The Global Burden of Chronic Kidney Disease Attributable to Hypertension in Young Adults From 1990 to 2021 and Projections to 2050

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Background: Chronic kidney disease (CKD) attributable to hypertension represents a major global public health challenge. This study evaluates the global burden of CKD statistically attributable to high systolic blood pressure (SBP), with a focus on young adults aged 25–49 years.

Aims: To analyze trends in mortality and disability-adjusted life years (DALYs) attributable to high SBP among individuals with CKD aged 25–49 years from 1990 to 2021 and to project the future attributable burden through 2050.

Study Design: Observational study.

Methods: Data were obtained from the Global Burden of Disease Study 2021. The analysis estimated the burden of CKD attributable to high SBP using a comparative risk assessment framework. Temporal trends were quantified using the estimated annual percentage change (EAPC). The association between attributable burden and the sociodemographic index (SDI) was also examined. Projections to 2050 were generated using autoregressive integrated moving average models.

Results: From 1990 to 2021, global mortality and DALY rates for CKD attributable to high SBP among young adults increased significantly (mortality EAPC, 1.75%; DALYs EAPC, 1.6%). The attributable burden remained consistently higher in males and increased with age, peaking in the 45–49-year age group. Overall, low- and low-middle-SDI regions experienced the greatest relative increases, although substantial heterogeneity was observed within SDI strata. At the national level, Ukraine showed the largest increase in mortality rate (EAPC, 13.21%), whereas the Republic of Korea exhibited the largest decline (EAPC, −4.68%). Model-based projections suggest a continued increase in both attributable mortality and DALYs through 2050, with persistent disparities by sex, age, and geographic region.

Conclusion: The burden of CKD attributable to high SBP among young adults has increased substantially over the past three decades and is projected to rise further, reflecting persistent global inequalities. These findings highlight the urgent need for strengthened and targeted strategies for hypertension prevention and management in younger populations worldwide.

INTRODUCTION

In contemporary society, hypertension has emerged as a major global public health problem and a leading modifiable risk factor for numerous cardiovascular and renal diseases, posing a substantial threat to population health and quality of life.[1] A considerable proportion of the associated renal burden is reflected in hypertension-related chronic kidney disease (HRCKD)—the component of chronic kidney disease (CKD) that is statistically attributable to elevated systolic blood pressure (SBP). Among many health conditions, the burden associated with CKD is particularly concerning.[2,3] CKD, including its end-stage form requiring dialysis or kidney transplantation, causes significant patient suffering and imposes substantial socioeconomic burdens.

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Within the public health research framework of the Global Burden of Disease (GBD) study, the proportion of CKD burden that can be statistically attributed to high SBP is quantified as "HRCKD".[4] However, the term "HRCKD" may be misinterpreted as a distinct clinical co-diagnosis rather than an attribution metric used within the GBD comparative risk assessment (CRA) framework. Throughout this manuscript, to maintain conceptual clarity and minimize ambiguity, we therefore use the explicit term "CKD burden attributable to high SBP" and avoid the abbreviated term "HRCKD." Over recent decades, alongside lifestyle changes and population aging, the global prevalence of hypertension has increased markedly.[5] Notably, the age of hypertension onset appears to be declining, prolonging cumulative exposure and potentially increasing the burden of CKD attributable to high SBP among younger adults (aged 25–49 years).[6] As the primary workforce supporting social and economic development, the health of this demographic group is critically important. Poor health in this population may result in reduced productivity and increased healthcare expenditures, with conditions such as CKD attributable to high SBP contributing substantially to this societal burden.

Although previous studies have examined the burden of CKD, comprehensive analyses specifically quantifying the evolving burden of CKD attributable to high SBP among young adults (aged 25–49 years), evaluating long-term temporal trends, and providing future projections remain limited.[7] Therefore, we used data from the GBD database to analyze trends in the burden of CKD attributable to high SBP among young adults aged 25–49 years from 1990 to 2021. We further conducted a detailed analysis of mortality and disability-adjusted life years (DALYs) attributable to CKD attributable to high SBP across global regions during the same period. In addition, we examined the influence of different sociodemographic index (SDI) levels on mortality and DALYs and projected future trends through 2050 to inform public health planning. Understanding these patterns of CKD attributable to high SBP burden is essential for informing public health strategies, guiding resource allocation, and prioritizing prevention efforts aimed at reducing the blood pressure–mediated burden of CKD.

MATERIALS AND METHODS

Data source and definition

Data for this analysis were obtained from the GBD 2021 study through the Global Health Data Exchange and were accessed on May 20, 2025. The dataset included annual estimates of mortality, DALYs, and their corresponding 95% uncertainty intervals (UIs) attributable to CKD attributable to high SBP from 1990 to 2021 (http://ghdx.healthdata.org/).[8,9] According to GBD definitions, data on mortality and DALYs attributable to CKD attributable to high SBP were available for both sexes across 21 global regions and five SDI categories.[10] These regions were defined based on geographic proximity and epidemiological similarity. Data on the burden of CKD attributable to high SBP were subsequently screened for the present analysis. Specifically, we selected data for young adults aged 25–49 years for detailed investigation and further stratified this population into five age groups (25–29, 30–34, 35–39, 40–44, and 45–49 years). Subsequently, we conducted a more detailed analysis of the epidemiological characteristics of this hypertension-attributable burden.

Definition of CKD burden attributable to high SBP

CKD was defined and classified according to the standardized protocols used in the GBD study. The primary outcome of this analysis was the burden of CKD attributable to high SBP.[4] This metric represents the estimated proportion of the total CKD burden that is attributable to elevated SBP, derived using the GBD CRA framework. It does not represent a distinct clinical entity with a specific International Classification of Diseases code but instead serves as a population-level metric for quantifying risk attribution. The underlying CKD case definition was based on permanent loss of kidney function, indicated by estimated glomerular filtration rate and urinary albumin-to-creatinine ratio.[8] CKD cases were mapped to the following ICD-10 codes: N18.1–N18.6, N18.8, and N18.9.

Following the GBD CRA framework, high SBP was defined as SBP ≥ 115 mmHg. The theoretical minimum risk exposure level (TMREL) was set at 110–115 mmHg.[3] The attributable burden was calculated as the proportion of total CKD burden associated with SBP levels exceeding this TMREL. This estimate represents a counterfactual measure of potentially preventable burden rather than the number of clinically diagnosed cases of hypertensive nephropathy. Consistent with GBD methodology, SBP was used as the primary exposure metric because of its stronger epidemiological association with cardiovascular and renal outcomes compared with diastolic blood pressure.

Statistical analysis

Both mortality and DALY rates as well as case numbers, were used to assess the burden of CKD attributable to high SBP. Rates were expressed as estimated values per 100,000 population to reflect the relative burden of disease, whereas case numbers represented the absolute burden. All corresponding estimates are presented with 95% UIs.

Temporal trends were quantified by calculating the estimated annual percentage change (EAPC) and its 95% confidence interval (CI). Prior to estimating the EAPC, long-term temporal patterns for all key outcomes (e.g., global, regional, and sex-specific rates) were visually examined to determine whether the overall trend could be reasonably approximated using a log-linear model. The EAPC was derived from a log-linear regression model [where $y = \ln(\text{rates})$ and x = calendar year] and expressed as follows:

$$y = \alpha + \beta x + \varepsilon$$

$$\text{EAPC} = 100 \times [\exp(\beta) - 1]$$

The EAPC provides a widely accepted summary measure of the average annual rate of change over a specified period and offers a useful approximation of long-term trends for comparative purposes in epidemiological studies.[11-13] A statistically significant decreasing trend was defined when the upper bound of the 95% CI of the EAPC was < 0, whereas a statistically significant increasing trend was defined when the lower bound of the 95% CI was > 0. Trends were considered stable when the 95% CI included 0.

Spearman correlation analyses were performed to examine the relationships between the EAPC and the number of CKD cases attributable to high SBP in 1990, between the EAPC and SDI in 2021, and between DALYs attributable to CKD attributable to high SBP and SDI across countries. The resulting ρ coefficients and *p* values were used to evaluate the strength and statistical significance of these associations. Additionally, global maps were generated to illustrate country-level mortality and DALY rates attributable to CKD attributable to high SBP among young adults aged 25–49 years in 2021 as well as EAPC trends in this hypertension-attributable burden from 1990 to 2021. These visualizations provide insight into the geographic distribution and temporal patterns of the burden of CKD attributable to high SBP among young adults across different regions. Finally, autoregressive integrated moving average (ARIMA) models were used to forecast mortality and DALYs through 2050. Time-series forecasting was conducted using ARIMA models implemented in R (forecast package).[14] The ARIMA model includes three principal parameters: *p*, *d*, and *q*, where *p* represents the order of the autoregressive term, *d* represents the order of differencing, and *q* represents the order of the moving average term. Optimal ARIMA (*p*,*d*,*q*) parameters were automatically selected using the auto.arima function based on minimization of the corrected Akaike Information Criterion (AICc).[15] Model adequacy was assessed through residual diagnostics, including inspection of autocorrelation function plots and Ljung–Box Q tests to confirm the absence of residual autocorrelation.[16] Stationarity of the time series was achieved through differencing as determined by the ARIMA algorithm.[17] To evaluate forecasting performance, an in-sample validation procedure was applied. Models were initially fitted using data from 1990 to 2014 and subsequently used to generate forecasts for the period 2015–2019. Predicted values were compared with the corresponding GBD estimates, and forecasting accuracy was quantified using the mean absolute error and root mean square error.[18] Following validation, final ARIMA models were fitted to the complete dataset (1990–2021) to generate projections through 2050. All primary parameters and selected ARIMA model parameters (*p*, *d*, *q*) are presented in Supplementary Table 1. All statistical analyses and visualizations were performed using R software (version 3.5.2) and GraphPad Prism (version 8.02).

RESULTS

Global burden of CKD attributable to high SBP

Globally, the annual number of deaths from CKD attributable to high SBP among young adults increased substantially, from 8,584 (95% UI, 3,742–14,034) in 1990 to 21,766 (95% UI, 9,395–36,267) in 2021, representing an absolute increase of 153.56% (Figure 1a; Table 1). Mortality attributable to high SBP was consistently higher in males than in females. In 1990, the crude death rate was 0.38 (95% UI, 0.16–0.62) per 100,000 population for males and 0.25 (95% UI, 0.11–0.41) for females, rising to 0.68 (95% UI, 0.30–1.11) for males and 0.42 (95% UI, 0.17–0.71) for females in 2021 (Figure 1a, b; Table 1).

The global trend in DALYs due to CKD attributable to high SBP paralleled that of attributable deaths. In 2021, these DALYs reached 1,321,478 (95% UI, 627,899–2,144,240) among young adults aged 25–49 years (Figure 1e; Table 2). The crude attributable DALY rate was approximately 33.47 (95% UI, 15.90–54.30) per 100,000 population (Figure 1f; Table 2). Attributable DALY rates increased significantly over the study period, with an EAPC of 1.6% (95% CI, 1.56–1.64). The attributable burden was higher in males than in females. In 2021, attributable DALY rates were 40.82 (95% UI, 19.17–64.87) per 100,000 population among males and 25.93 (95% UI, 11.46–42.53) among females (Figure 1f; Table 2).

Age-specific trends in the attributable burden

From 1990 to 2021, the global burden of CKD attributable to high SBP showed an upward trend across all age groups among young adults aged 25–49 years. The attributable burden exhibited a clear age-dependent gradient, with the highest mortality (Figure 1 c,d; Table 1) and attributable DALY rates (Figure 1g, h; Table 2) consistently observed in the 45–49-year subgroup.

Among younger adults, both the attributable mortality rate and DALYs continued to rise over time, with the smallest increase seen in the 25–29 age group. The absolute number of deaths from CKD attributable to high SBP increased from 684 (95% UI, 273–1,259) in 1990 to 1,529 (95% UI, 646–2,694) in 2021, while the corresponding mortality rate rose from 0.15 (95% UI, 0.06–0.28) to 0.26 (95% UI, 0.11–0.46) per 100,000 population (Figure 1c, d; Table 1). Similarly, the absolute number of DALYs due to CKD attributable to high SBP increased from 57,834 (95% UI, 25,140–100,087) to 120,981 (95% UI, 55,640–207,705), and the attributable DALY rate increased from 13.07 (95% UI, 5.68–22.61) to 20.56 (95% UI, 9.46–35.30) per 100,000 population (Figure 1g, h; Table 2).

Variations in attributable burden by SDI and region

From 1990 to 2021, substantial variation was observed in the mortality and DALY burden of CKD attributable to high SBP across SDI regions. However, trends were not uniform within each SDI category. At the aggregate SDI level, the high-middle SDI region exhibited the smallest relative increases in both attributable death counts (41.99%; 95% UI, 15.20–72.34) and attributable DALYs (40.66%; 95% UI, 19.19–67.24), with corresponding EAPCs of 0.29% and 0.41%, respectively (Figure 2a-d; Tables 1–2). In contrast, low and low-middle SDI regions showed the largest percentage increases in attributable death counts (190.65% and 212.41%) and attributable DALYs (190.22% and 203.32%) on average (Figure 2a-d; Tables 1–2).

Marked geographic disparities were evident, underscoring heterogeneity within broader SDI strata. The most pronounced increases in attributable mortality and DALYs occurred in Oceania, Central Latin America, high-income North America, and Western Sub-Saharan Africa. For example, in Oceania, attributable death counts increased by 393.34% (95% UI, 214.77–704.53) and attributable DALYs by 384.67% (95% UI, 229.83–615.26), with EAPCs of 2.67% and 2.62%, respectively (Tables 1–2; Figure 2e, f). Notably, several regions within lower SDI categories demonstrated flat or declining trends, while divergent patterns were observed among high-SDI regions. For instance, high-income Asia Pacific experienced substantial decreases, with a 61.93% reduction in attributable death counts and a 47.02% reduction in attributable DALYs (Table 1; Figure 2e, f). These complex patterns suggest that the trajectory of CKD burden attributable to high SBP is influenced by factors beyond national SDI level alone.

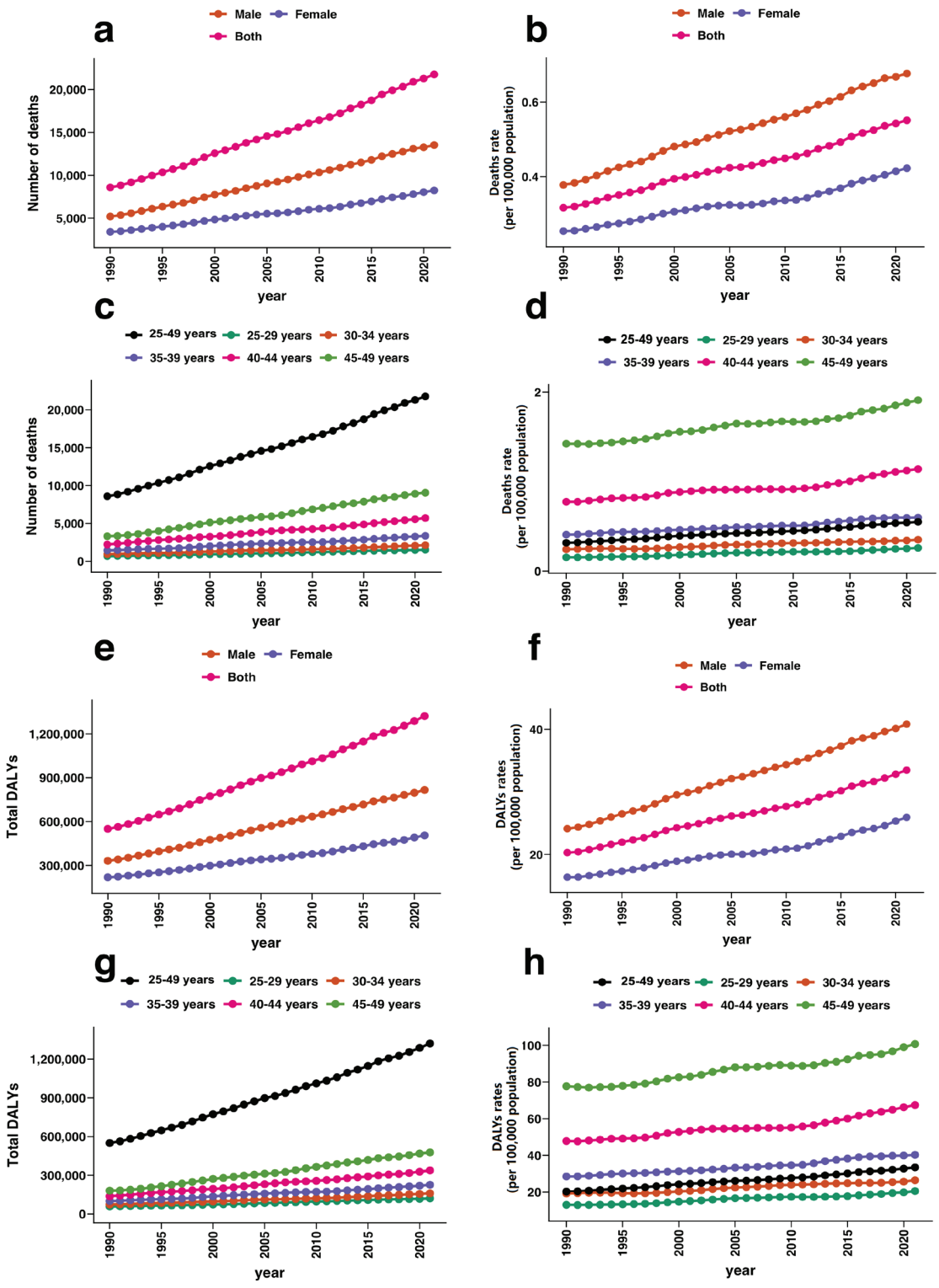

FIG. 1. Global trends in the number of deaths and DALYs from CKD attributable to high SBP among young adults aged 25–49 years from 1990 to 2021. (a, b) The number of attributable deaths and sex-specific attributable death rates over time. (c, d) The number of attributable deaths and age-specific attributable death rates by age group over time. (e, f) Number of attributable DALYs and sex-specific attributable DALY rates over time. (g, h) Number of attributable DALYs and age-specific attributable DALY rates by age group over time.

SBP, systolic blood pressure; CKD, chronic kidney disease; DALYs, disability-adjusted life years.

TABLE 1. Global and Regional Trends in Attributable Deaths from CKD due to High SBP Among Young Adults Aged 25–49 Years (1990–2021).

Feature	Cases_1990 (per 100,000 population, 95% UI)	Rates_1990 (95% UI)	Cases_2021 (per 100,000 population, 95% UI)	Rates_2021 (95% UI)	Cases_change (95% UI)	EAPC (95% CI)
Global	8584 (3742 to 14034)	0.32 (0.14 to 0.52)	21766 (9395 to 36267)	0.55 (0.24 to 0.92)	153.56 (121.45 to 186.3)	1.75 (1.69 to 1.81)
Sex group						
Female	3397 (1418 to 5494)	0.25 (0.11 to 0.41)	8237 (3402 to 13833)	0.42 (0.17 to 0.71)	142.49 (99.33 to 186.98)	1.54 (1.45 to 1.62)
Male	5188 (2210 to 8550)	0.38 (0.16 to 0.62)	13529 (6035 to 22101)	0.68 (0.3 to 1.11)	160.8 (117.9 to 200.09)	1.88 (1.83 to 1.94)
Age group						
25–29 years	684 (273 to 1259)	0.15 (0.06 to 0.28)	1529 (646 to 2694)	0.26 (0.11 to 0.46)	123.46 (83.85 to 176.51)	1.69 (1.59 to 1.79)
30–34 years	939 (400 to 1623)	0.24 (0.1 to 0.42)	2125 (919 to 3633)	0.35 (0.15 to 0.6)	126.23 (88.27 to 170.17)	1.25 (1.18 to 1.33)
35–39 years	1436 (557 to 2499)	0.41 (0.16 to 0.71)	3357 (1344 to 5729)	0.6 (0.24 to 1.02)	133.84 (90.99 to 180.73)	1.29 (1.23 to 1.34)
40–44 years	2220 (854 to 3953)	0.77 (0.3 to 1.38)	5709 (2211 to 10362)	1.14 (0.44 to 2.07)	157.16 (117.59 to 202.3)	1.13 (1.02 to 1.23)
45–49 years	3305 (1345 to 5777)	1.42 (0.58 to 2.49)	9047 (3943 to 15847)	1.91 (0.83 to 3.35)	173.7 (133.62 to 217.14)	0.93 (0.88 to 0.99)
SDI regions						
High SDI	662 (267 to 1094)	0.14 (0.06 to 0.24)	1428 (618 to 2410)	0.28 (0.12 to 0.48)	115.71 (70.19 to 169.76)	2.28 (1.89 to 2.67)
High-middle SDI	1238 (524 to 2037)	0.22 (0.09 to 0.36)	1758 (795 to 2931)	0.28 (0.13 to 0.47)	41.99 (15.2 to 72.34)	0.29 (0.09 to 0.49)
Middle SDI	3253 (1427 to 5347)	0.36 (0.16 to 0.59)	8127 (3614 to 13757)	0.65 (0.29 to 1.1)	149.82 (109 to 194.7)	1.91 (1.83 to 1.99)
Low-middle SDI	2249 (971 to 3704)	0.41 (0.18 to 0.67)	7027 (3078 to 11500)	0.69 (0.3 to 1.13)	212.41 (158.18 to 269.42)	1.79 (1.73 to 1.84)
Low SDI	1171 (501 to 1918)	0.53 (0.23 to 0.87)	3402 (1506 to 5640)	0.63 (0.28 to 1.04)	190.65 (148.7 to 242.11)	0.53 (0.49 to 0.57)
Geographical regions						
Andean Latin America	61 (21 to 118)	0.33 (0.11 to 0.63)	243 (99 to 423)	0.7 (0.28 to 1.21)	299.39 (162.99 to 559.18)	2.75 (2.55 to 2.96)
Australasia	5 (2 to 10)	0.05 (0.01 to 0.09)	10 (3 to 19)	0.07 (0.02 to 0.13)	80.95 (20.88 to 152.11)	1.24 (0.91 to 1.57)
Caribbean	121 (56 to 195)	0.66 (0.31 to 1.07)	348 (181 to 543)	1.45 (0.76 to 2.27)	187.33 (121.65 to 284.13)	3.06 (2.92 to 3.2)
Central Asia	95 (37 to 151)	0.28 (0.11 to 0.45)	311 (121 to 505)	0.64 (0.25 to 1.04)	228.24 (157.76 to 332.84)	2.06 (1.65 to 2.47)
Central Europe	237 (95 to 387)	0.38 (0.15 to 0.62)	139 (59 to 225)	0.26 (0.11 to 0.43)	−41.31 (−51.16 to −26.88)	−1.14 (−1.32 to −0.95)
Central Latin America	383 (173 to 630)	0.47 (0.21 to 0.77)	1693 (717 to 2870)	1.27 (0.54 to 2.16)	342.2 (215.23 to 518.15)	3.54 (3.31 to 3.77)
Central Sub-Saharan Africa	241 (100 to 416)	0.99 (0.41 to 1.7)	604 (252 to 1105)	0.93 (0.39 to 1.7)	150.35 (65.68 to 274.77)	−0.47 (-0.58 to -0.37)
East Asia	902 (330 to 1782)	0.13 (0.05 to 0.26)	1248 (473 to 2425)	0.18 (0.07 to 0.35)	38.31 (−24.95 to 138.45)	0.75 (0.5 to 1.01)
Eastern Europe	371 (163 to 588)	0.34 (0.15 to 0.53)	273 (115 to 436)	0.28 (0.12 to 0.45)	−26.42 (−35.85 to −14.42)	−2 (−2.48 to −1.52)
Eastern Sub-Saharan Africa	385 (156 to 663)	0.46 (0.19 to 0.8)	1347 (590 to 2239)	0.64 (0.28 to 1.07)	249.98 (186.3 to 339.55)	1.09 (1.02 to 1.15)
High-income Asia Pacific	162 (72 to 263)	0.17 (0.08 to 0.28)	62 (24 to 110)	0.08 (0.03 to 0.14)	−61.93 (−73.59 to −47.83)	−3.44 (-3.96 to −2.93)
High-income North America	177 (72 to 310)	0.12 (0.05 to 0.21)	741 (323 to 1217)	0.44 (0.19 to 0.72)	319.16 (204.57 to 522.2)	4.63 (4.07 to 5.2)
North Africa and Middle East	716 (305 to 1232)	0.45 (0.19 to 0.77)	2392 (994 to 4230)	0.72 (0.3 to 1.27)	234.03 (112.47 to 352.61)	1.7 (1.5 to 1.9)
Oceania	2 (1 to 3)	0.05 (0.02 to 0.11)	9 (3 to 17)	0.12 (0.05 to 0.24)	393.34 (214.77 to 704.53)	2.67 (2.4 to 2.94)
South Asia	1852 (797 to 3182)	0.35 (0.15 to 0.6)	4735 (1910 to 8363)	0.47 (0.19 to 0.83)	155.66 (90.86 to 215.5)	0.78 (0.69 to 0.88)
Southeast Asia	1378 (589 to 2360)	0.58 (0.25 to 1)	3861 (1722 to 6824)	1.04 (0.46 to 1.84)	180.14 (122.5 to 244.46)	2.25 (2.14 to 2.35)
Southern Latin America	68 (26 to 130)	0.28 (0.11 to 0.53)	109 (42 to 192)	0.32 (0.12 to 0.55)	61.14 (9.24 to 137.21)	0.8 (0.59 to 1.01)
Southern Sub-Saharan Africa	209 (90 to 355)	0.81 (0.35 to 1.38)	620 (270 to 1032)	1.44 (0.63 to 2.39)	196.82 (123.74 to 305.97)	1.33 (0.89 to 1.76)
Tropical Latin America	554 (272 to 829)	0.71 (0.35 to 1.06)	796 (385 to 1188)	0.66 (0.32 to 0.99)	43.7 (27.42 to 62.54)	−0.58 (−0.76 to −0.4)
Western Europe	151 (57 to 254)	0.08 (0.03 to 0.13)	109 (44 to 181)	0.06 (0.02 to 0.1)	−28 (-38.17 to −13.81)	−0.85 (−0.99 to −0.71)
Western Sub-Saharan Africa	513 (210 to 903)	0.6 (0.25 to 1.06)	2116 (974 to 3515)	0.92 (0.42 to 1.53)	312.43 (221.01 to 446.38)	1.63 (1.46 to 1.81)

CI, confidence interval; EAPC, estimated annual percentage change; UI, uncertainty intervals; SDI, sociodemographic index; SBP, systolic blood pressure; CKD, chronic kidney disease.

TABLE 2. Global and Regional Trends in Attributable DALYs from CKD due to High SBP Among Young Adults Aged 25–49 years (1990–2021).

Feature	Cases_1990 (per 100,000 population, 95% UI)	Rates_1990 (95% UI)	Cases_2021 (per 100,000 population, 95% UI)	Rates_2021 (95% UI)	Cases_change (95% UI)	EAPC (95% CI)
Global	549888 (250984 to 881977)	20.29 (9.26 to 32.54)	1321478 (627899 to 2144240)	33.47 (15.9 to 54.3)	140.32 (113.68 to 167.4)	1.6 (1.56 to 1.64)
Sex group						
Female	218822 (100337 to 350516)	16.36 (7.5 to 26.21)	505258 (223419 to 828799)	25.93 (11.46 to 42.53)	130.9 (96 to 167.17)	1.42 (1.35 to 1.48)
Male	331066 (149731 to 530608)	24.11 (10.9 to 38.64)	816220 (383415 to 1297203)	40.82 (19.17 to 64.87)	146.54 (113.24 to 177.7)	1.72 (1.67 to 1.76)
Age group						
25-29 years	57834 (25140 to 100087)	13.07 (5.68 to 22.61)	120981 (55640 to 207705)	20.56 (9.46 to 35.3)	109.19 (74.85 to 150.84)	1.49 (1.39 to 1.58)
30-34 years	74053 (33185 to 122342)	19.21 (8.61 to 31.74)	159971 (69435 to 263543)	26.46 (11.49 to 43.6)	116.02 (82.26 to 154.45)	1.13 (1.05 to 1.22)
35-39 years	100464 (40150 to 169083)	28.52 (11.4 to 48)	226117 (94183 to 373040)	40.32 (16.79 to 66.51)	125.07 (90.13 to 162.88)	1.18 (1.12 to 1.23)
40-44 years	137079 (58110 to 238386)	47.85 (20.28 to 83.21)	337478 (140920 to 592469)	67.46 (28.17 to 118.43)	146.19 (112.7 to 183.47)	1.04 (0.95 to 1.12)
45-49 years	180458 (77769 to 306447)	77.72 (33.49 to 131.98)	476931 (213189 to 808785)	100.72 (45.02 to 170.81)	164.29 (129.68 to 200.66)	0.84 (0.79 to 0.89)
SDI regions						
High SDI	60346 (28159 to 96128)	13.09 (6.11 to 20.86)	102065 (45020 to 165689)	20.32 (8.96 to 32.99)	69.13 (40.55 to 105.79)	1.35 (1.02 to 1.68)
High-middle SDI	85523 (39405 to 134880)	15.15 (6.98 to 23.9)	120298 (56895 to 192550)	19.11 (9.04 to 30.58)	40.66 (19.19 to 67.24)	0.41 (0.27 to 0.56)
Middle SDI	195469 (89029 to 315129)	21.47 (9.78 to 34.61)	476204 (221602 to 788245)	37.94 (17.66 to 62.81)	143.62 (111.78 to 183.47)	1.84 (1.77 to 1.91)
Low-middle SDI	139387 (62996 to 229400)	25.29 (11.43 to 41.63)	422794 (192146 to 673762)	41.6 (18.91 to 66.3)	203.32 (157.96 to 251.79)	1.73 (1.68 to 1.77)
Low SDI	68493 (29544 to 113180)	30.99 (13.37 to 51.2)	198781 (89475 to 323342)	36.65 (16.5 to 59.62)	190.22 (151.4 to 236.41)	0.54 (0.51 to 0.57)
Geographical regions						
Andean Latin America	3328 (1207 to 6274)	17.86 (6.48 to 33.67)	13228 (5512 to 22211)	37.82 (15.76 to 63.5)	297.46 (167.67 to 538.93)	2.81 (2.61 to 3.01)
Australasia	697 (311 to 1188)	6.46 (2.88 to 11.01)	1185 (494 to 2069)	8.2 (3.42 to 14.33)	69.97 (27.47 to 119.76)	0.32 (0.03 to 0.61)
Caribbean	6914 (3180 to 10924)	37.85 (17.41 to 59.8)	19035 (10100 to 29089)	79.5 (42.18 to 121.48)	175.3 (116 to 261.54)	2.87 (2.75 to 2.99)
Central Asia	9566 (4771 to 14678)	28.69 (14.31 to 44.02)	26102 (12129 to 40863)	53.53 (24.88 to 83.81)	172.87 (127.89 to 232.85)	1.73 (1.53 to 1.92)
Central Europe	16341 (7386 to 25831)	26.32 (11.89 to 41.6)	11762 (5513 to 17991)	22.32 (10.46 to 34.15)	−28.02 (-38.15 to −14.58)	−0.34 (-0.44 to −0.23)
Central Latin America	25033 (11575 to 40731)	30.67 (14.18 to 49.9)	96323 (42439 to 159265)	72.35 (31.88 to 119.63)	284.79 (176 to 421.01)	3.09 (2.93 to 3.24)
Central Sub-Saharan Africa	13769 (5961 to 23665)	56.39 (24.42 to 96.92)	33591 (14414 to 60514)	51.52 (22.11 to 92.81)	143.96 (65.24 to 249.24)	−0.59 (-0.7 to −0.48)
East Asia	53058 (19770 to 101677)	7.7 (2.87 to 14.76)	79303 (31269 to 146177)	11.52 (4.54 to 21.23)	49.46 (-15.93 to 153.98)	1.02 (0.78 to 1.26)
Eastern Europe	27017 (12801 to 41211)	24.5 (11.61 to 37.37)	21032 (10069 to 32427)	21.86 (10.46 to 33.7)	−22.15 (-30.74 to −11.9)	−1.46 (-1.81 to −1.11)
Eastern Sub-Saharan Africa	21735 (9248 to 36529)	26.06 (11.09 to 43.79)	75970 (34463 to 124968)	36.28 (16.46 to 59.68)	249.52 (189.89 to 325.68)	1.11 (1.06 to 1.17)
High-income Asia Pacific	13566 (6586 to 21528)	14.61 (7.1 to 23.19)	7187 (3196 to 11798)	9.19 (4.09 to 15.08)	−47.02 (-60.65 to −32.51)	−2.06 (−2.55 to −1.57)
High-income North America	15727 (6906 to 26119)	10.55 (4.63 to 17.53)	47697 (21176 to 76522)	28.28 (12.55 to 45.37)	203.29 (130.85 to 316.6)	3.36 (2.88 to 3.85)

TABLE 2. Continued.

Feature	Cases_1990 (per 100,000 population, 95% UI)	Rates_1990 (95% UI)	Cases_2021 (per 100,000 population, 95% UI)	Rates_2021 (95% UI)	Cases_change (95% UI)	EAPC (95% CI)
North Africa and Middle East	41772 (18113 to 69517)	26.06 (11.3 to 43.37)	134720 (58607 to 229225)	40.3 (17.53 to 68.56)	222.51 (119.17 to 324.59)	1.62 (1.46 to 1.78)
Oceania	122 (49 to 222)	3.82 (1.54 to 6.96)	592 (256 to 1099)	8.37 (3.62 to 15.53)	384.67 (229.83 to 615.26)	2.62 (2.36 to 2.88)
South Asia	125332 (54601 to 210815)	23.69 (10.32 to 39.85)	319550 (140762 to 536372)	31.74 (13.98 to 53.28)	154.96 (104.51 to 199.03)	0.87 (0.8 to 0.94)
Southeast Asia	74364 (32471 to 123604)	31.43 (13.72 to 52.24)	202127 (91546 to 351008)	54.51 (24.69 to 94.66)	171.81 (118.67 to 229.56)	2.11 (2.02 to 2.21)
Southern Latin America	4089 (1683 to 7625)	16.69 (6.87 to 31.13)	7357 (3075 to 12546)	21.21 (8.87 to 36.17)	79.93 (23.9 to 157.14)	1.25 (1.04 to 1.46)
Southern Sub-Saharan Africa	12260 (5436 to 20770)	47.6 (21.1 to 80.64)	33978 (14784 to 56659)	78.71 (34.25 to 131.25)	177.15 (110.78 to 279.3)	1.13 (0.71 to 1.54)
Tropical Latin America	33274 (16871 to 50233)	42.38 (21.49 to 63.98)	49198 (25185 to 73019)	41.06 (21.02 to 60.94)	47.86 (31.48 to 67.4)	−0.39 (−0.52 to −0.26)
Western Europe	23371 (11069 to 37844)	12.08 (5.72 to 19.57)	20570 (9534 to 32811)	10.91 (5.06 to 17.41)	−11.99 (−21.48 to −1.03)	−0.43 (-0.53 to −0.33)
Western Sub-Saharan Africa	28552 (11413 to 50010)	33.35 (13.33 to 58.42)	120970 (55057 to 201273)	52.75 (24.01 to 87.77)	323.68 (233.98 to 449.41)	1.76 (1.58 to 1.94)

CI, confidence interval; EAPC, estimated annual percentage change; UI, uncertainty intervals; SDI, sociodemographic index; SBP, systolic blood pressure; CKD, chronic kidney disease; DALYs, disability-adjusted life years.

National variations in the attributable burden across 204 countries

From 1990 to 2021, the mortality burden of CKD attributable to high SBP varied substantially among 204 countries and territories. The absolute number of attributable deaths increased by more than 600% in 10 countries, including Ukraine, Uzbekistan, Guatemala, Cameroon, Belize, Papua New Guinea, Oman, Zambia, Saudi Arabia, and Libya (Supplementary Figure 1a, b; Supplementary Table 1). In contrast, the number of attributable deaths decreased in several countries, with reductions greater than 50% in seven countries, including the Republic of Korea, Czechia, Germany, Poland, Japan, Romania, and Hungary (Supplementary Figure 1a, b; Supplementary Table 1).

Regarding the attributable mortality rate in 2021, the highest value was observed in Mauritius (3.08 per 100,000 population; 95% UI, 1.35–5.51), whereas the lowest value was found in Sweden (0.02 per 100,000 population; 95% UI, 0.01–0.05) (Supplementary Figure 1a; Supplementary Table 1). Among trends, Ukraine had the largest annual increase in the attributable mortality rate (EAPC, 13.21%; 95% CI, 11.20–15.25), while the Republic of Korea achieved the largest annual decline (EAPC, −4.68%; 95% UI, −5.14 to −4.22) (Supplementary Figure 1c; Supplementary Table 2).

From 1990 to 2021, DALYs due to CKD attributable to high SBP showed substantial variation among 204 countries and territories. Guatemala exhibited the largest increase, with attributable DALYs rising by 1,033.96% (95% UI, 618.78–1,918.25) (Supplementary Figure 1d, e; Supplementary Table 3). In contrast, the Republic of Korea reported the largest reduction in attributable DALYs. Guatemala also had the fastest annual growth rate in attributable DALY rates (EAPC, 6.5%; 95% CI, 5.73–7.27), whereas the Republic of Korea experienced the largest declines (Supplementary Figure 1f; Supplementary Table 3).

Correlations between the attributable burden and SDI

Globally, we assessed the correlation between SDI and two aspects of the CKD burden attributable to high SBP: its temporal trend and its absolute level in 2021. Regarding the temporal trend, the EAPC in mortality attributable to high SBP showed no significant correlation with the baseline attributable mortality rate in 1990 ($\rho = -0.017$, $p = 0.812$) (Figure 3a), nor with national SDI levels ($\rho = -0.005$, $p = 0.972$) (Figure 3b). These results suggest that the rate of change in attributable mortality over the study period was not systematically associated with a country's initial attributable burden or its level of socioeconomic development. In contrast, when examining the absolute burden level, a significant negative correlation was observed between SDI and the attributable mortality rate in 2021 ($\rho = -0.372$, $p < 0.001$) (Figure 3c), indicating that regions with higher SDI generally exhibited lower attributable mortality rates.

A parallel pattern was observed for DALYs. The EAPC for attributable DALYs was not significantly correlated with baseline DALYs in 1990 ($\rho = -0.029$, $p = 0.682$) (Figure 3d) or with SDI levels ($\rho = -0.031$, $p = 0.829$) (Figure 3e). This suggests that the pace of change in attributable DALYs over time was similar across countries, regardless of their initial burden or development status. However, the attributable DALY rate in 2021 showed a significant negative correlation with SDI ($\rho = -0.32$, $p < 0.001$) (Figure 3f), indicating that regions with higher sociodemographic development tended to have a lower absolute attributable burden.

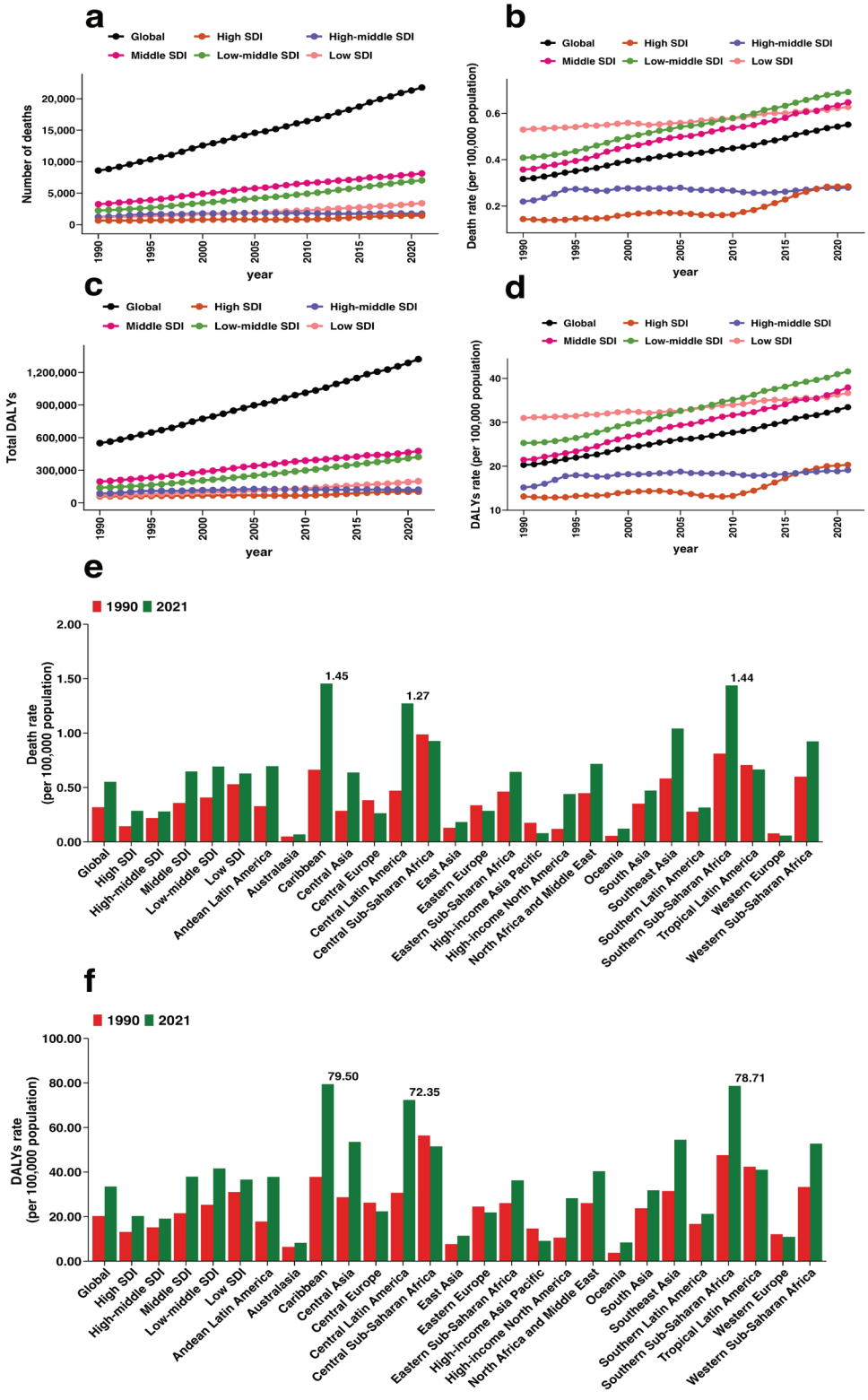

FIG. 2. Regional differences in the number of deaths and DALYs from CKD attributable to high SBP among young adults aged 25–49 years in 1990 and 2021. (a, b) The number of attributable deaths and attributable death rates over time at SDI region and globally. (c, d) Temporal trend of attributable DALYs and attributable DALY rates at SDI region and globally. (e, f) Attributable death and DALY rates at the global, SDI, and regional levels.
SDI, sociodemographic index; SBP, systolic blood pressure; CKD, chronic kidney disease; DALYs, disability-adjusted life years.

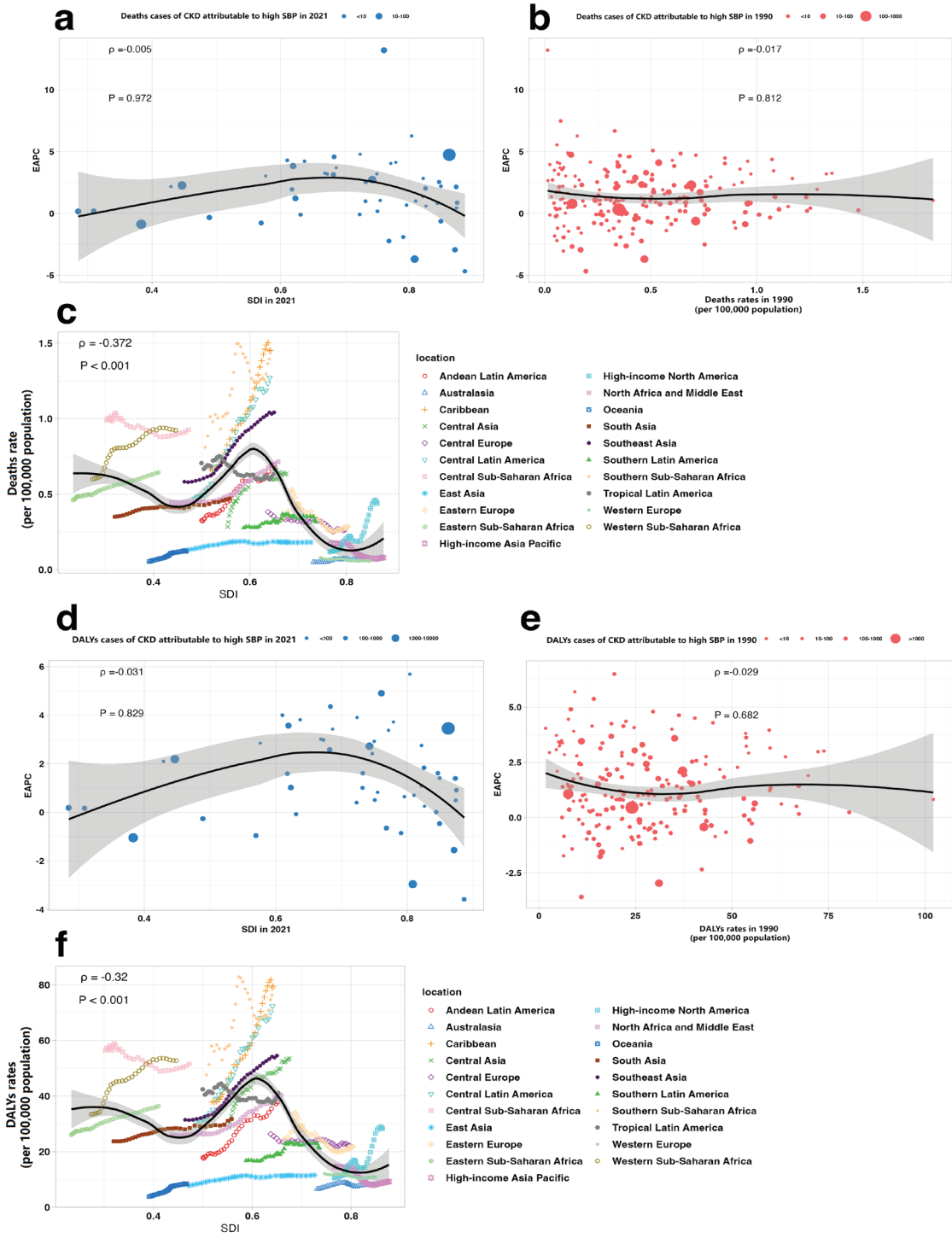

FIG. 3. Correlations between the attributable burden, its temporal trends, and SDI among young adults aged 25-49 years. (a) Association between the SDI in 2021 and the EAPC in attributable death rates from 1990 to 2021. (b) Association between attributable death rates in 1990 and EAPC in attributable death rates from 1990 to 2021. (c) Relationship between SDI and attributable death rates from 1990 to 2021 across global regions. (d) Association between the SDI in 2021 and the EAPC in attributable DALY rates from 1990 to 2021. (e) Association between attributable DALY rates in 1990 and EAPC in attributable DALY rates from 1990 to 2021. (f) Relationship between SDI and attributable DALY rates from 1990 to 2021 across global regions. Note: Spearman rank correlation coefficients (ρ) were calculated to assess associations between variables. The solid curves represent locally weighted regression (LOESS) smoothing to illustrate potential non-linear trends, with shaded areas indicating 95% confidence intervals.

SDI, sociodemographic index; DALYs, disability-adjusted life years; EAPC, estimated annual percentage change.

Projected trends in attributable burden to 2050

The projected trend for mortality from CKD burden attributable to high SBP among young adults aged 25–49 years suggests a potential global increase, with substantial variation across sex, age, and region. According to model projections, the attributable mortality rate for males is expected to reach approximately 0.96 (95% UI, 0.92–0.99) per 100,000 population in 2050, whereas for females, it is projected to reach approximately 0.66 (95% UI, 0.19–1.13) per 100,000 population (Figure 4a; Supplementary Table 4). The projections indicate a notably higher potential increase in attributable mortality among the 45–49-year age group compared with other age groups (Figure 4b; Supplementary Table 5). Globally, the attributable mortality rate is projected to rise to 0.77 (95% UI, 0.73–0.81) per 100,000 population in 2050 (Figure 4a-c; Supplementary Tables 4-6). Model results suggest that mortality from high SBP–related CKD may increase to varying degrees across SDI regions, although a slight decrease is projected in high-middle SDI regions (Figure 4c; Supplementary Table 6).

The projected trend for DALYs due to CKD attributable to high SBP among the 25–49 age group indicates a potential global increase, with persistent disparities by sex, age, and SDI level. Based on projections, attributable DALYs for both males and females are expected to increase by 2050 (Figure 4d; Supplementary Table 7). Age-specific predictions suggest that older age groups may experience a greater rate of increase, with the 40–44-year age group showing the largest projected rise, from 72.31 (95% UI, 68.54–76.08) in 2025 to 102.59 (95% UI, 38.91–166.28) per 100,000 population in 2050 (Figure 4e; Supplementary Table 8). The global attributable DALY rate is projected to increase from 35.68 (95% UI, 34.77–36.59) in 2025 to 49.23 (95% UI, 41.30–57.16) per 100,000 population in 2050 (Figure 4d-f; Supplementary Tables 7-9). The model projects that middle and low-middle SDI regions will experience the greatest increases in the attributable DALY rate, from 40.20 (95% UI, 39.14–41.26) in 2025 to 53.47 (95% UI, 50.45–56.49) and from 43.80 (95% UI, 42.75–44.86) to 56.62 (95% UI, 52.85–60.38) per 100,000 population, respectively, by 2050 (Figure 4f; Supplementary Table 9).

DISCUSSION

The burden of CKD attributable to high SBP represents a significant and growing public health concern globally. Our findings indicate an increasing trend in both mortality and DALYs attributable to this risk factor among young adults aged 25–49 years between 1990 and 2021. Epidemiological studies suggest a trend toward earlier onset of hypertension, which may contribute to the rising attributable burden in this age group.[19,20] This trend may be influenced by multiple factors, including lifestyle behaviors (such as obesity and alcohol consumption), genetic susceptibility, and environmental changes.[21,22] Young and middle-aged adults often face considerable life and work pressures, which can lead to emotional tension. Coupled with irregular diet and rest, this may result in abnormal sympathetic nervous system activation, thereby increasing the risk of high blood pressure.[23] However, hypertension control in this demographic remains suboptimal. For example, data from the China Health and Nutrition Survey (2011) showed that among individuals aged 40–59, the awareness, treatment, and control rates of hypertension were 50.9%, 40.9%, and 18.8%, respectively.[24] In contrast, corresponding rates in the United States were notably higher at 83.0%, 73.7%, and 57.8%.[25] Furthermore, renal damage caused by hypertension is cumulative over time and often asymptomatic in early stages. This insidious nature may foster complacency in blood pressure control, ultimately contributing to CKD development. These findings underscore the need for enhanced public health efforts focused on improving hypertension awareness, detection, and management among young adults, which could serve as a foundational strategy for mitigating the future burden of CKD attributable to this risk factor.

The estimated burden of CKD attributable to high SBP varied substantially by sex, with a consistently higher burden observed in males than in females. This disparity may partly reflect a higher prevalence of modifiable risk factors commonly reported among men, including smoking, harmful alcohol use, and potentially lower rates of adherence to hypertension treatment.[26-28] In addition, the Global Status Report on Alcohol and Health highlights that, except in the WHO European Region, global alcohol consumption is increasing, particularly among young men.[29] Simultaneously, differences exist in the proportion of attributable burden across age groups. Generally, the burden increases with age, with the greatest rise observed in adults aged 45–49 years. This pattern is likely due to the longer duration of illness and higher prevalence of comorbidities in this age group, including diabetes,[30] dyslipidemia,[31] and hyperuricemia.[32] Therefore, these sex- and age-specific risk factors should be considered when developing targeted policies for young adults.

Our analysis revealed significant disparities in the attributable burden across regions and SDI levels. Both attributable mortality and DALYs were generally higher in regions with lower SDI and lower in high-SDI regions, a pattern consistent with trends observed for many noncommunicable diseases.[33] These disparities may be influenced by differences in health policies, public awareness, and chronic disease management capacity. Our results underscore the importance of equity-oriented approaches in global health. To address these disparities, future efforts could focus on strengthening health systems, improving access to care, and implementing context-specific hypertension management programs, particularly in low-resource settings. International collaboration and investment may be crucial to support such efforts in low-SDI regions.

Notably, our forecasting model indicates that the mortality and DALYs attributable to CKD from high SBP are projected to continue rising globally over the next three decades. Although these projections are uncertain, they suggest a persistent and growing public health challenge associated with this risk factor. The forecasts also reveal heterogeneous trends across development strata, with minimal projected change in high-SDI regions. This disparity may reflect advances in healthcare systems, broader access to effective management, and the implementation of comprehensive noncommunicable disease policies in these settings. Therefore, the international community and governments can leverage

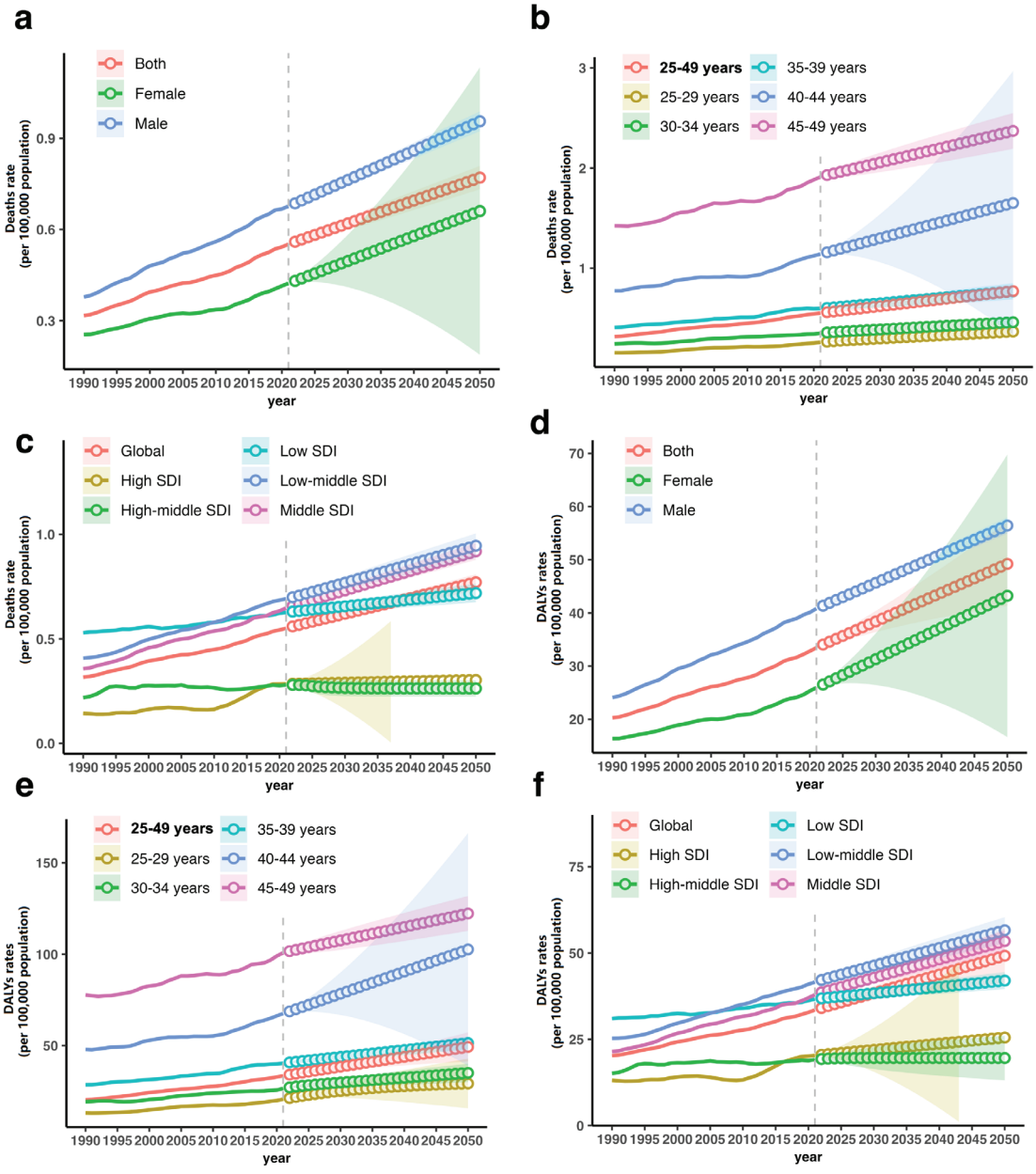

FIG. 4. Projected trends in attributable death and DALY rates by sex, age and SDI region. (a-c) Trends and projections in attributable death rate by sex, age, and SDI region. (d-f) Trends and projections in attributable DALY rates by sex, age, and SDI region.
SDI, sociodemographic index; DALYs, disability-adjusted life years.

the valuable experience of high-SDI countries to support under-resourced regions and achieve truly global health.

Several limitations of this study should be acknowledged to ensure appropriate interpretation of our findings. First, the analysis relies on GBD data and its methodological framework. As a secondary analysis, the estimates depend on the quality, coverage, and modeling assumptions of the underlying source data, which vary across regions and over time. Observed trends may also be influenced by methodological updates across GBD cycles, not solely by true epidemiological changes. Second, our use of the EAPC to quantify temporal trends assumes an approximately log-linear pattern over the study period (1990–2021). While trends were visually inspected before analysis and EAPC provides a robust summary measure of net change, it may not fully capture sub-

period accelerations, decelerations, or more complex nonlinear fluctuations, particularly at the regional level. A single EAPC estimate could smooth over important temporal variations. More nuanced methods, such as segmented regression, could be considered in future studies to identify potential turning points in specific contexts. Third, comparisons may be biased by differences in population age structure. Although this study focused on adults aged 25–49 years, rates were not age-standardized within this range. Given the strong age gradient shown in the results, differences in population age structure across countries could affect the comparability of crude rates. Fourth, the study assesses attributable burden, not direct causation. This population-level observational analysis quantifies the statistical association between high SBP and CKD within a counterfactual framework. It does not establish individual-level clinical causation or evaluate the effectiveness of specific interventions. Fifth, estimates for some subgroups have greater uncertainty. UIs were wider for groups with low event rates or high internal heterogeneity, reflecting data sparsity. Finally, long-term projections are inherently uncertain. Future changes in demographics, risk factors, health policies, or treatments could alter the projected burden. Despite these limitations, this study provides valuable evidence to guide interventions and policy planning aimed at reducing the CKD burden attributable to high SBP.

In conclusion, our analysis reveals a rising and inequitably distributed burden of CKD attributable to high SBP among young adults globally, with pronounced disparities by sex and SDI. These findings highlight the potential need for enhanced, equity-focused public health strategies that prioritize hypertension prevention and management within broader noncommunicable disease agendas. They also underscore the importance of sustained surveillance and research to track trends and evaluate the impact of interventions. Ultimately, this study provides a population-level evidence base to inform health policy planning and guide future investigations aimed at reducing the blood pressure–mediated burden of kidney disease.

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Informed Consent: Not applicable.

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Conflict of Interest: The authors declared that they have no conflict of interest.

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Supplementary Tables: https://balkanmedicaljournal.org/img/files/Supplemental-Tables.pdf

Supplementary Figure: https://balkanmedicaljournal.org/img/files/Supplemental-Figure.pdf

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