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Trends in global and regional incidence and prevalence of hypertensive disordersin pregnancy (1990–2021): an age-period-cohort analysis

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Hypertensive disorders of pregnancy (HDP) are significant global health issues. This study utilized data from the Global Burden of Disease Study 2021 to analyze trends in incidence, prevalence, and Disability-Adjusted Life Years (DALY) associated with HDP across 204 countries from 1990 to 2021. The analysis employed estimated annual percentage changes and an age-period-cohort model, stratifying data by age, year, geographical region, and sociodemographic index (SDI). Statistical analyses and visualizations were conducted using R. Between 1990 and 2021, global HDP incidence rose from 31.33 million to 36.10 million cases (15.24%), while prevalence surged from 6.15 million to 36.10 million cases (487%). Despite the increase in absolute cases, the age-standardized rates for incidence and prevalence exhibited only modest changes, with incidence up by 15.23% and prevalence slightly declining. Regions with high and high-middle SDI showed decreasing trends, whereas middle, low-middle, and low SDI regions faced rising trends. DALYs linked to HDP decreased from 6.96 million in 1990 to 4.94 million in 2021, with significant reductions in high SDI areas. Projections indicate a continued decrease in the global burden of HDP by 2040. The study concludes that continued efforts in prenatal care and health education are vital, particularly in low SDI regions, to mitigate the impact of HDP.

Keywords Burden of disease, Hypertensive disorders of pregnancy, Sociodemographic index

Hypertensive disorders during pregnancy (HDP), which encompass gestational hypertension, chronic hypertension, and preeclampsia, represent significant health risks for both mothers and infants[1]. Current estimates suggest that approximately 10–22% of pregnant women are affected by these conditions, with prevalence expected to rise due to increasing maternal age and the growing incidence of risk factors such as obesity and metabolic syndrome[2]. The complexity of managing HDP is underscored by its associations with cardiovascular diseases, hemolytic anemia, elevated liver enzymes, and low platelet count syndrome. These disorders are notably linked to maternal mortality, particularly in developing countries, and can lead to severe complications, including heart disease and adverse fetal outcomes like low birth weight and intrauterine growth restriction[3]. Despite the growing acknowledgment of HDP's significance in risk assessment and prevention, understanding its epidemiology remains limited, especially in less developed nations. This gap in knowledge can hinder effective prevention strategies and the formulation of maternal healthcare policies. Given that HDP is among the top three causes of maternal complications and fatalities globally[4], there is an urgent need for comprehensive research in this area. While various studies have focused on HDP, they often lack broad, comparative data across different countries.

The global burden of diseases (GBD), injuries, and risk factors study, initiated in the early 1990s, provides vital estimates on the global impact of diseases and injuries on population health, assisting in the assessment

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of progress towards international health objectives. The latest iteration, GBD 2021, emphasizes health threats that require prioritization on public health agendas. It delivers up-to-date insights into health disparities across populations by offering estimates for 371 conditions (including 95 communicable, maternal, neonatal, and nutritional diseases; 234 non-communicable diseases; and 40 injuries) across 204 countries and territories, as well as 21 countries at subnational levels. The data spans 25 age groups and covers both sexes, allowing for analysis from 1990 to 2021. This comprehensive approach enables the identification of health gains and potential policies or interventions that could effectively address these health challenges[5].

The primary objective of this manuscript is to identify the epidemiological features of gestational hypertension using a population-based cohort. This study will provide modeled prevalence and incidence rates at global, regional, and national levels, alongside mortality rates related to HDP, as reported in the GBD, Injuries, and Risk Factors Study, 2021. Furthermore, this research explores the connections between epidemiological data and socioeconomic factors, including the sociodemographic index (SDI) and human development index (HDI), aiming to deliver comprehensive and comparable insights on the burden of HDP.

Materials and methods

In the current study, we extracted and analyzed annual data (inclusive dates: 1990 to 2021) on prevalence, incidence, and DALYs and the corresponding age-standardized rates (ASRs), as well as risk factors attributable to HDPs from the Global Health Data Exchange (GHDx) database. Detailed methodology of GBD 2021 including data collection, modelling, and estimation process has been published elsewhere[5–7]. Briefly, the GBD utilized 100,983 data sources to estimate the global burden of HDP. It employed a variety of data inputs, including literature, claims data, and hospital records. A detailed list of these data sources, abbreviations, and additional information can be found in the GBD 2021 Methods Appendix (https://www.healthdata.org/gbd/methods-appendices-2021).

The modeling framework and a detailed flowchart (including the specific code used for estimating hypertensive disorders in pregnancy in the GBD study) are available at (https://www.healthdata.org/gbd/methods-appendices-2021). The modeling process involved the following steps: (1) assembling data sources through identification and extraction; (2) adjusting the data; and (3) estimating incidence, prevalence, and DALYs using DisMod-MR 2.1.

To describe the global burden of HDP, we used publicly available data from https://vizhub.healthdata.org/gbd-results/. We collected data on incident cases, incidence rates, ASR, prevalent cases, prevalence rates, age-standardized prevalence rates, DALYs counts, DAYLs rates, and age-standardized DALYs rates for HDP across 204 countries or territories and five socio-demographic index (SDI) quintiles from 1990 to 2021. The age range was 10 to 69 years, and results were reported with 95% uncertainty intervals (UIs). The 95% UI represents the 2.5th and 97.5th percentiles of the distribution from 1,000 draws at each modeling stage. All countries were categorized into five SDI quintiles (high, high-middle, middle, low-middle, and low) based on their 2021 SDI values. SDI, ranging from 0 to 1, is an index that estimates a country's socio-economic status based on per capita income, average educational attainment, and fertility rates among women under 25. A higher SDI indicates a higher socio-economic level[8].

This study employed an Age-Period-Cohort (APC) model to analyze trends in the incidence, prevalence, and DALYs of HDP across different age groups, periods, and birth cohorts[9]. The APC model effectively separates the effects of age, period, and cohort, which is crucial for studying health trend variations across different age groups and cohorts over time. This model allows us to capture long-term trend changes in HDP more accurately and identify the independent effects of various factors on HDP incidence and prevalence, providing valuable insights for policymaking and health interventions. The age effect refers to changes in disease patterns with age, which is one of the most significant determinants of disease. The period effect reflects changes in the social, cultural, economic, or physical environment over time, affecting all age groups simultaneously. The cohort effect is defined as changes in the characteristics of groups born in the same year[10].

The APC model can be represented as follows:

$Y = \log(M) = \mu + \alpha(\mathrm{age})_i + \beta(\mathrm{period})_j + \gamma(\mathrm{cohort})_k + \varepsilon.$

In this equation, M represents the incidence rate, prevalence rate, or DALYs rate of gestational hypertension. The parameters μ and ε correspond to the intercept and random error, respectively. The terms $\alpha(\mathrm{age})_i$, $\beta(\mathrm{period})_j$ and $\gamma(\mathrm{cohort})_k$ capture the effects of the age group α, period β, and birth cohort γ, respectively.

Incidence, prevalence, and DALY rate estimates for hypertensive disorders of pregnancy, as well as population data from various regions and countries, were used as inputs for the APC model, based on GBD 2021 data. For the APC analysis, data were organized into consecutive age groups with 5-year intervals, ranging from 10 to 14 years to 65–69 years. The time periods were arranged in 5-year intervals from 1990 to 1994 (median year 1992) to 2015–2021 (median year 2018), with 2000–2004 as the reference period. Additionally, 17 partially overlapping decadal birth cohorts were arranged, ranging from 1921 to 1929 (1925 cohort) to 2001–2009 (2005 cohort), with the 1961–1969 cohort (1965 cohort) as the reference.

The longitudinal age curve illustrates the age-specific incidence rates adjusted for period deviations relative to the reference cohort. Relative risks (RRs) for periods and cohorts were calculated by comparing age-specific incidence rates for each period and cohort with the reference group. Two key parameters in the APC model are net drift and local drift. Net drift refers to the overall average annual percentage change in the expected age-adjusted rates over time, based on period and birth cohort trends. Local drift represents the annual percentage change in expected age-specific rates over time for each age group, based on period and cohort trends[11]. An annual drift value greater than 0.0% indicates an increasing trend, while a value below 0.0% suggests a decreasing trend in the annual percentage change. The significance of annual percentage change trends was tested using the Wald chi-square test. Two-sided statistical tests were conducted, with a p-value < 0.05 considered significant. All data analysis and visualization were performed using R (version 4.3.2) with "tmap", "Rcan", "ggplot2" and other related packages.

Results

The Global and Regional Burden of Hypertensive disorder of pregnancy (HDP)

The burden of gestational hypertension across global and regional levels over the past 31 years is summarized in Table 1, with a focus on incident cases, ASR for incidence, prevalent cases, ASR for prevalence, number of DALYs, ASR for DALYs, and the net drift values.

Over the past 31 years, the global incidence of hypertension disorders increased from 31.33 million cases in 1990 to 36.10 million in 2021, reflecting a 15.24% growth. The ASR for incidence rose from 15662.9 per 100,000 people in 1990 to 18050.1 per 100,000 people in 2021, representing a 15.23% increase. Despite this rise, the net drift for incidence was slightly negative at -0.755% per year (95% CI: -0.995 to -0.514), suggesting a gradual reduction in the rate of increase over time. The ASR for incidence in 2021 varied significantly across different regions, ranging from 1235.2 per 100,000 people (95% UI: 908.1 to 1647.6) in the high SDI region to 6749.9 per 100,000 people (95% UI: 5019.8 to 8631.0) in the low SDI region. Among the five SDI regions, high SDI and high-middle SDI regions showed a declining trend in incidence rates from 1990 to 2021, with the most significant reduction observed in the high-middle SDI region, where the net drift was − 0.444% per year (95% CI: -0.904 to -0.017). Conversely, middle SDI, low-middle SDI, and low SDI regions exhibited an upward trend in incidence rates over the same period, with the highest growth occurring in the low-middle SDI region, which had a net drift of 0.790% per year (95% CI: -0.165 to 1.756).

The prevalence of gestational hypertension also saw a substantial increase, rising from 6.15 million cases in 1990 to 36.10 million in 2021, a growth of 487%. Despite this increase in cases, the global ASR for prevalence

	Cases in 1990	ASR in 1990 (per 100,000 people)	Cases in 2021	ASR in 2021 (per 100,000 people)	Net Drift (% per year)
Incidence					
Global	31,325,790 (24070324–40545899)	15662.895 (11135.179-21291.386)	36,100,170 (28700057–44966614)	18050.085 (13343.933-23447.410)	-0.755 (-0.995–0.514)
High SDI	2,467,043 (1793085–3403786)	1233.521 (826.434-1791.643)	2,470,487 (1931535–3160852)	1235.243 (908.131-1647.637)	-0.444 (-0.904–0.017)
High middle SDI	2,977,036 (2112029–4152631)	1488.518 (962.713-2185.597)	2,498,758 (1889673–3290296)	1249.379 (880.839-1728.081)	0.790 (-0.165–1.756)
Middle SDI	8,113,937 (6110217–10754640)	4056.968 (2806.287-5656.632)	7,402,512 (5820573–9391100)	3701.256 (2710.245-4922.622)	-0.988 (-1.457–0.517)
Low-middle SDI	9,468,662 (7344822–12143351)	4734.331 (3371.275-6380.932)	10,206,007 (8051021–12709538)	5103.003 (3759.230-6654.435)	-2.294 (-2.585–2.001)
Low SDI	8,278,607 (6541749–10198700)	4139.303 (3054.406-5331.557)	13,499,763 (10747460–16586531)	6749.881 (5019.837-8631.008)	-1.486 (-1.653–1.318)
Prevalence					
Global	6,153,384 (3678841–9491168)	3076.691 (1681.212-5010.092)	36,100,170 (28700057–44966614)	3520.624 (2028.597-5486.380)	-0.865 (-1.196–0.534)
High SDI	523,372 (304849–831235)	261.686 (137.835-439.448)	2,470,487 (1931535–3160852)	259.629 (152.157-408.089)	-0.491 (-1.134–0.155)
High middle SDI	656,973 (377722–1062130)	328.486 (170.871–562.310)	2,498,758 (1889673–3290296)	281.971 (161.004-447.605)	0.774 (-0.363–1.926)
Middle SDI	1,634,651 (965440–2549221)	817.325 (438.824-1347.748)	7,402,512 (5820573–9391100)	734.683 (419.125-1165.815)	-1.102 (-1.718–0.481)
Low-middle SDI	1,723,432 (1021582–2686102)	861,716 (466536–1418384)	10,206,007 (8051021–12709538)	939.108 (534.073-1485.859)	-2.461 (-2.856–2.063)
Low SDI	1,610,702 (986947–2422747)	805.351 (457.779-1251.247)	13,499,763 (10747460–16586531)	1,302,927 (747316–2017062)	-1.578 (-1.769–1.386)
DALYs					
Global	6,959,769 (6116571–7823502)	3479.884 (3030.689–3950.300)	4,939,272 (4132885–5945774)	2469.636 (2049.487-2987.561)	-2.024 (-2.151–1.897)
High SDI	66,500 (51123–87953)	33.250 (25.027–45.101)	40,982 (27937–59613)	20.491 (13.677–30.357)	-1.503 (-1.875–1.130)
High middle SDI	278,605 (221832–340631)	139.302 (109.405-171.641)	69,768 (53205–92363)	34.884 (26.020-47.481)	-4.023 (-4.283–3.761)
Middle SDI	1,381,533 (1197862–1583075)	690.766 (590.254-802.827)	659,172 (558532–791393)	329.586 (275.621-399.863)	-2.986 (-3.166–2.806)
Low-middle SDI	2,960,456 (2537687–3356850)	1480.228 (1248.709-1713.351)	1,776,007 (1426689–2216685)	888.003 (709.194-1115.120)	-3.307 (-3.448–3.166)
Low SDI	2,268,356 (1911389–2606283)	1134.178 (950.586-1316.869)	2,389,269 (1950957–2926867)	1194.634 (967.218-1472.116)	-2.539 (-2.625–2.454)

Table 1. Global and Socio-Demographic Index (SDI) Quintile trends in Hypertensive disorders of pregnancy (HDP), 1990 and 2021. Parenthesis for all GBD health estimates indicates 95% uncertainty intervals; parenthesis for net drift indicates 95% confidence intervals.

increased slightly from 3076.7 per 100,000 people in 1990 to 3520.6 per 100,000 people in 2021, with a net drift of -0.865% per year (95% CI: -1.196 to -0.534). The ASR for prevalence in 2021 ranged from 2596.3 per 100,000 people (95% UI: 1521.6 to 4080.9) in the high SDI region to 13029.3 per 100,000 people (95% UI: 7473.2 to 20170.6) in the low SDI region. Like incidence trends, high SDI and high-middle SDI regions experienced decreases in prevalence rates, with the most significant reduction in the high-middle SDI region, where the net drift was – 1.102% per year (95% CI: -1.718 to -0.481). On the other hand, middle SDI, low-middle SDI, and low SDI regions displayed upward trends in prevalence, with the highest increase occurring in the low-middle SDI region, which had a net drift of -2.461% per year (95% CI: -2.856 to -2.063).

In terms of DALYs due to gestational hypertension, there was a notable reduction over the past 31 years, with the number of DALYs decreasing from 6.96 million in 1990 to 4.94 million in 2021. The global ASR for DALYs dropped from 3479.9 per 100,000 people in 1990 to 2469.6 per 100,000 people in 2021, with a net drift of -2.024% per year (95% CI: -2.151 to -1.897). The ASR for DALYs in 2021 ranged from 2049.1 per 100,000 people (95% UI: 1367.7 to 3035.7) in the high SDI region to 11946.3 per 100,000 people (95% UI: 9672.2 to 14721.2) in the low SDI region. The high-middle SDI region experienced the most significant reduction in DALYs rates, with a net drift of -4.023% per year (95% CI: -4.283 to -3.761), while the low-middle SDI region showed the highest increase in DALYs rates, with a net drift of -3.307% per year (95% CI: -3.448 to -3.166).

These findings underscore significant global and regional disparities in the burden of gestational hypertension. While high SDI regions have made strides in reducing incidence, prevalence, and DALYs, lower SDI regions, particularly low-middle SDI and low SDI regions, continue to face increasing challenges. This highlights the need for targeted public health interventions and resource allocation to address the growing burden of gestational hypertension in low SDI regions.

The burden of HDP at national level

The ASR for prevalence varied substantially by country in 2021, ranging from 1.65 to 241.12 per 100,000 women. South Sudan (241.12 [95% UI: 160.13 to 345.68] per 100,000 women), Niger (234.84 [95% UI: 157.03 to 342.07] per 100,000 women), and Chad (220.7 [95% UI: 144.22 to 316.16] per 100,000 women) had the highest ASR for prevalence. In contrast, the Republic of Korea (1.65 [95% UI: 0.96 to 2.76] per 100,000 women), Guatemala (2.41 [95% UI: 2.17 to 2.65] per 100,000 women), and Canada (3.00 [95% UI: 1.54 to 5.20] per 100,000 women) showed the lowest ASR. Of the 204 countries and territories, 29 showed an increasing trend (net drift > 0.0% per year) in prevalence rate. Ecuador (net drift: 1.488% [95% CI: -0.675 to 3.689] per year), Kazakhstan (net drift: 0.994% [95% CI: -1.893 to 3.990] per year), and Slovenia (net drift: 0.968% [95% CI: -2.035 to 4.138] per year) exhibited the largest increasing trend. Guatemala (net drift: -5.721% [95% CI: -7.457 to -3.966] per year), Canada (net drift: -4.526% [95% CI: -7.595 to -1.493] per year), and Maldives (net drift: -3.972% [95% CI: -6.799 to -1.007] per year) had the most significant decrease in net drift. (Fig. 1A,B, supplementary Table S1, Table S2).

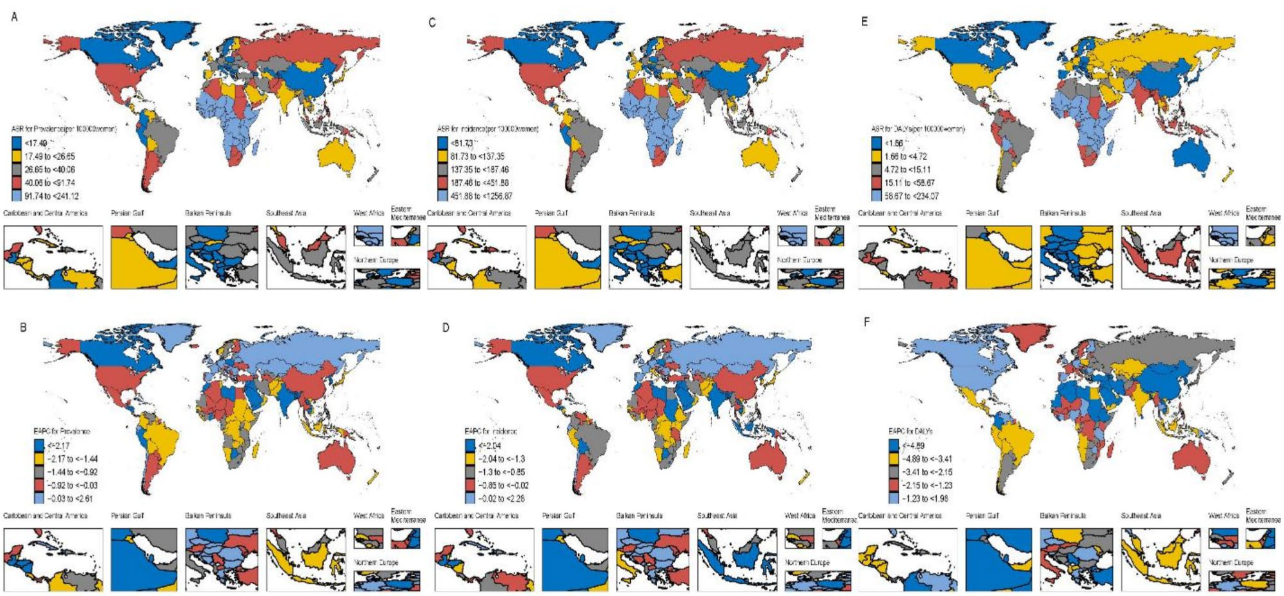

Fig. 1. Age-Standardized Rates (ASR) and Estimated Annual Percentage Change (EAPC) of hypertensive disorder during pregnancy (HDP) in 204 countries and territories between 1990 and 2021. (**A**) Presents the ASR for Prevalence (per 100,000 women), showing a color-coded map of prevalence rates. (**B**) Depicts the EAPC for Prevalence, illustrating annual percentage changes. (**C**) Shows the ASR for Incidence (per 100,000 women), while (**D**) presents the EAPC for Incidence, highlighting changes in incidence over time. (**E**) Provides the ASR for Disability-Adjusted Life Years (DALYs) (per 100,000 women), and (**F**) illustrates the EAPC for DALYs, showing the annual percentage changes in DALY rates. The figure was generated using R software (version 4.3.2) with “tmap” package.

Among 204 countries and territories, 2021 the ASR for incidence ranged from 16.46 to 1256.87 per 100,000 women. South Sudan (1256.87 [95% UI: 1082.71 to 1440.21] per 100,000 women), Chad (1130.1 [95% UI: 942.97 to 1343.14] per 100,000 women), and Niger (1111.53 [95% UI: 901.18 to 1327.24] per 100,000 women) had the highest ASR for incidence, while the Republic of Korea (16.46 [95% UI: 13.3 to 19.96] per 100,000 women), Canada (19.5 [95% UI: 14.42 to 26.18] per 100,000 women), and Luxembourg (27.19 [95% UI: 21.32 to 34.84] per 100,000 women) had the lowest. Of the 204 countries and territories, 186 showed an increasing trend (net drift > 0.0% per year) in incidence rate. Ecuador (net drift: 1.282% [95% CI: 1.154 to 1.395] per year), Slovenia (net drift: 0.937% [95% CI: -1.067 to 3.038] per year), and Kazakhstan (net drift: 0.930% [95% CI: -0.661 to 2.672] per year) showed the largest increases. Maldives (net drift: -3.993% [95% CI: -5.566 to -2.391] per year), Saudi Arabia (net drift: -3.511% [95% CI: -5.088 to -1.935] per year), and Canada (net drift: -3.419% [95% CI: -4.855 to -1.929] per year) experienced the most significant decreases.(Fig. 1C,D, supplementary Table S3, Table S2).

The ASR for DALYs ranged from 0.43 to 234.07 per 100,000 women across the 204 countries and territories in 2021. The highest DALYs ASR was observed in Bermuda (234.07 per 100,000), followed by Liberia (228.23 per 100,000), Bahamas (212.79 per 100,000), Palau (195.85 per 100,000), and Andorra (183.18 per 100,000). These countries also exhibited notable increasing trends in net drift, Andorra the most significant increase at 17.277% per year, followed by Montenegro showing an increase of 14.424% per year and Belgium (13.53% per year) (Table S2). On the other hand, the countries with the lowest DALYs ASR in 2021 were Luxembourg (0.43 per 100,000), Comoros (0.59 per 100,000), Zimbabwe (0.62 per 100,000), Mali (0.65 per 100,000), and the Philippines (0.71 per 100,000). These countries demonstrated significant reductions in their net drift, with Mali showing the most substantial decline at -17.138% per year, followed by Comoros (-16.727% per year) and Sudan (-16.341% per year) (Fig. 1E,F, supplementary Table S2, Table S4).

Out of 204 countries and territories, 69 showed an increasing trend in ASR for DALYs. Among them, Andorra, Montenegro, Belgium, Iceland, and Portugal exhibited the most significant increases in net drift. Conversely, Mali, Comoros, Sudan, Malawi, and Senegal experienced the most substantial decreases in net drift, indicating a notable reduction in their ASR for DALYs over time (Fig. 2). These findings provide valuable insights into public health policy, highlighting the need for targeted interventions in countries with rising ASR for DALYs and continued support for those successfully reducing their disease burden.

Local drift and age effects in HDP across different SDI levels

In the context of gestational hypertension, the analysis of Fig. 3A–C highlights significant age-related changes and SDI level differences. First, from the perspective of local drift and net drift, the incidence rate increases significantly between the ages of 20 and 40, particularly peaking between 30 and 35 years. For example, in low SDI regions, the annual growth rate of incidence in this age group is 3.5% (95% CI: 2.8–4.2), whereas in high SDI regions, it is 2.5% (95% CI: 2.0–3.0). Subsequently, the incidence rate rapidly decreases after the age of 40, with a decline rate of -4.5% (95% CI: -5.0 to -4.0) in low SDI regions, while the decline is relatively moderate in high SDI regions, at -3.0% (95% CI: -3.5 to -2.5). Similar trends are observed in the prevalence and DALYs rates. Between the ages of 30 and 40, the prevalence rate in low SDI regions grows at 2.7% per year (95% CI: 2.1–3.3), compared to 2.0% (95% CI: 1.6–2.4) in high SDI regions. The DALYs rate peaks in the same age group with an annual growth of 2.3% (95% CI: 1.8–2.8) in low SDI regions, followed by a steep decline after 40, with a drop of -5.5% (95% CI: -6.2 to -4.8) per year in low SDI regions and – 4.0% (95% CI: -4.5 to -3.5) in high SDI regions. These data from Fig. 3A–C highlight the heightened health risks faced by women in low SDI regions during their reproductive years, as well as the challenges these regions face in disease management and prevention.

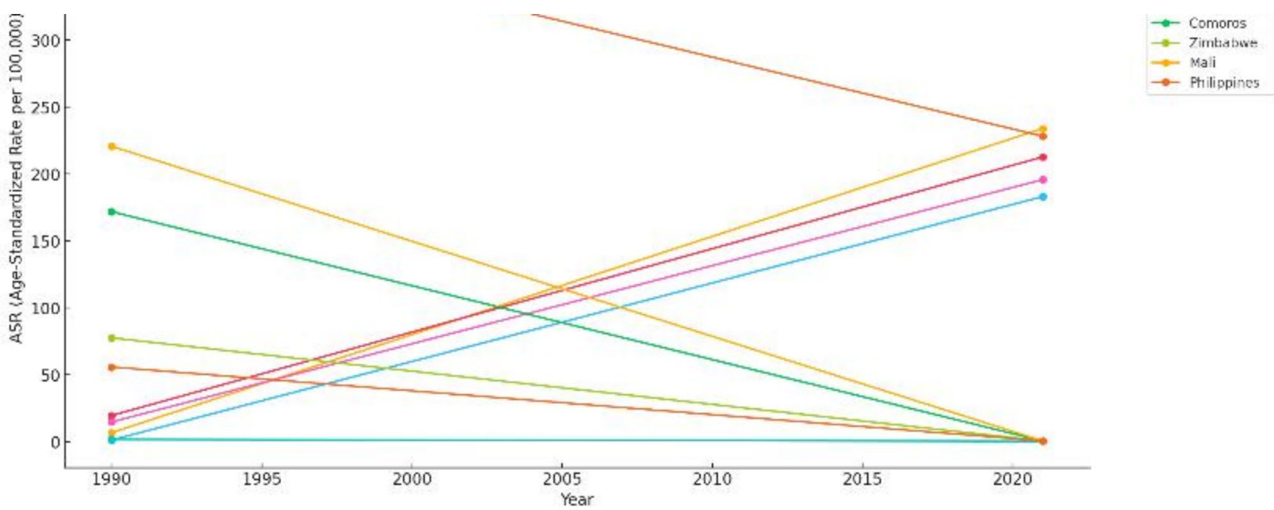

Fig. 2. The trend analysis of ASR for DALYs in different countries (with highest and lowest values of net drift) over the period from 1990 to 2021.

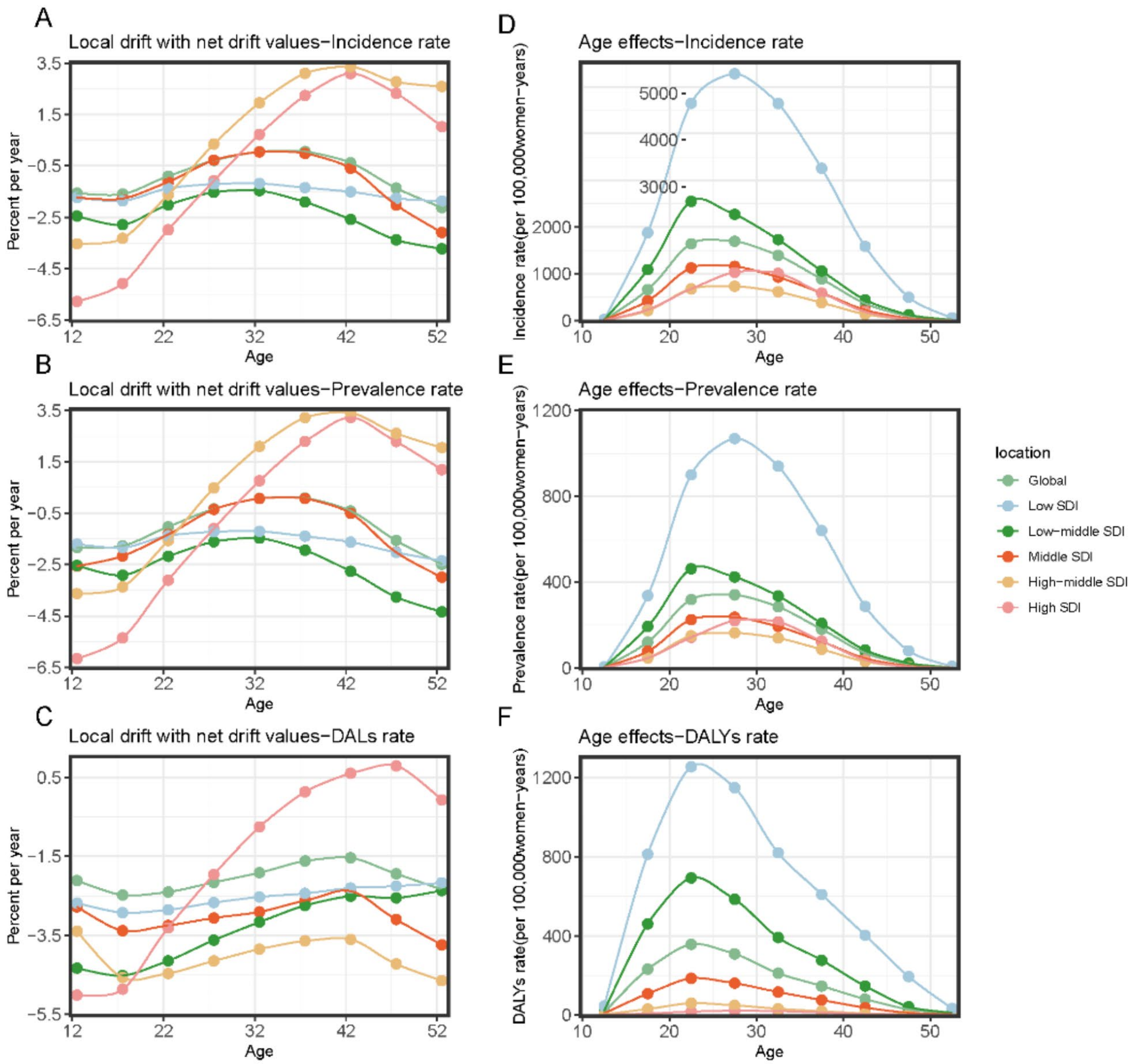

Fig. 3. Local drift and age effects the incidence rate, prevalence rate, and DALYs rate of gestational hypertension across SDI regions. Local drift with net drift values for incidence rate (**A**), prevalence rate (**B**), and DALYs rate (**C**) of pregnancy-induced hypertension across different SDI regions. Age effects on incidence rate (**D**), prevalence rate (**E**), and DALYs rate (**F**) are shown for the same SDI regions. Note: A-F uses the same set of legends.

The age effects on the incidence, prevalence, and DALYs rates of gestational hypertension, as shown in Fig. 3D–F, are particularly pronounced. The incidence rate peaks between the ages of 25 and 35, with a global incidence rate of 5000 cases per 100,000 (95% CI: 4800–5200). In low SDI regions, the incidence in this age group is 4500 cases per 100,000 (95% CI: 4300–4700), compared to 4000 cases per 100,000 (95% CI: 3800–4200) in high SDI regions. The prevalence rate follows a similar pattern, peaking between 30 and 35 years, with a global rate of 1200 cases per 100,000 (95% CI: 1150–1250). In low SDI regions, the prevalence rate is 1100 cases per 100,000 (95% CI: 1050–1150), while in high SDI regions, it is 900 cases per 100,000 (95% CI: 850–950). The global DALYs rate peaks between 30 and 35 years, reaching 1000 cases per 100,000 (95% CI: 950–1050), with 950 cases per 100,000 (95% CI: 900–1000) in low SDI regions and 850 cases per 100,000 (95% CI: 800–900) in high SDI regions. As women age, particularly after 40, there is a marked decline in incidence, prevalence, and DALYs rates across all SDI regions, reflecting a decrease in pregnancy-related health risks. This decline is particularly pronounced likely due to higher rates of early miscarriage, postpartum mortality, and limited medical resources.

Period and cohort effects on HDP incidence, prevalence, and DALYs rates across different SDI regions

The effects of period on the incidence, prevalence, and DALYs rates, as shown in Fig. 4A–C, highlight notable differences across SDI regions from 1994 to 2019. In high SDI and high-middle SDI regions, period effects consistently showed a declining trend for incidence, prevalence, and DALYs rates. For example, the relative risk (RR) of the incidence rate in high SDI regions decreased from 1.15 (95% CI: 1.10 to 1.20) in 1994–1999 to 0.85 (95% CI: 0.80 to 0.90) in 2015–2019. Similarly, in high-middle SDI regions, the RR for the prevalence rate declined from 1.10 (95% CI: 1.05 to 1.15) in 1994–1999 to 0.90 (95% CI: 0.85 to 0.95) in 2015–2019. In contrast, the period effects in low SDI and low-middle SDI regions exhibit mixed patterns, without uniformly increasing risks. For instance, the RR of incidence rates in low SDI regions shows fluctuations, starting from 1.00 (95% CI: 0.95 to 1.05) in 1994–1999 and peaking at 1.20 (95% CI: 1.15 to 1.25) in 2015–2019. However, the DALYs rate in low-middle SDI regions reveals a less pronounced increase, with the RR rising modestly from 1.05 (95% CI: 1.00 to 1.10) in 1994–1999 to 1.15 (95% CI: 1.10 to 1.20) in 2015–2019.

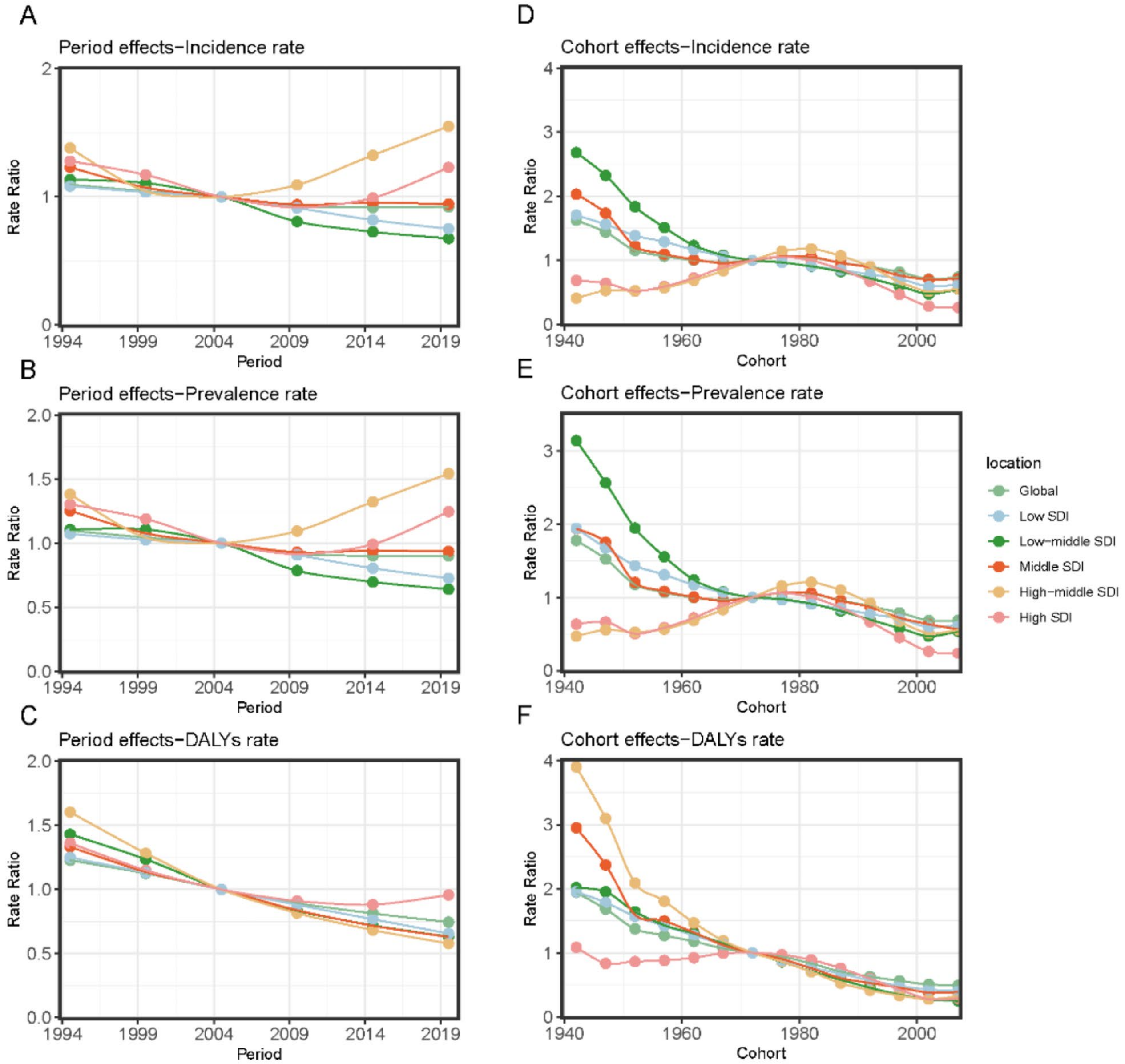

Fig. 4. Period and cohort effects on the incidence rate, prevalence rate, and DALYs rate of gestational hypertension across SDI regions. Period effects for incidence rate (**A**), prevalence rate (**B**), and DALYs rate (**C**) show trends from 1990 to 2021, highlighting differences across SDI regions. Cohort effects for incidence rate (**D**), prevalence rate (**E**), and DALYs rate (**F**) demonstrate the variations across different birth cohorts from 1990 to 2021. Note: A–F uses the same set of legends.

Similarly, Fig. 4D–F explores the effects on gestational hypertension incidence, prevalence, and DALYs rates, showing substantial differences across birth cohorts and SDI regions. Middle SDI, low-middle SDI, and low SDI regions exhibit increasing risks in individuals born after 1965, whereas the risk in high SDI and high-middle SDI regions has remained relatively stable. For instance, compared to those born in the 1965 cohort, the relative risk of incidence rate for individuals born in the 2000 cohort increased to 1.25 (95% CI: 1.20 to 1.30) in low SDI regions, while in high SDI regions, it only slightly increased to 1.05 (95% CI: 1.00 to 1.10). The relative cohort risk of prevalence rate for those born in the 2000 cohort compared to the 1965 cohort ranged from 1.20 (95% CI: 1.15 to 1.25) in low-middle SDI regions to 1.10 (95% CI: 1.05 to 1.15) in high-middle SDI regions. Additionally, the relative cohort risk of DALYs rate for individuals born in the 2000 cohort compared to the 1965 cohort increased to 1.20 (95% CI: 1.15 to 1.25) in low SDI regions, while it remained relatively unchanged at 1.05 (95% CI: 1.00 to 1.10) in high SDI regions. These findings underscore the enduring impact of socio-economic factors on HDP risk across generations, with lower SDI regions experiencing a growing burden, particularly among more recent cohorts. Similarly, Fig. 5 illustrates the negative correlation between DALYs, prevalence, and incidence with the SDI across 204 countries, highlighting the global burden of disease in relation to socio-economic factors.

In these three figures, countries with low SDI values (such as Niger, Chad and Somalia) typically appear in the upper left, indicating higher DALYs and lower prevalence and incidence rates. Conversely, countries with high SDI values (such as New Zealand, Switzerland, and Norway) usually appear in the lower right, reflecting lower DALYs alongside lower prevalence and incidence rates. The overall trend shows a negative correlation between SDI and disease burden (DALYs, prevalence, and incidence), indicating that as SDI increases, the disease burden generally decreases. Countries with low SDI tend to have a heavier disease burden, while those with high SDI exhibit better health indicators.

Future forecasts of global burden of HDP

The global burden of HDP is projected to evolve significantly from 1990 to 2040, with consistent declining trends observed across different measures. The age-standardized DALY rate for HDP is expected to decrease globally, dropping from over 150 per 100,000 population in 1990 to approximately 50 per 100,000 by 2020, and is further projected to decline to about 15 per 100,000 by 2040 (Fig. 6A). This trend reflects significant improvements in the management and prevention of HDP, contributing to a reduced overall disease burden.

Similarly, the ASPR of HDP has shown a marked decline over the same period. The prevalence was nearly 150 per 100,000 population in 1990, and it steadily decreased to around 75 per 100,000 by 2020. Future projections suggest that this downward trend will continue, potentially reaching about 20 per 100,000 by 2040, indicating successful public health interventions and broader access to care (Fig. 6B).

In terms of ASIR, HDP also experienced a significant decrease. The incidence rate declined from approximately 750 per 100,000 population in 1990 to nearly 400 per 100,000 by 2020. This rate is expected to continue its decline, potentially reaching close to 200 per 100,000 by 2040, suggesting ongoing advancements in early detection and intervention strategies (Fig. 6C). Across all three measures, DALY rate, prevalence, and incidence, there is a clear and consistent downward trend, highlighting the global progress in reducing the burden of hypertensive disorders during pregnancy.

Discussion

The current study found that the global incidence of HDP has increased by more than 15%, yet the overall trend shows a negative drift, indicating a gradual reduction in occurrence rates over time. When examining country-specific data, the ASR for incidence reveals that high and high-middle SDI regions exhibit significant declining trends, whereas low and low-middle SDI regions demonstrate upward trends from 1990 to 2021. Likewise, the ASR for the prevalence of HDP also shows a decreasing trend in high and high-middle SDI regions, while low and low-middle regions experience increasing prevalence. Remarkably, a 487% growth in the prevalence of HDP was observed, alongside a net drift of -0.865% per year. Conversely, the number of DALYs and ASR for DALYs decreased, with high-middle SDI regions showing the most substantial reduction in DALY rates. In contrast, low-middle SDI regions exhibited the highest increase in DALY rates among all SDI categories. Additionally, the incidence rate of HDP significantly rises between the ages of 20 and 40, peaking particularly between 30 and 35 years, before declining after the age of 40. Similar trends can be seen in both prevalence and DALY rates. As women age, especially after 40, there is a pronounced decline in incidence, prevalence, and DALY rates across all SDI regions, indicating a reduction in pregnancy-related health risks. This decline is especially notable in low SDI regions, likely due to elevated rates of early miscarriage, postpartum mortality, and limited access to medical resources. Further analysis indicates that the effects of the study period on incidence rates, prevalence rates, and DALYs varied across SDI regions. High SDI and high-middle SDI regions showed declining risks for these measures over time, while the RR increased in low SDI regions. The lower prevalence rates in higher SDI regions may reflect effective preventive strategies, early detection efforts, or more favorable baseline risk factors among these populations. The ASR for DALYs in 2021 also varied significantly among countries. For instance, Eritrea reported one of the highest ASRs for DALYs, consistent with its high prevalence of gestational hypertension. A similar pattern was observed in Guyana and Argentina, where the disability burden due to gestational hypertension was substantial. These elevated DALYs highlight the long-term health impacts of gestational hypertension in these regions, emphasizing the need for comprehensive management and intervention strategies. These findings highlight the increased health risks faced by women in low SDI regions during their reproductive years, as well as the considerable challenges these regions experience in disease management and prevention.

Socioeconomic status significantly influences health outcomes, including increased susceptibility to various diseases. Research has shown that lower SDI is associated with higher incidences of neurological and immune-related disorders[12]. Specifically, women experiencing HDP often hail from low-income families, where

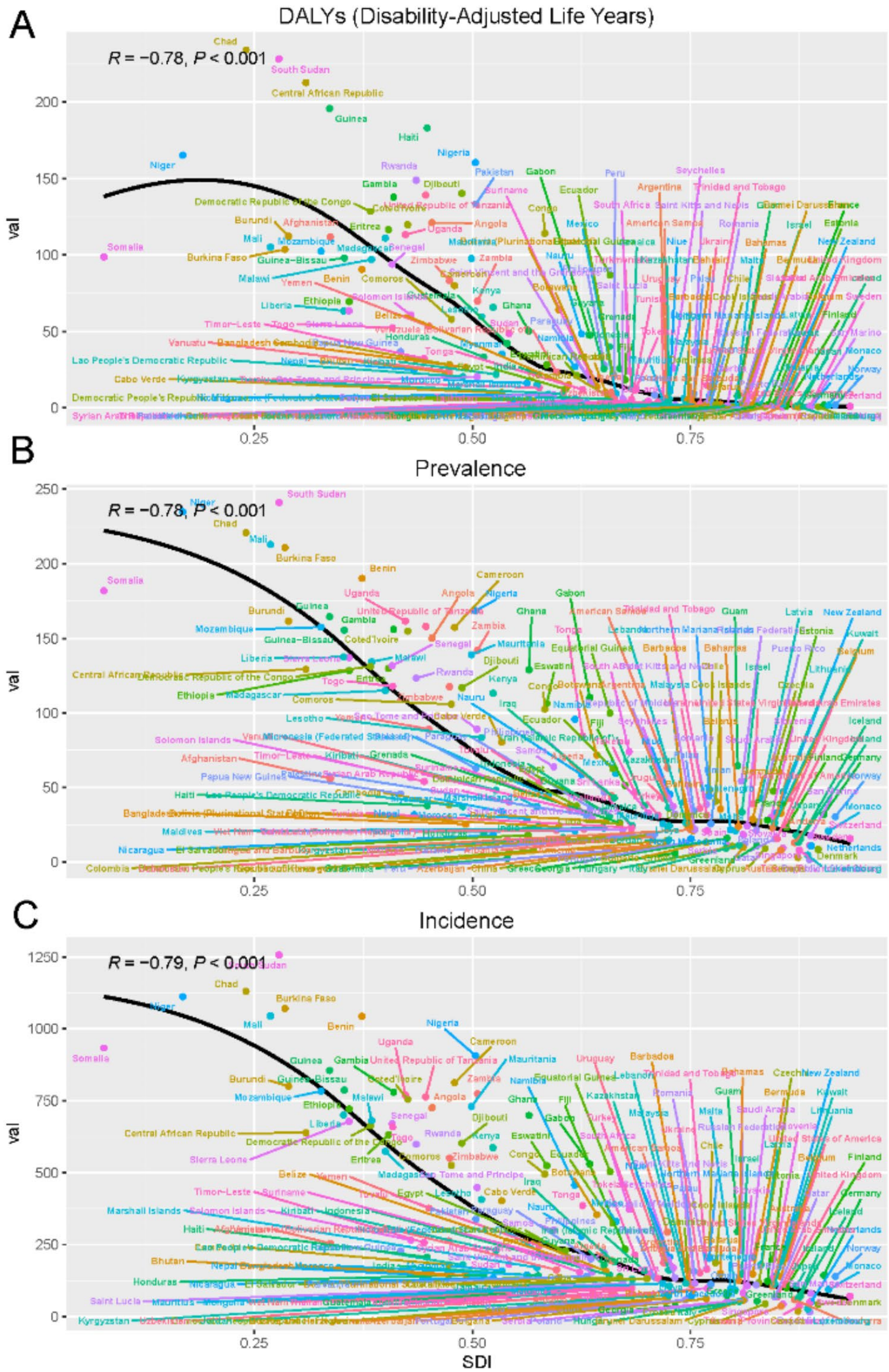

Fig. 5. Correlation between Disability-Adjusted Life Years (DALYs) (**A**), prevalence (**B**), and incidence (**C**) with the Sociodemographic Index (SDI) globally across 204 nations. *R*: correlation coefficient; *P*: significance level.

the mortality rate from these conditions is inversely related to family income levels[13]. Maternal deaths from hypertension and eclampsia (a severe complication of HDP) are notably higher in impoverished communities. Studies have indicated that the incidence of HDP varies by income: preeclampsia is more frequently documented in upper middle-income countries, while eclampsia is particularly prevalent in lower middle-income nations[14,15]. The correlation between higher economic status and lower rates of HDP suggests that economic support plays a

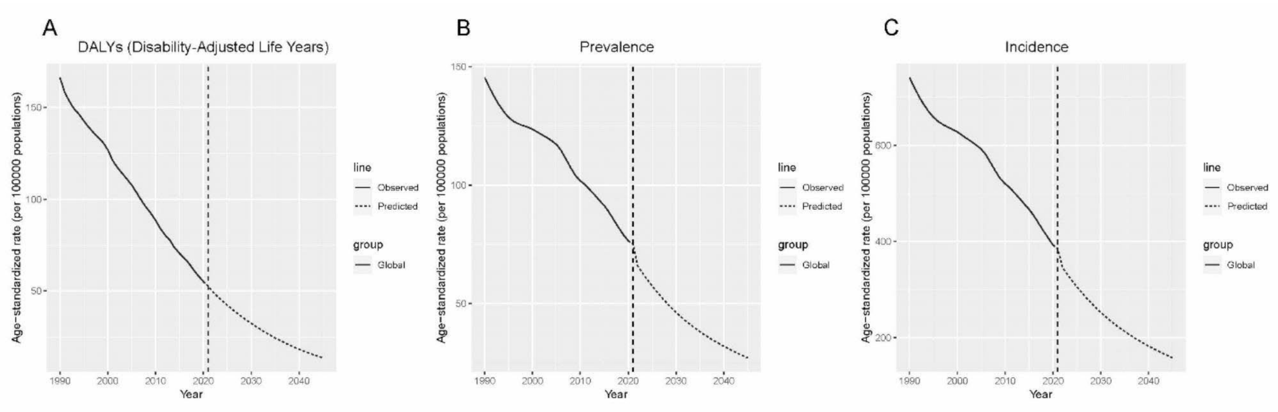

Fig. 6. Projected evolution of the global burden of HDP from the late 20th century to 2040: (**A**) DALYs, (**B**) Prevalence, (**C**) Incidence.

crucial role in enhancing maternal healthcare. For example, in higher-income countries, access to comprehensive prenatal care, education about pregnancy complications, and resources such as dietary supplements and medications significantly reduce the risk of HDP[16,17]. In lower SDI regions, there is a lack of clear guidelines and inconsistent support for management in antenatal care, leading to missed opportunities for intervention. Midwives are often not adequately equipped to address issues with pregnant women due to factors like lack of training, and time constraints. Personalized, culturally sensitive approaches that leverage a strong partnership between health professionals and pregnant women are crucial for better outcome[18].

Women experience significant alterations in blood lipid levels during early pregnancy, which are particularly important in understanding HDP[19]. A study found that high triglyceride (TG) levels during pregnancy, particularly when elevated from the first to third trimester, are associated with increased risk of HDP and gestational diabetes mellitus. High levels of low-density lipoprotein cholesterol (LDL-c) in the first trimester were also associated with an increased risk of HDP/GDM. Controlling weight gain during pregnancy could reduce TG elevation and lower the risk of HDP/GDM. TGs could be used as a follow-up index in complicated pregnancies, while other lipid levels are only meaningful in the first trimester[20]. Thus, the importance of managing lipid disorders during pregnancy to improve maternal and fetal health could not be neglected. For managing dyslipidemias during pregnancy, various treatments are explored, including nutritional interventions, bile acid resins, omega-3 fatty acids, and low-density lipoprotein cholesterol apheresis. Additionally, newer therapies such as mipomersen and proprotein convertase subtilisin/kexin type 9 (PCSK9) inhibitors are also considered[21]. By integrating lipid profiling into routine prenatal care, healthcare providers may better stratify risk and implement preventative strategies for at-risk populations. Inadequate nutrition during pregnancy, particularly deficiencies in essential vitamins and minerals has been linked to an increased risk of HDP, which can lead to severe complications for both the mother and the baby. For instance, a recent study reviewed that several maternal nutritional risk factors, including vitamin C, vitamin D, and calcium, are linked to an increased risk of pre-eclampsia. Dietary patterns that emphasize high consumption of fruits, vegetables, whole grains, and fish and seafood are protective against pre-eclampsia. Added sugar intake is associated with an increased risk of pre-eclampsia[22]. Further research should be carried out to investigate the role of dietary diversity, social and cultural contexts of meals, and potential interactions between dietary factors. Another cohort study in Ethiopia investigated the association between maternal undernutrition and adverse obstetric outcomes, finding that undernourished pregnant women have a significantly higher risk of HDP, antepartum haemorrhage, preterm labor, operative delivery, postpartum haemorrhage, and sepsis[23]. Overweight and obesity in pregnancy are associated with numerous adverse outcomes including infertility, miscarriage, stillbirth, gestational diabetes, hypertension, pre-eclampsia, labor complications, and maternal death[18]. A retrospective cohort study in Chinese women with obesity examined the relationship between gestational weight gain patterns and HDP, finding that excessive weight gain during the first trimester and rapid weight gain after 20 weeks significantly increased the risk of HDP[24]. Thyroid dysfunction in pregnancy is associated with hypertensive disorders and poor maternal and fetal outcomes. Both hypothyroidism and hyperthyroidism can contribute to hypertension in pregnancy[25]. Recently an article presented two cases demonstrating the complex relationship between thyroid disease and hypertension in pregnancy, emphasizing the need for careful monitoring and management of both conditions for optimal maternal and fetal outcomes[26].

Pregnancy induces physiological and immunological adaptations that make women more susceptible to infection[27]. Infectious diseases in adults pose significant challenges to healthcare systems and public health in developing countries. Low SDI countries often have a higher prevalence of infectious diseases leading to increased risks of preeclampsia and hypertension in pregnant women. Poverty, limited access to healthcare, inadequate sanitation, and poor hygiene practices contribute to the burden of these diseases. Social determinants of health, environmental factors, and occupational exposures also play a crucial role[28]. Global changes have increased the risk of infectious disease outbreaks, despite progress in sanitation and healthcare. Climate change, urbanization, and technological advancements have altered patterns of pathogen emergence, local disease dynamics, and global spread. Urbanization has created new opportunities for the emergence and spread of arboviral diseases, such as dengue, Zika virus disease, and chikungunya. International travel has facilitated the global spread of both emerging and endemic pathogens. Human migration has also contributed to the introduction of infectious diseases, particularly in cases where migrant groups have limited access to healthcare. Intensification of animal and plant trade has driven the emergence and spread of novel pathogens, including Xylella fastidiosa, African swine fever virus, and Vibrio parahaemolyticus[29].

Limitations

This study has several limitations that should be acknowledged. First, due to the unavailability of specific data, we were unable to perform separate analyses for each type of hypertensive disorder, such as preeclampsia, gestational hypertension, and chronic hypertension. This limitation restricts our ability to accurately assess the burden of more prevalent hypertensive disorders in specific age groups and geographical regions. Second, the study does not account for the impact of nutritional factors, lifestyle changes, or socioeconomic status, as the data is entirely dependent on the GBD 2021 database. Additionally, the potential effects of recent diseases, such as COVID-19, and other emerging health threats were not considered in this analysis. Furthermore, the reliance on the GBD database means that any inaccuracies or gaps in the source data could affect our findings. For instance, in low SDI regions, healthcare infrastructure may be less developed, leading to underreporting or inconsistent reporting of HDP and it may result in higher rates of data missingness or need for imputed estimates. Lastly, the study's retrospective nature limits our ability to establish causality or temporal relationships between hypertensive disorders and their potential risk factors.

Conclusion

Based on GBD 2021 data, this study comprehensively analyzed the HDP burden globally from 1990 to 2021. The results indicate both similarities and significant differences in the disease burden among different SDI regions, which might help to provide important insights for future health strategies and policy development in these countries. Overall, this research underscores significant global and regional disparities in the burden of gestational hypertension. While regions with high SDI have made progress in reducing incidence, prevalence, and DALYs associated with HDP, lower SDI regions, particularly low-middle and low SDI areas, continue to encounter escalating challenges. This situation emphasizes the urgent need for targeted public health interventions and appropriate resource allocation to address the rising burden of gestational hypertension in low SDI regions.

Data availability

The datasets analyzed during this study are available in the Global Health Data Exchange GBD Results Tool repository (https://ghdx.healthdata.org/gbd-2021).

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Author contributions

The roles in this study were assigned as follows: Conceptualization was led by A.U.R.A. and N.Z.; Data curation was performed by W.L., S.S., and A.U.R.A.; Methodology was developed by X.Z.; Writing of the original draft was conducted by W.L. and A.U.R.A.; Supervision was undertaken by A.U.R.A.; Writing - review and editing was done by N.Z.; Funding acquisition was secured by W.L., S.S., and N.Z.; and Project administration was managed by A.U.R.A. and N.Z. All authors have read and approved the final manuscript for publication.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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