidence and mortality, with specific attention to age, period, and birth cohort effects, is critical for identifying gaps in healthcare services and guiding future interventions[9,10]. While existing research often explores overall MHD trends, it frequently lacks the granularity necessary to assess how these factors influence observed patterns[2]. An in-depth examination of age, period, and cohort effects could offer key insights into identifying high-risk age groups, critical time periods, and vulnerable birth cohorts that require more focused attention and resource allocation.

This study aims to address this gap by leveraging data from the Global Burden of Disease (GBD) 2021 study to analyze global trends in MHD incidence and mortality between 1990 and 2021. The GBD 2021 study employs consistent methodologies to population-level data across 204 countries and territories, generating comprehensive global health metrics on MHD. By conducting a detailed age-period-cohort analysis over three decades, this research will provide a strong evidence base to support health policy development and clinical interventions aimed at reducing the global burden of MHD. The findings will highlight critical disparities and inform targeted strategies to improve maternal health outcomes on a global scale.

Methods

Data sources and study population

This study utilized data from the 2021 GBD study, which provides comprehensive and up-to-date estimates for 369 diseases and injuries across 204 countries and territories from 1990 to 2021[11]. The underlying data used in this study are publicly accessible through the Global Health Data Exchange (GHDx) web tool (https://ghdx.healthdata.org), which serves as the world's most comprehensive catalog of health-related data. The GBD study employs standardized tools within a Bayesian framework to synthesize available data across time, age, geography, and disease domains. This approach allows for "borrowing" information to generate estimates for regions with limited primary data. MHD are coded as 642–642.9 in ICD-9 and O10-O16.9 in ICD-10[12]. In this study, we extracted data related to the incidence and mortality of MHD for analysis. To account for differences in population structures over time and between countries, we used age-standardized rates for both incidence and mortality, applying the GBD world population age standard to ensure comparability across populations and time periods.

Socio-demographic index analysis

We categorized each country and territory into one of five Sociodemographic Index (SDI) quintiles based on their SDI values[13]. The SDI is a composite measure reflecting development status, incorporating income per capita, average educational attainment, and total fertility rate. In short, it is the geometric mean of 0 to 1 indices of total fertility rate for those younger than 25 years old, mean education for those 15 years old and older, and lag-distributed income per capita. The SDI ranges from 0 to 1, where 0 represents the lowest level of development and 1 represents the highest. This classification facilitated the analysis of trends in MHD incidence and mortality across varying levels of socioeconomic development. To investigate the relationship between SDI and disease burden indicators (ASIR and ASDR), we performed correlation analysis using Spearman's rank correlation coefficient (ρ). The correlation strength and statistical significance were calculated to quantify the association between these socioeconomic and epidemiological variables.

Joinpoint regression analysis

To identify statistically significant changes in the temporal trends of MHD incidence and mortality, we performed Joinpoint regression analysis using the Joinpoint Regression Program (Version 5.3.0, National Cancer Institute)[14]. This method fits a series of connected straight lines to the age-standardized rates on a logarithmic scale, allowing for the identification of points (joinpoints) where significant changes in the temporal trend occur. The analysis started with the minimum number of joinpoints (0 joinpoints, representing a straight line) and tested whether adding additional joinpoints (up to a maximum of 5) significantly improved model fit. We quantified the trends from 1990 to 2021 using the annual percent change and average annual percent change (AAPC) calculated from the optimal model. The annual percent change was computed using the formula: annual percent change = $(\exp(\beta) - 1) \times 100\%$, where β represents the regression coefficient of the log-linear model $\ln y = \beta^* x$. The AAPC was calculated as a weighted geometric average of the annual percent changes, with weights proportional to the length of each line segment, representing the overall trend from 1990 to 2021.

Age-period-cohort analysis

We employed an age-period-cohort model to disentangle the effects of age, period, and birth cohort on the trends in MHD incidence and mortality[15]. The age-period-cohort analysis was conducted using the National Cancer Institute's web-based tool (https://dceg.cancer.gov/tools/analysis/apc). The age-period-cohort analysis provides a comprehensive framework to separate the temporal trends into three distinct time-related components: age effects (reflecting biological and social processes of aging), period effects (reflecting population-wide exposures at specific time points), and cohort effects (reflecting unique exposures of birth cohorts). The age-period-cohort model outputs included the overall temporal trend, expressed as the annual percentage change (net drift); the annual percentage change within each age group (local drift); the longitudinal age-specific rates adjusted for period deviations (age effects); and the relative risks for each period and cohort (period and cohort effects). The analysis used 5-year age groups (15–19, 20–24, 45–49 years) and 5-year periods (1992–1996, 1997–2001, ., 2017–2021), with the initial age group (15–19 years) and the earliest period (1992–1996) serving as references. For the cohort effect analysis, we calculated rate ratios (RRs) to quantify the relative risk between different birth cohorts. The rate ratio represents the ratio of the disease rate in one birth cohort compared to a reference cohort, where a RR > 1 indicates a higher risk and a RR < 1 indicates a lower risk compared to the reference group. For example, a rate ratio of 1.5 means the risk in that birth cohort is 50% higher than in the reference cohort.

Statistical analysis

All analyses were conducted using R version 4.4.1. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. For the age-standardized incidence rate (ASIR) and age-standardized death rate (ASDR), we used the 95% uncertainty intervals (UIs) provided directly by the GBD 2021 study database. Uncertainty was estimated by predicting 1000 draws based on the variance-covariance matrix, and a random sample of the dispersion parameter from a gamma distribution[16]. These UIs were generated through 1,000 draws based on the variance-covariance matrix and random samples of the dispersion parameter from a gamma distribution. The bounds of the 95% UIs were determined by the 2.5th and 97.5th percentiles of these draws, with the point estimates representing the mean of all draws.

Results

Global level

Globally, the ASIR of MHD decreased from 554.35 per 100,000 (95%UI: 461.38 to 675.43) in 1990 to 461.94 per 100,000 (95% UI, 392.73 to 551.65) in 2021, with an AAPC of −0.6% (95% confidence interval [CI], −0.67% to −0.53%) (Table 1). The global ASDR of MHD showed a more pronounced decline, from 1.94 per 100,000 (95% UI, 1.71 to 2.15) in 1990 to 0.97 per 100,000 (95% UI, 0.81 to 1.18) in 2021, reflecting an AAPC of −2.18% (95% CI, −2.30% to −2.06%) (Table 1). Analysis across SDI quintiles revealed significant disparities in both incidence and mortality rates. In 2021, low SDI regions had the highest ASIR at 1202.32 per 100,000 (95% UI, 1025.84 to 1408.89) and ASDR at 3.38 per 100,000 (95% UI, 2.77 to 4.15), while high-middle SDI regions had the lowest ASIR at 207.21 per 100,000 (95% UI, 166.86 to 257.15) (Table 1). High SDI regions reported the lowest ASDR at 0.03 per 100,000 (95% UI, 0.02 to 0.03). The most notable reductions in ASIR were observed in low-middle SDI regions (AAPC − 1.72%; 95% CI, −1.93% to −1.52%), while high-middle SDI regions experienced the largest decrease in ASDR (AAPC: −5.48%; 95% CI, −5.95% to −5.02%) (Table 1). Despite these overall improvements, substantial disparities persisted, with low SDI regions continuing to experience ASIRs and ASDRs several times higher than those of high SDI regions by 2021.

Regional and national level

In 1990, Western Sub-Saharan Africa had the highest ASIR (2256.21 per 100,000), while East Asia had the lowest (171.41 per 100,000) (Fig. 1A, Supplementary Table S1). By 2021, Western Sub-Saharan Africa had the highest ASIR (1678.15 per 100,000), and East Asia maintained the lowest (108.74 per 100,000) (Fig. 1B, Supplementary Table S1). For ASDR, Central Sub-Saharan Africa had the highest rate in 1990 (10.17 per 100,000), while Western Europe and Australasia shared the lowest (0.04 per 100,000) (Fig. 1C, Supplementary Table S1). In 2021, Central Sub-Saharan Africa still had the highest ASDR (4.17 per 100,000), while High-income Asia Pacific, Central Europe, Western Europe, and Australasia shared the lowest rate (0.01 per 100,000) (Fig. 1D, Supplementary Table S1).

In 1990, the highest ASIR was observed in Somalia (2508.37 per 100,000), while the lowest was in Republic of Korea (37.75 per 100,000) (Fig. 1A, Supplementary Table S2). By 2021, South Sudan had the highest ASIR (2337.93 per 100,000), while Republic of Korea maintained the lowest (34.99 per 100,000) (Fig. 1B, Supplementary Table S2). Regarding ASDR, Rwanda had the highest rate in 1990 (22.36 per 100,000), while Montenegro had the lowest (0.01 per 100,000) (Fig. 1C, Supplementary Table S2). By 2021, South Sudan still showed the highest

Location	ASIR			ASDR		
	1990 ASIR	2021 ASIR	1990–2021 AAPC (95% CI)	1990 ASDR	2021 ASDR	1990–2021 AAPC (95% CI)
Global	554.35(461.38 to 675.43)	461.94(392.73 to 551.65)	−0.6 (−0.67 to −0.53)	1.94(1.71 to 2.15)	0.97(0.81 to 1.18)	−2.18 (−2.3 to −2.06)
High SDI	269.60(211.65 to 353.21)	250.31(208.38 to 304.89)	−0.25 (−0.42 to −0.07)	0.07(0.06 to 0.09)	0.03(0.02 to 0.03)	−3.12 (−3.52 to −2.72)
High-middle SDI	251.01(195.55 to 331.19)	207.21(166.86 to 257.15)	−0.6 (−0.66 to −0.55)	0.35(0.28 to 0.42)	0.06(0.05 to 0.08)	−5.48 (−5.95 to −5.02)
Middle SDI	422.36(348.93 to 524.25)	300.80(252.74 to 364.43)	−1.08 (−1.14 to −1.03)	1.13(1.00 to 1.27)	0.40(0.34 to 0.48)	−3.29 (−3.42 to −3.17)
Low-middle SDI	823.86(699.94 to 989.06)	487.24(411.49 to 575.58)	−1.72 (−1.93 to −1.52)	4.04(3.49 to 4.54)	1.37(1.10 to 1.71)	−3.43 (−3.61 to −3.24)
Low SDI	1792.92(1531.06 to 2095.17)	1202.32(1025.84 to 1408.89)	−1.28 (−1.32 to −1.25)	7.88(6.72 to 8.98)	3.38(2.77 to 4.15)	−2.67 (−2.8 to −2.53)

Table 1. Global and regional ASIR, ASDR, and AAPC of MHD (1990–2021). This table presents the ASIR and ASDR of MHD in 1990 and 2021, along with the AAPC over the 32-year period across global and regional settings classified by the SDI.

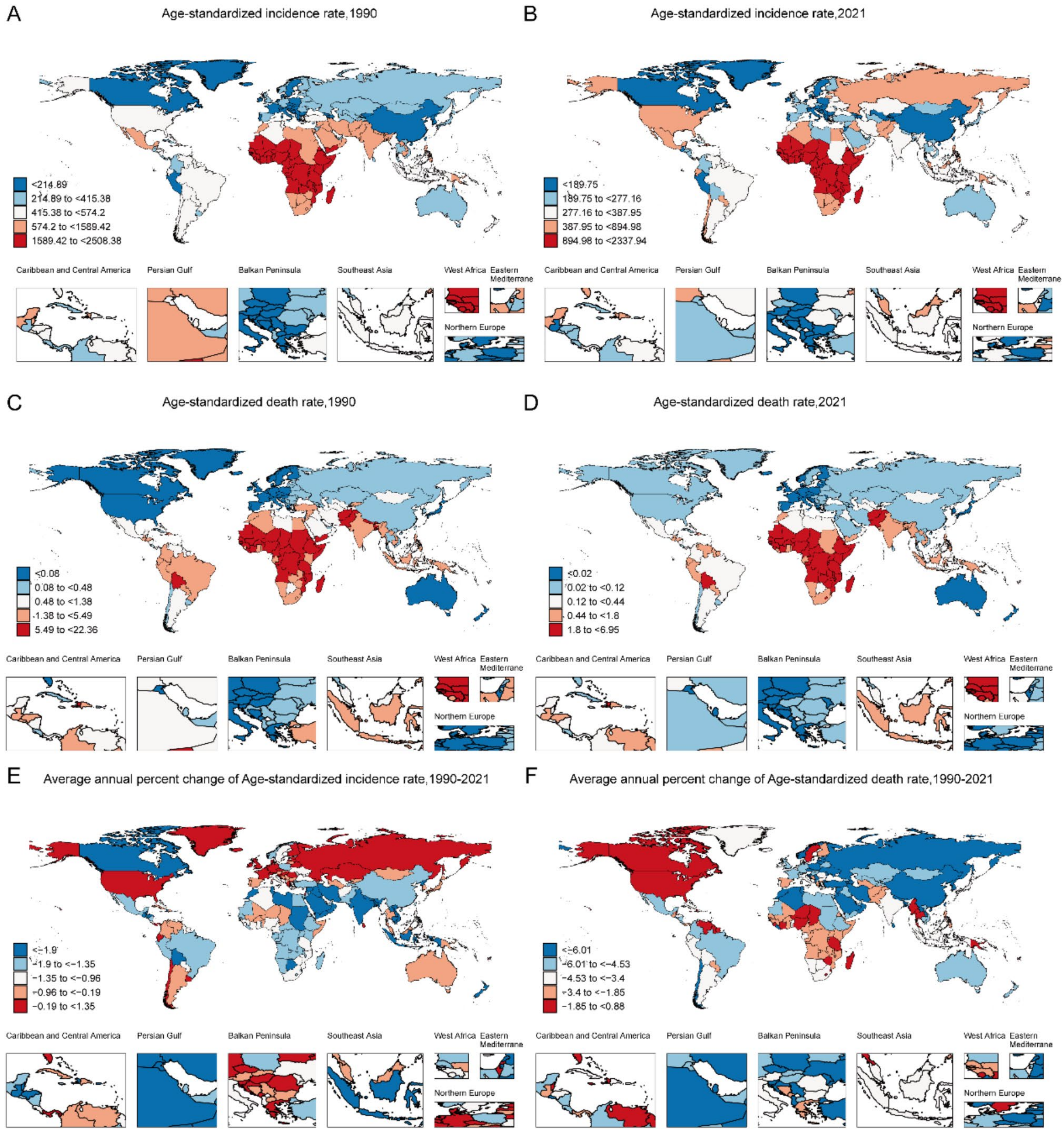

Fig. 1. Global ASIR, ASDR, and AAPC of MHD from 1990 to 2021. Panels **A** and **B** show the global ASIR in 1990 and 2021, respectively, while panels **C** and **D** present the global ASDR in the same years. Panels **E** and **F** illustrate the AAPC of ASIR and ASDR, respectively, for MHD over the study period (1990–2021). The map was generated using the R package maps (version 3.4.2.1; DOI: https://doi.org/10.32614/CRAN.package.maps). The geographical boundaries shown in this publication are for illustrative purposes only and do not represent any political stance on territorial claims. The map is based on publicly available geographical databases and is intended solely for the visualization of scientific data.

ASDR (6.95 per 100,000), while Slovenia showed the lowest rate (0.003 per 100,000) (Fig. 1D, Supplementary Table S2).

For ASIR, the country with the largest decrease in AAPC was Libya, with an AAPC of −3.67 (95% CI: −3.76 to −3.58) (Fig. 1E, Supplementary Table S2). The country with the largest increase in AAPC was Ecuador, with an AAPC of 1.35 (95% CI: 1.31 to 1.39) (Fig. 1E, Supplementary Table S2). For ASDR, the country with the largest decrease in AAPC was Jordan, with an AAPC of −10.86 (95% CI: −10.86 to −10.25) (Fig. 1F, Supplementary

Table S2). The country with the largest increase in AAPC was Guam, with an AAPC of 0.88 (95% CI: −0.62 to 2.41) (Fig. 1F, Supplementary Table S2).

Trends of MHD across different SDI regions and countries

Both the incidence and mortality rates of MHD displayed a clear gradient across SDI regions, with low SDI regions consistently experiencing the highest burden and high SDI regions the lowest (Fig. 2). Across all SDI regions, the decline in mortality was more pronounced than the decline in incidence. Although all regions demonstrated overall improvement, the rate and pattern of decline varied significantly, with low and low-middle SDI regions showing more substantial reductions, particularly in mortality rates (Fig. 2). Both ASIR and ASDR are age-standardized to facilitate comparisons across different countries (Fig. 3).

Local and net drift

Global incidence trends exhibited heterogeneity across age groups (Fig. 4A). The most significant decline occurred in the 15–19 age group (−1.62% per year; 95% CI, −1.88% to −1.35%), while slight increases were noted in the 30–34 and 35–39 age groups (0.05% and 0.06% per year, respectively) (Supplementary Table S3). High SDI countries experienced the most substantial reductions in incidence among younger age groups (15–19 years: −5.10% per year; 95% CI, −5.68% to −4.51%) but showed notable increases in elder age groups (35–39 years: 2.24% per year; 95% CI, 1.98–2.50%) (Supplementary Table S3). Low SDI countries exhibited consistent declines across all age groups, with the largest decrease in the 15–19 age group (−1.86% per year; 95% CI, −2.05% to −1.68%) (Supplementary Table S3). Middle SDI countries showed a mixed pattern, with declines in younger age groups and minimal changes in elder groups (Fig. 4A).

Global mortality rates decreased across all age groups, with the most substantial reductions observed in younger women (15–19 years: −2.57% per year; 95% CI, −2.78% to −2.35%) (Supplementary Table S4). High SDI countries showed the most significant reductions in mortality, particularly among younger age groups (15–19 years: −4.78% per year; 95% CI, −7.41% to −2.07%) (Supplementary Table S4). Low SDI countries also exhibited consistent declines in mortality across all age groups, with the largest decrease in the 15–19 age group (−2.99% per year; 95% CI, −3.14% to −2.84%) (Supplementary Table S4). Across all SDI levels, the magnitude of mortality reduction generally diminished with increasing age (Fig. 4B).

Age effect

Globally, the incidence of MHD followed a nonlinear pattern with age, peaking in the 25–29 age group before gradually declining (Fig. 4C, D and Supplementary Table S5). The shape and magnitude of age effect varied significantly across SDI regions, though the overall trend exhibited an inverted U-shape, with incidence rising to a peak and then tapering off (Fig. 4C). Mortality trends mirrored incidence trends, with an initial rise in mortality rates, peaking between ages 20 and 30, followed by a gradual decline (Fig. 4D and Supplementary Table S6). In higher SDI regions, the decline in mortality rates was particularly sharp for individuals aged 30 and above, while the peak was less pronounced compared to lower SDI regions (Fig. 4D and Supplementary Table S6).

Period effect

The period effect for MHD incidence displayed a mixed pattern across SDI regions (Fig. 4E, F). In High-middle and High SDI regions, incidence rates initially declined but then experienced an uptick in later periods (Fig. 4E). Conversely, other SDI regions showed a consistent decline in period-specific incidence rates throughout the study period (Fig. 4E). The reference period (1992–1996) was assigned a rate ratio of 1.0, and subsequent periods

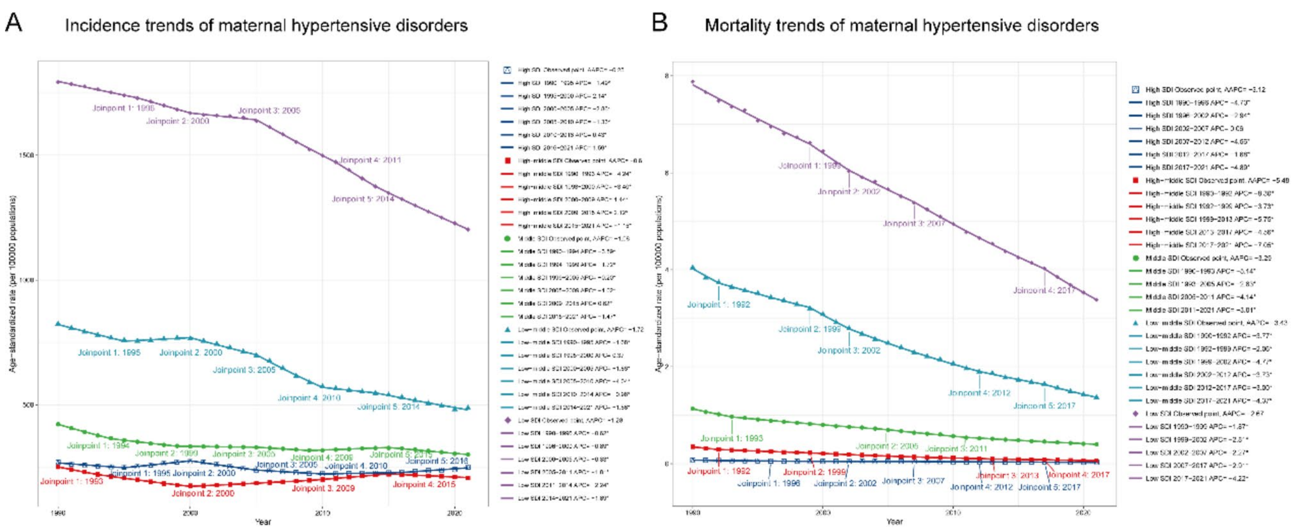

Fig. 2. Trends of MHD Across Different SDI Regions (1990–2021). Panel **A** shows the incidence trends of MHD, while panel **B** illustrates the mortality trends across various SDI regions between 1990 and 2021.

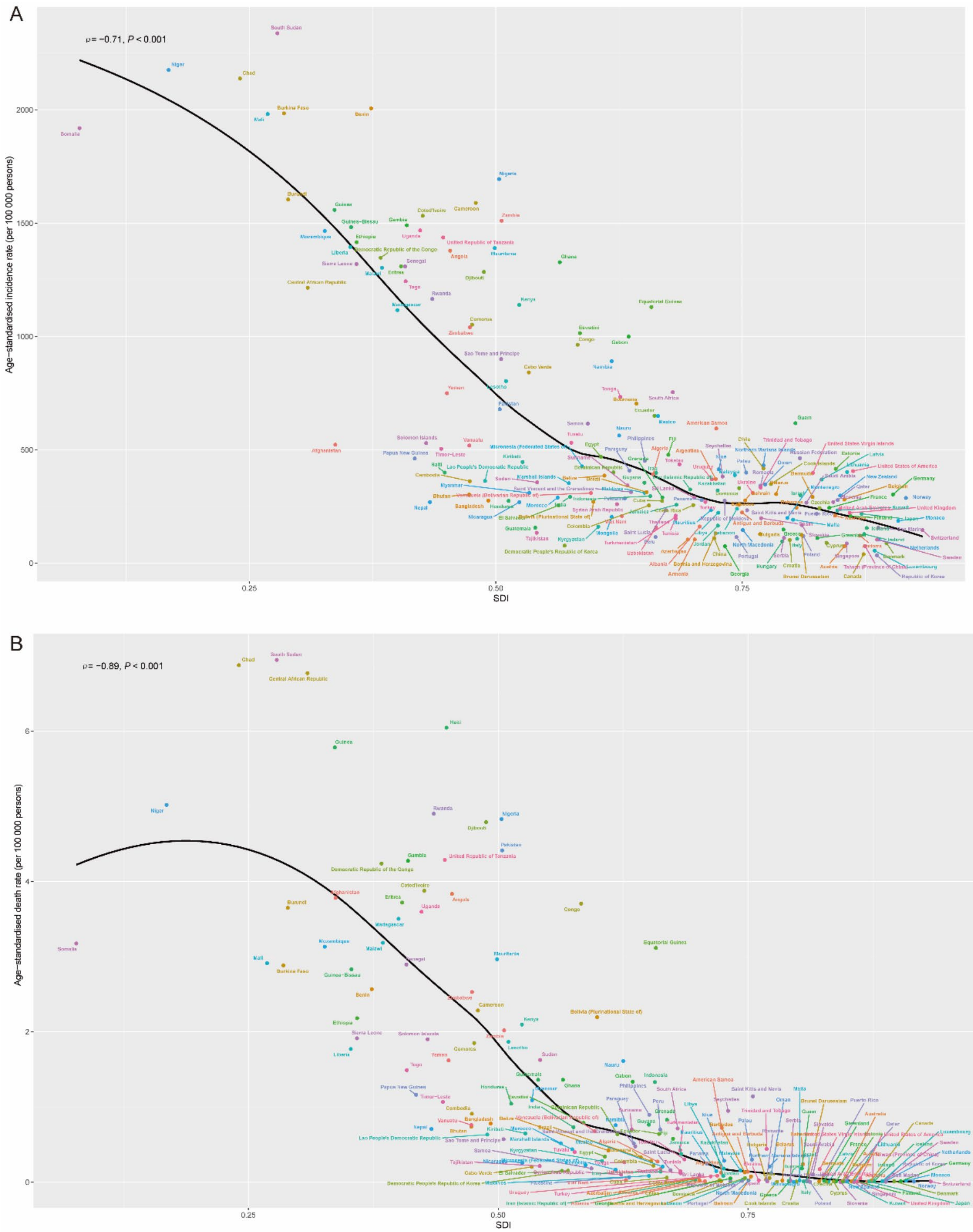

Fig. 3. Association between SDI and ASIR and ASDR of MHD at the National Level, 2021. Panel **A** shows the association between SDI and the ASIR of MHD, while Panel **B** depicts the association between SDI and the ASDR of MHD.

saw a gradual reduction in the risk of MHD incidence (Supplementary Table S7 and S8). Similarly, the period effect for MHD-related mortality indicated a substantial decline over time, reflecting significant improvements in maternal health outcomes across most SDI regions (Fig. 4F).

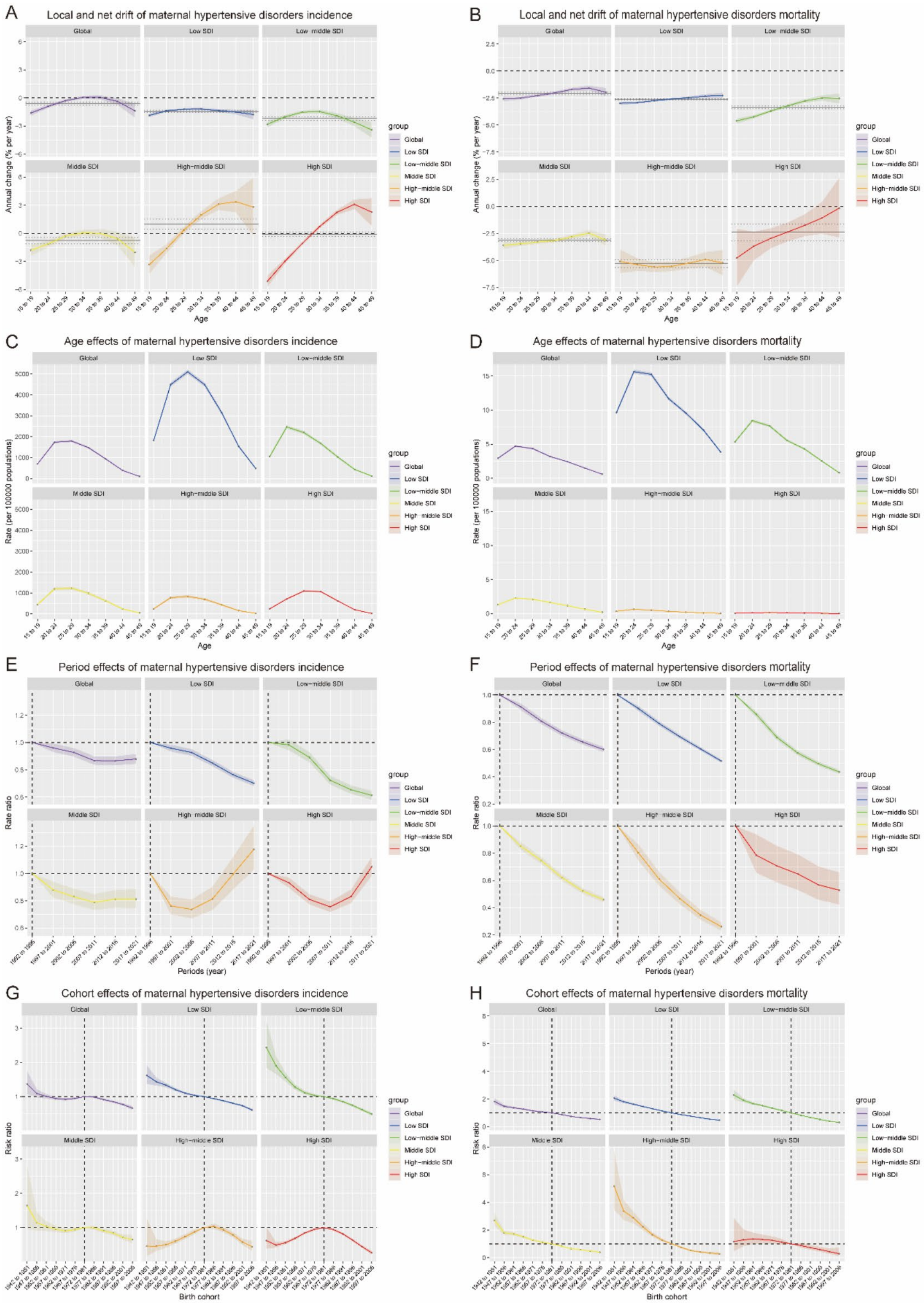

Fig. 4. Local drift and age–period–cohort effects on MHD incidence and mortality from 1992 to 2021. Panel**A** depicts the local drift of incidence, and panel **B** shows the mortality for MHD across different age groups globally. Shaded areas indicating 95% Cis of local drift. The horizontal solid line and its upper and lower dotted lines represent net drift and its upper and lower 95%Cis. Panel **C** shows the nonlinear pattern of MHD incidence by age. Panel **D** presents the mortality trends by age. Panel **E** shows the period-specific incidence rate ratios, and panel **F** presents the period-specific mortality rate ratios for MHD, demonstrating how risks evolved over time across different SDI regions. Panel **G** displays the cohort-specific incidence rate ratios, and panel **H** shows the cohort-specific mortality rate ratios for MHD across different SDI regions.

Cohort effect

In all regions except for High-middle SDI and High SDI regions, the cohort effect for MHD incidence showed a steady decline over time (Fig. 4G, H). The earliest cohort, born between 1942 and 1951, had the highest rate ratio of 1.37 (95% CI, 1.08 to 1.74), but subsequent birth cohorts exhibited a progressive decrease in MHD incidence risk (Supplementary Table S9). However, in High-middle and High SDI regions, the cohort-specific incidence rates initially increased before showing a decline in more recent cohorts (Fig. 4G).

Similarly, the cohort effect for MHD-related mortality demonstrated a clear decline across successive cohorts in all SDI regions (Fig. 4H and Supplementary Table S10). Although mortality consistently decreased across all regions, lower-SDI regions experienced higher mortality rates in earlier cohorts, underscoring disparities in healthcare access and outcomes. In contrast, higher-SDI regions showed a more rapid decline in cohort-specific mortality rates over time.

Discussion

This comprehensive analysis of global trends in MHD incidence and mortality over the past three decades reveals significant progress alongside persistent challenges. Our study found that the global ASIR of MHD decreased from 554.35 per 100,000 in 1990 to 461.94 per 100,000 in 2021, with an AAPC of −0.6%. Concurrently, the ASDR showed a more substantial decline, from 1.94 per 100,000 to 0.97 per 100,000, with an AAPC of −2.18%. These findings highlight a global trend of decreasing MHD burden, particularly in terms of mortality reduction, underscoring advancements in maternal healthcare over the study period.

The more pronounced decline in mortality compared to incidence suggests that while the occurrence of MHD remains considerable, improvements in clinical management, early detection, and access to maternal healthcare services have effectively reduced fatal outcomes. Advancements in obstetric care, the implementation of evidence-based guidelines, and the increased availability of antihypertensive therapies during pregnancy may have contributed to these positive trends[17,18]. In high-SDI regions like the United States, specific interventions have proven effective, as demonstrated by Ananth et al.[17], who documented substantial reductions in hypertension-related maternal mortality from 1979 to 2018 through standardized approaches including earlier detection, improved clinical guidelines, and widespread use of antihypertensive medications like methyldopa, labetalol, and nifedipine. Webster et al.[18] provided robust evidence through meta-analysis that timely antihypertensive treatment for pregnant women with chronic hypertension significantly reduces the risk of severe hypertension and improves perinatal outcomes.

However, despite these overall improvements, substantial disparities persist across different SDI regions. Low SDI regions continue to bear a disproportionately higher burden of MHD, with ASIRs and ASDRs several times higher than those in high SDI regions. For instance, in 2021, low SDI regions reported an ASIR of 1202.32 per 100,000 and an ASDR of 3.38 per 100,000, whereas high SDI regions had an ASDR as low as 0.03 per 100,000. Previous studies have similarly observed that MHD is more prevalent among women from lower-income families and areas with higher poverty levels[19,20]. Women from lower socioeconomic status backgrounds face multiple barriers to accessing quality maternal healthcare, including financial constraints, limited healthcare infrastructure, and lower health literacy. These challenges contribute to delayed diagnosis, inadequate management of hypertensive disorders, and higher rates of severe maternal complications. Studies have shown that women in low-income households are less likely to receive timely antenatal care or have access to essential medications such as magnesium sulfate and antihypertensive drugs, leading to worse outcomes[21–23]. These disparities underscore the uneven progress in maternal health outcomes globally, highlighting the urgent need for targeted interventions in regions with the highest burden.

Our age-period-cohort model revealed important patterns in MHD incidence and mortality. The most substantial global decline in incidence was observed in the 15–19 age group, with a decrease of −1.62% per year, likely reflecting improved health education, increased access to contraception, and enhanced antenatal care targeting younger women. In contrast, a slight increase in incidence was noted among elder age groups (30–34 and 35–39 years), indicating that women of advanced maternal age remain at higher risk for MHD. Notably, we observed an increasing trend in the incidence of MHD among pregnant women over 30 years of age in middle and high SDI regions. This trend may be attributed to delayed childbearing in these regions, which results in a higher proportion of elder pregnant women—an important risk factor for gestational hypertension[24,25]. Addressing this issue will require greater emphasis on prenatal screening and monitoring in these regions, particularly among elder expectant mothers.

Cohort-specific trends showed a declining risk of MHD incidence and mortality over successive birth cohorts, except in high-middle and high SDI regions, where incidence rates first increased before eventually declining. This pattern may be influenced by changes in reproductive behaviors, such as delayed childbearing, along with shifts in dietary and exercise habits, and the rising prevalence of chronic conditions such as hypertension and obesity[26–30]. These variations in age, period, and cohort effects underscore the need for tailored public health interventions that address the unique risks faced by different age groups and birth cohorts.

Strengths and limitations

A major strength of this study lies in the use of comprehensive, large-scale data from the GBD 2021 study, which spans 204 countries and territories over a 31-year period. This extensive dataset enables robust global and regional estimates of MHD incidence and mortality, offering valuable insights into long-term trends. The inclusion of SDI, age, period, and cohort analyses adds depth to the study by providing a nuanced understanding of how various factors influence the global MHD burden. By examining age-specific and cohort-specific trends across SDI regions, our study identifies critical areas where interventions can be most effective. These findings contribute to the global understanding of MHD and offer guidance to policymakers and healthcare providers in designing targeted strategies to reduce MHD incidence and mortality. The comprehensive nature of the analysis ensures that the results are relevant to global health initiatives aimed at improving maternal health outcomes and achieving the Sustainable Development Goals related to maternal mortality reduction.

Despite these strengths, several limitations must be acknowledged. First, the reliance on secondary data from the GBD study introduces potential biases due to inaccuracies in data collection, particularly in low-resource settings where underreporting and misclassification of MHD cases are more likely. The quality and completeness of data vary significantly between countries and regions, potentially affecting the precision of our estimates. Second, our analysis may be constrained by the inability to adjust for all potential confounders, such as variations in healthcare policies, cultural practices, and socioeconomic factors that influence maternal health outcomes across countries and regions. Additionally, although the study spans a substantial temporal scope from 1990 to 2021, more recent data beyond 2021 may reveal emerging trends not captured in this analysis, especially considering the potential impacts of global events like the COVID-19 pandemic on maternal health. Lastly, the ecological nature of this study limits the ability to establish causal relationships between observed trends and specific interventions or policies. Future research incorporating individual-level data and more granular indicators could provide deeper insights into the factors driving MHD trends.

Future directions

Given these limitations, future research should address the gaps identified in this study. There is a pressing need for more detailed, region-specific studies in low SDI countries to identify the underlying causes of persistently high MHD incidence and mortality. Such research could explore factors such as healthcare access, quality of care, nutritional status, and socio-cultural practices affecting maternal health. Longitudinal studies examining the impact of specific healthcare interventions and policies in both high- and low-SDI regions would offer valuable insights into effective strategies for reducing the MHD burden. Additionally, further investigation into the rising incidence of MHD among elder pregnant women is warranted. Understanding the risk factors and health needs of this demographic could inform targeted interventions to mitigate the increasing trend in MHD incidence among elder age groups. Moreover, future studies should examine the potential effects of recent global events, such as the COVID-19 pandemic, on maternal health outcomes. Understanding these impacts will be crucial for developing resilient healthcare systems that can sustain maternal health services during crises.

Conclusion

In conclusion, this study demonstrates significant global reductions in the incidence and mortality of MHD from 1990 to 2021. However, substantial disparities persist across regions and age groups, with low SDI regions and elder pregnant women experiencing a disproportionately higher burden. These findings underscore the urgent need for targeted public health interventions and resource allocation to low-resource settings to address inequities in maternal health outcomes. The insights provided by this comprehensive analysis contribute to the global understanding of MHD and highlight critical areas where intensified efforts are necessary to further reduce the global burden of this condition. By informing policymakers, healthcare providers, and international health organizations, our study supports the development of effective strategies and policies aimed at improving maternal health and achieving global health equity.

Data availability

The data used in this study were obtained from the GBD 2021 study, which is publicly available through the Institute for Health Metrics and Evaluation (IHME) database. Further information on how to access this data can be found at https://ghdx.healthdata.org/gbd-2021.

Received: 2 December 2024; Accepted: 10 March 2025
Published online: 16 March 2025

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Acknowledgements
The authors would like to express their gratitude to the Institute for Health Metrics and Evaluation (IHME) for providing access to the Global Burden of Disease 2021 study data, which made this research possible. We also thank all the individuals and organizations involved in data collection and curation.

Author contributions
W.K: Conceptualization, Data Curation, Supervision, Writing-review & editing; X.Z: Data Curation, Writing-original draft preparation, Writing-review & editing, Visualization, Software.

Funding
This study did not receive any specific funding. No external funding sources were used for the preparation of this manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Ethics
This study used publicly available, de-identified data from the GBD 2021 study. As such, it was exempt from ethics review as per the guidelines of the University of Washington Institutional Review Board.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-93673-3.

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