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Global, Regional, and National Burden of Stroke on Children and Adolescents Aged Under 20 Years From 1990 to 2021, With Projections of Disability-Adjusted Life Year to 2050: A Comprehensive Demographic Analysis for the Global Burden of Disease Study 2021

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ABSTRACT

Background: Stroke in children is a global epidemic.

Methods: Data on stroke, including incidence, DALYs, mortality, and associated risk factors from 1990 to 2021, were obtained from the Global Burden of Disease (GBD) study, 2021. Estimated annual percentage changes were calculated to evaluate changes in the age-standardized rates of incidence (ASIR), DALYs (ASDR), and mortality (ASMR), as well as trends by age, sex, and sociodemographic index (SDI). Projections of DALYs to 2050 were made.

Results: In 2021, there were 310,133 incident stroke cases, accounting for 24,807 deaths and 2,414,655 DALYs among children and adolescents. The global ASIR, ASDR, and ASMR for stroke were 11.8, 93.9, and 1.0 per 100,000 population, respectively. Middle-to-low-SDI regions accounted for 81.6% of incident cases, 90.2% of DALYs, and 92.7% of deaths. A reversed V-shaped association was observed between SDI and ASRs. Children < 1 year had the highest ASRs, with rates generally decreasing with age, and the highest incidence of hemorrhagic stroke. Adolescents aged 15–19 years had the highest incidence of ischemic stroke. Non-optimal temperature contributed the most to the DALYs and death rates for stroke. By 2050, it is projected that 282,404 DALYs will be lost due to stroke.

Conclusions: Stroke burden varies by the GBD region, country, age, sex, and SDI. Despite declines in ASRs, stroke remains a significant burden, especially in middle-to-low-SDI regions, among children < 1 year, and among those with intracerebral hemorrhage. Non-optimal temperature emerges as the leading modifiable risk factor for children stroke; targeted interventions can prevent this.

Jing-Jie Li, Xiao-Peng Wang, Qian-Nan Wang and Zi-Qing Kong contributed equally to this article.

1 | Introduction

Stroke remains a leading cause of death and disability worldwide. In 2021, stroke was the third leading cause of death at Global Burden of Disease (GBD) level 3, following ischemic heart disease and coronavirus 2019, and the fourth leading cause of disability-adjusted life years (DALYs). In 2021, 11.9 million strokes occurred globally, resulting in 7.3 million deaths and 160.5 million DALYs [1–3].

Stroke causes significant neurological morbidity in children, often resulting in permanent life-long neurological deficits [4–7]. Notably, the incidence of stroke in children is comparable to that of brain tumors [8]. However, stroke is slightly more common in this population, with an occurrence rate of 2–13 cases per 100,000 person-years [5, 9–11]. The severity of pediatric stroke and the substantial burden it imposes have been reported [12]. Despite continued efforts to raise awareness about pediatric stroke, it is still often overlooked as a possible cause of symptoms by both healthcare providers and families.

Current prevention and treatment strategies are adult-focused, leading to delayed detection and intervention for stroke in children and adolescents, making stroke a life-threatening event in this population. Despite global stroke epidemiology studies, updated data specific to children and adolescents remain limited [13].

GBD 2021 provides a unique framework for evaluating disease burden, integrating multiple factors for a comprehensive view of health challenges worldwide [14]. This study examined stroke incidence, mortality, DALYs, and risk factors in children and adolescents at global, regional, and national levels from 1990 to 2021, with analyses by social development level, age, and sex. Furthermore, we forecast DALYs through 2050. These findings aim to support effective prevention and control policies, enhance public healthcare, reduce stroke burden in young populations, and promote overall health and well-being.

2 | Methods

2.1 | Study Population and Data Collection

Childhood stroke data were sourced from GBD 2021 via the Global Health Data Exchange query tool (http://ghdx.healthdata.org/gbd-results-tool). The study adheres to the Guidelines for Accurate and Transparent Health Estimates Reporting. GBD 2021 systematically estimates publicly available, published, and contributed data with enhanced method performance and standardization of the prevalence, incidence, mortality, and DALYs of 370 injuries and diseases across 204 countries and territories from 1990 to 2021, stratified by age, sex, and country. Detailed methods for GBD 2021 have been documented previously [14]. Data on stroke incidence, mortality, and DALYs were extracted, focusing on ischemic stroke (IS), intracerebral hemorrhage (ICH), and subarachnoid hemorrhage (SAH) in children and adolescents (< 20 years). Six age groups were analyzed: < 1, 1, 2–4, 5–9, 10–14, and 15–19 years. For DALYs projection, four age groups were used: < 5, 5–9, 10–14, and 15–19 years.

2.2 | Estimation Framework of the Disease Burden of Stroke in Children and Adolescents

In GBD 2021, a Bayesian meta-regression tool estimated stroke incidence from population surveys, cohorts, registries, health system administrative data, and microdata from registry and cohort studies. Mortality rates were primarily estimated using the cause-of-death ensemble model. Disability weight measures health loss severity or the extent of nonfatal disability. Years lived with disability (YLD) were calculated by multiplying patient count by duration until remission or death, adjusted for disability weight. Years of life lost (YLL) were determined by multiplying death count by standard life expectancy from a reference life table. DALYs represent the total healthy years lost from disease onset to death, calculated as the sum of YLL and YLD. DALYs serve as a crucial parameter for assessing disease burden.

2.3 | Definition of Stroke

In GBD 2021, IS was defined according to International Classification of Diseases (ICD)-10 (codes I63.0–I63.9) and ICD-9 (codes 434.0–434.9 and 436). ICH was defined according to ICD-10 (codes I61.0–I61.9) and ICD-9 (code 431). SAH was defined according to the ICD-10 (codes I60.0–I60.9, I62.0, I67.0–I67.1, and I69.0) and ICD-9 (430.0–430.9).

2.4 | Sociodemographic Index

The sociodemographic index (SDI) is a composite indicator of a country or region's level of development, based on lag-distributed income per capita and average educational attainment for individuals under 20 years. SDI strongly correlates with health outcomes including disease incidence, mortality, and DALY rates. SDI ranges from 0 (lowest development) to 1 (highest). We classified 204 countries and 21 regions into five groups: low, low-middle, middle, high-middle, and high based on their SDI values to examine the relationship between stroke burden and SDI.

2.5 | Risk-Attributable Burden

GBD 2021 yields 87 risk factors, with two (high and low temperature) contributing to childhood stroke DALYs. We assessed their percentage contributions to childhood stroke DALYs in 2021. These risk factors were previously defined [1].

2.6 | Cross-Country Social Inequalities Analysis

The study assessed the distributive inequality of stroke burden across countries using the slope index of inequality (SII) and health inequality concentration index, representing absolute and relative gradients, respectively. The SII was calculated by regressing the age-standardized DALY rate (ASDR) for stroke among individuals under 20 years on an income-related relative social position scale based on the cumulative class interval midpoint of populations ranked by gross domestic product per capita. A weighted regression model addressed heteroskedasticity, and a logarithmic transformation was applied for non-linearity due to marginal utility.

The health inequality concentration index was determined by fitting a Lorenz concentration curve to the cumulative relative distributions of income-ranked populations and DALY burden of disease. This index was calculated by numerically integrating the area under the Lorenz curve. The SII and concentration index were calculated to quantify the absolute and relative cross-country inequalities in the burden of stroke, with negative and positive values indicating a higher burden in lower SDI and higher SDI countries, respectively.

2.7 | Statistical Analysis

The age-standardized rate (ASR) was computed per 100,000 individuals as follows:

$$\mathrm{ASR} = \frac{\sum_{i=1}^{A} a_i \omega_i}{\sum_{i=1}^{A} \omega_i} \times 100{,}000$$

(a_i: the age-specific rate in the ith age group; ω: the number of people in the corresponding ith age group among the standard population; A: the number of age groups).

The estimated annual percentage changes (EAPCs) in ASRs were calculated to evaluate trends over time. The natural logarithm of the ASR follows the linear regression model $y = \alpha + \beta x + \varepsilon$, where y represents the natural logarithm of ASR and x denotes the calendar year. EAPCs were calculated as $100 \times (e\text{^}\beta - 1)$, with 95% confidence intervals (CIs) derived from the same model.

Smoothing spline models evaluated the relationship between stroke burden in individuals under 20 years and SDI across 21 regions and 204 countries and territories. The expected values were based on SDI and disease rates. We applied locally weighted scatterplot smoothing, which automatically adjusts the degree, number, and placement of knots based on the data and span parameters.

We used forecasted SDI as a predictor in a regression model to estimate stroke-related DALYs through 2050, broken down by age, sex, year, and location. For each location (l), age (a), sex (s), and year (y), we logit-transformed the GBD 2021 stroke DALYs estimates logit ($Y_{l,a,s,y}$) and applied a fixed coefficient ($\beta 1$) on SDI over time for stroke, with a random intercept (α).

$$E\left[\mathrm{logit}\left(Y_{\{l,a,s,y\}}\right)\right] = \beta_1 SDI + \alpha_{\{l,a,s\}}$$

We calculated the difference between the GBD estimates in rate space and the forecasted estimates for 2021, adjusting the trend through 2050 to align with GBD data. To estimate case numbers, we multiplied the forecasted population by the predicted DALYs.

A descriptive analysis characterized the global stroke burden in individuals under 20 years. We calculated the age-standardized incidence rate (ASIR), ASDR, and age-standardized mortality rate (ASMR) per 100,000 population with 95% uncertainty intervals (UIs) from 1990 to 2021 across age groups, sexes, SDI scores, regions, and countries. Age standardization eliminated population age composition effects, enhancing comparability. All analyses and mapping were performed using R software (version 4.4.1), with two-sided hypothesis tests and significance set at $p < 0.05$.

3 | Results

3.1 | Global Trends

In 2021, the global burden of stroke in individuals under 20 years remained significant, with 310,133 (95% UI: 227,648 to 438,746) new cases. The ASIR decreased from 14.6/100,000 (95% UI: 9.8 to 21.5) in 1990 to 11.8/100,000 (95% UI: 7.7 to 17.9) in 2021, with an EAPC of −0.91% (95% CI: −1.00% to −0.81%), indicating a consistent global incidence decline from 1990 to 2021 (Table 1; Figure 1A; Figure S1). Among females, the stroke incidence in 2021 was 163,459 (95% UI: 117,414 to 236,489), with an ASIR of 13.5/100,000 population (95% UI: 9.0 to 20.0) and an EAPC of −0.90% (95% UI: −1.00% to −0.79%). Among males, there were 146,673 cases (95% UI: 109,400 to 201,455), with an ASIR of 10.8/100,000 (95% UI: 7.1 to 16.3), and a slightly higher decline with an EAPC of −0.91% (95% CI: −1.00% to 0.82%) (Tables S1 and S2).

In 2021, global stroke DALYs reached 2,414,655 (95% UI: 2,077,840 to 2,772,840), with an ASDR of 93.9/100,000 (95% UI: 76.9 to 113.5) and an EAPC of −3.14% (95% CI: −3.21 to −3.07) from 1990 to 2021 (Table 1; Figure 1B; Figure S2). The ASDR for females was 88.9/100,000 (95% UI: 72.6 to 109.6), lower than that for males at 98.6/100,000 (95% UI: 79.4 to 119.8). ASDR declined more for females from 1990 to 2021, with a reduction of −3.28% (95% CI: −3.34 to −3.22) versus −3.02% (95% CI: −3.09 to −2.94) for males (Tables S1 and S2).

Globally, stroke mortality in 2021 was estimated at 248,075 deaths (95% UI: 20,858 to 28,757), with an ASMR of 1.0/100,000 (95% UI: 0.8 to 1.2) and an EAPC of −3.31% (95% CI: −3.39% to −3.22%) (Table 1; Figure 1C; Figure S3). Overall, stroke ASRs decreased significantly from 1990 to 2021. Females had a higher ASIR but slower decrease than males, while males had higher ASDR and ASMR but slower decreases than females (Supplemental Results in Data S1; Tables S2 and S3). The decrease in female deaths showed a significantly higher EAPC (−3.54 [95% CI: −3.62 to −3.46]) compared to males (−3.12 [95% CI: −3.21 to −3.03]) (Tables S1 and S2).

3.2 | Geographical and SDI Regional Trends

The global stroke burden exhibited significant regional variations closely tied to SDI levels. In 2021, middle-to-low-SDI regions accounted for 81.6% of cases, 90.2% of DALYs, and 92.7% of childhood stroke deaths (Figure 2). Regions with the highest stroke incidence in 2021 included Western Sub-Saharan Africa, North Africa and the Middle East, Oceania, the Caribbean, and Southeast Asia, with Western Sub-Saharan Africa having the highest ASIR for stroke at 18.9/100,000 (95% UI: 13.2 to 27.2). All regions showed ASIR declines (EAPC < 0), with the greatest

TABLE 1 | Incident cases, disability-adjusted life years (DALYs), and deaths for stroke from 1990 to 2021 and estimated annual percentage change (EAPC) in age-standardized rates (ASRs) per 100,000, by Global and Regional Level, from 1990 to 2021 in Children and Adolescents.

	Number of cases, 1990 (95% UI)	ASIR per 100,000 population, 1990 (95% UI)	Number of cases, 2021 (95% UI)	ASIR per 100,000 population, 2021 (95% UI)	EAPC 1990–2021 (95% CI)
Incidence					
Global	328,299 (247,647 to 448,848)	14.6 (9.8 to 21.5)	310,133 (227,648 to 438,746)	11.8 (7.7 to 17.9)	−0.91% (−1.00 to −0.81)
SDI					
High SDI	31,475 (22,575 to 44,862)	12.7 (8.1 to 19.5)	23,099 (16,145 to 33,921)	10.0 (6.1 to 15.8)	−0.99% (−1.07 to −0.91)
High-middle SDI	57,180 (43,193 to 77,697)	15.6 (10.6 to 22.8)	33,748 (24,100 to 49,015)	11.2 (7.1 to 17.2)	−1.34% (−1.45 to −1.23)
Middle SDI	118,372 (90,097 to 160,052)	15.6 (10.6 to 22.7)	87,192 (63,479 to 123,739)	11.7 (7.5 to 17.7)	−1.17% (−1.28 to −1.06)
Low-middle SDI	75,495 (56,326 to 104,286)	12.8 (8.5 to 19.1)	86,470 (63,672 to 122,241)	11.3 (7.4 to 17.1)	−0.57% (−0.67 to −0.47)
Low SDI	45,496 (34,963 to 61,264)	16 (10.9 to 23.5)	79,375 (60,262 to 109,336)	13.5 (9.1 to 20)	−0.79% (−0.89 to −0.69)
Regions					
East Asia	78,028 (59,833 to 104,141)	17.2 (11.9 to 24.8)	40,406 (28,334 to 58,374)	11.8 (7.5 to 18.3)	−1.48% (−1.60 to −1.36)
Southeast Asia	33,602 (25,506 to 45,662)	15.4 (10.4 to 22.5)	28,503 (21,379 to 39,380)	12.4 (8.1 to 18.4)	−0.83% (−0.92 to −0.74)
Oceania	587 (447 to 780)	17.2 (11.7 to 24.9)	1008 (788 to 1321)	15.2 (10.6 to 21.8)	−0.42% (−0.48 to −0.37)
Central Asia	3880 (2824 to 5569)	12.5 (7.9 to 19.1)	3534 (2506 to 5211)	10.4 (6.3 to 16.5)	−0.76% (−0.85 to −0.66)
Central Europe	4744 (3505 to 6680)	12.2 (7.9 to 18.2)	2186 (1561 to 3179)	9.2 (5.6 to 14.4)	−1.07% (−1.18 to −0.97)
Eastern Europe	7748 (5459 to 11,390)	11.5 (7 to 18.1)	4403 (3043 to 6581)	9.5 (5.7 to 15.1)	−0.85% (−1.03 to −0.66)
High-income Asia Pacific	6037 (4366 to 8441)	12.2 (7.9 to 18.6)	2954 (2043 to 4223)	9.7 (5.9 to 15.3)	−1.09% (−1.22 to −0.97)
Australasia	483 (341 to 696)	7.7 (4.6 to 12.2)	526 (386 to 701)	7 (4.3 to 10.7)	−0.31% (−0.40 to −0.23)
Western Europe	9558 (6687 to 13,991)	9.8 (5.9 to 15.3)	6697 (4514 to 9864)	7.3 (4.3 to 11.8)	−1.17% (−1.27 to −1.06)
Southern Latin America	2714 (2087 to 3607)	14.1 (9.5 to 20.1)	2038 (1500 to 2794)	10.5 (6.7 to 15.8)	−1.15% (−1.29 to −1.01)
High-income North America	11,759 (8082 to 17,447)	14.5 (8.7 to 23.1)	9704 (6612 to 14,629)	11.1 (6.5 to 17.8)	−1.20% (−1.31 to −1.09)
Caribbean	2357 (1840 to 3055)	15.7 (11 to 22.2)	1984 (1542 to 2589)	13.2 (9.2 to 18.8)	−0.73% (−0.82 to −0.65)
Andean Latin America	2986 (2398 to 3827)	15.8 (11.4 to 21.7)	2734 (2073 to 3652)	11.5 (7.6 to 16.9)	−1.20% (−1.29 to −1.11)
Central Latin America	12,990 (9915 to 17,516)	15.7 (10.8 to 22.9)	9618 (7095 to 13,307)	11.3 (7.4 to 17)	−1.29% (−1.39 to −1.20)
Tropical Latin America	8443 (6208 to 11,637)	12.3 (8.1 to 18.4)	5451 (3899 to 7646)	8.2 (5.1 to 12.5)	−1.58% (−1.74 to −1.42)

(Continues)

TABLE 1 | (Continued)

	Number of cases, 1990 (95% UI)	ASIR per 100,000 population, 1990 (95% UI)	Number of cases, 2021 (95% UI)	ASIR per 100,000 population, 2021 (95% UI)	EAPC 1990–2021 (95% CI)
North Africa and Middle East	36,086 (27,834 to 47,938)	20.4 (14.2 to 29.4)	36,908 (27,635 to 51,168)	15.7 (10.5 to 23.4)	−1.10% (−1.20 to −1.00)
South Asia	54,938 (39,192 to 79,181)	10.2 (6.4 to 15.8)	60,219 (42,084 to 88,419)	8.7 (5.2 to 13.8)	−0.67% (−0.80 to −0.53)
Central sub-Saharan Africa	4930 (3762 to 6743)	15.6 (10.4 to 23.3)	8551 (6212 to 12,198)	11.7 (7.4 to 17.9)	−1.24% (−1.34 to −1.14)
Eastern sub-Saharan Africa	17,054 (12,942 to 23,156)	15.4 (10.3 to 22.9)	27,544 (20,110 to 39,055)	12.1 (7.8 to 18.5)	−0.99% (−1.09 to −0.89)
Southern sub-Saharan Africa	3626 (2583 to 5323)	13.7 (8.4 to 21.5)	3460 (2381 to 5253)	11.1 (6.7 to 17.8)	−0.94% (−1.16 to −0.73)
Western sub-Saharan Africa	25,742 (20,183 to 33,831)	22.9 (16.1 to 32.6)	51,694 (40,191 to 69,222)	18.9 (13.2 to 27.2)	−0.87% (−0.97 to −0.76)
DALYs					
Global	5,876,672 (4,780,062 to 7,896,538)	264.4 (209.7 to 360.7)	2,414,655 (2,077,840 to 2,772,840)	93.9 (76.9 to 113.5)	−3.14% (−3.21 to −3.07)
SDI					
High SDI	221,290 (201,391 to 249,215)	90.6 (78.5 to 105.9)	76,835 (64,911 to 88,834)	32.3 (26.7 to 38)	−3.26% (−3.34 to −3.17)
High-middle SDI	763,059 (666,861 to 932,417)	217.1 (181 to 275.7)	156,186 (135,513 to 176,623)	52.2 (43.4 to 61.1)	−4.47% (−4.58 to −4.35)
Middle SDI	1,811,397 (1,582,529 to 2,200,524)	245.4 (206 to 305)	536,944 (478,473 to 593,114)	72.7 (62.6 to 83.2)	−3.61% (−3.71 to −3.51)
Low-middle SDI	2,056,552 (1,564,849 to 2,962,769)	340.3 (250.8 to 496.9)	796,580 (677,584 to 923,487)	105.8 (86.5 to 128.8)	−3.55% (−3.64 to −3.46)
Low SDI	1,019,255 (691,452 to 1,600,160)	332.6 (222.3 to 518.7)	845,201 (634,425 to 1,095,433)	142.1 (104.5 to 189.3)	−2.89% (−2.98 to −2.79)
Regions					
East Asia	1,204,207 (1,059,715 to 1,385,181)	269.7 (225.3 to 325.8)	189,631 (154,249 to 222,829)	56.6 (44.4 to 69.1)	−5.06% (−5.17 to −4.94)
Southeast Asia	674,619 (529,528 to 910,281)	318.3 (242.5 to 437.7)	313,334 (271,883 to 355,460)	137 (111.5 to 163.1)	−2.46% (−2.51 to −2.40)
Oceania	10,037 (6347 to 15,244)	288.5 (167.4 to 479.3)	15,892 (11,165 to 21,873)	233.6 (142.8 to 358.8)	−0.38% (−0.73 to −0.04)
Central Asia	24,769 (22,075 to 27,905)	80.5 (68.7 to 94.2)	13,254 (11,403 to 15,435)	40 (32.9 to 47.5)	−2.56% (−2.78 to −2.33)
Central Europe	39,577 (36,607 to 43,313)	106.8 (95.2 to 120.8)	7665 (6382 to 8922)	31.6 (25.7 to 37.6)	−3.69% (−3.85 to −3.53)

(Continues)

TABLE 1 | (Continued)

	Number of cases, 1990 (95% UI)	ASIR per 100,000 population, 1990 (95% UI)	Number of cases, 2021 (95% UI)	ASIR per 100,000 population, 2021 (95% UI)	EAPC 1990–2021 (95% CI)
Eastern Europe	36,444 (32,778 to 40,266)	55 (49 to 61.7)	14,072 (11,854 to 16,372)	29.9 (24.9 to 35.3)	−2.27% (−2.88 to −1.65)
High-income Asia Pacific	46,619 (40,660 to 53,197)	94.3 (77.9 to 113.4)	9259 (7530 to 10,926)	28.1 (22.7 to 33.7)	−3.94% (−4.18 to −3.70)
Australasia	2360 (2121 to 2598)	36.5 (31.8 to 41.5)	1157 (940 to 1389)	14.9 (11.8 to 18.1)	−2.99% (−3.16 to −2.82)
Western Europe	63,953 (60,153 to 68,228)	64.1 (59.1 to 69.4)	17,125 (14,280 to 19,938)	17.9 (14.7 to 21.2)	−4.03% (−4.17 to −3.88)
Southern Latin America	25,504 (23,887 to 27,211)	134.4 (119.9 to 150.4)	7954 (7041 to 8942)	38.7 (32.9 to 45)	−3.34% (−3.67 to −3.00)
High-income North America	58,089 (51,970 to 64,649)	71.8 (63.3 to 80.9)	37,113 (31,223 to 43,213)	41.1 (33.8 to 48.9)	−2.03% (−2.19 to −1.86)
Caribbean	53,281 (37,809 to 76,421)	356.6 (236 to 548.3)	32,481 (22,650 to 45,364)	219.1 (138.9 to 332.1)	−1.12% (−1.44 to −0.79)
Andean Latin America	57,569 (50,043 to 70,150)	306.4 (248.2 to 391.4)	22,967 (19,285 to 27,491)	96.3 (75.5 to 120.4)	−3.31% (−3.47 to −3.16)
Central Latin America	105,805 (99,638 to 113,334)	128.9 (118.6 to 140.8)	49,236 (41,459 to 57,887)	57.8 (47.7 to 70)	−2.17% (−2.41 to −1.93)
Tropical Latin America	67,278 (60,523 to 76,352)	102.2 (88.3 to 121.1)	30,026 (26,866 to 33,481)	43.7 (38.1 to 49.8)	−1.99% (−2.17 to −1.81)
North Africa and Middle East	1,430,050 (1,109,785 to 2,161,900)	800.1 (583.6 to 1217.8)	353,939 (296,041 to 438,627)	153.3 (119.9 to 197.1)	−4.99% (−5.09 to −4.89)
South Asia	1,071,311 (734,034 to 1,592,831)	196.7 (129.8 to 298.6)	471,272 (388,905 to 571,570)	71.6 (54.5 to 91.5)	−3.12% (−3.23 to −3.01)
Central sub-Saharan Africa	163,374 (80,865 to 271,913)	464.4 (224.2 to 797.3)	75,659 (49,315 to 105,914)	103.1 (61.9 to 157.4)	−5.14% (−5.45 to −4.83)
Eastern sub-Saharan Africa	299,620 (221,252 to 416,777)	256.8 (187.5 to 360.2)	224,292 (191,313 to 262,985)	98.6 (79.6 to 120.8)	−3.36% (−3.45 to −3.28)
Southern sub-Saharan Africa	28,181 (22,092 to 36,089)	107 (75.7 to 148)	22,308 (18,631 to 26,704)	71.0 (55 to 91.4)	−0.81% (−1.12 to −0.49)
Western sub-Saharan Africa	414,014 (283,660 to 639,254)	343.9 (230.4 to 534.8)	506,010 (326,974 to 713,710)	180.2 (115 to 257.7)	−2.07% (−2.32 to −1.81)
Death					
Global	64,671 (52,278 to 87,871)	2.9 (2.3 to 4)	24,807 (20,858 to 28,757)	1.0 (0.8 to 1.2)	−3.31% (−3.39 to −3.22)
SDI					
High SDI	2106 (1939 to 2332)	0.9 (0.8 to 1)	474 (438 to 506)	0.2 (0.2 to 0.2)	−4.61% (−4.73 to −4.50)
High-middle SDI	8139 (7079 to 10,070)	2.3 (1.9 to 3)	1305 (1149 to 1477)	0.4 (0.4 to 0.5)	−5.11% (−5.29 to −4.93)
Middle SDI	19,797 (17,183 to 24,313)	2.7 (2.2 to 3.4)	5283 (4720 to 5842)	0.7 (0.6 to 0.8)	−3.85% (−3.98 to −3.72)

(Continues)

TABLE 1 | (Continued)

	Number of cases, 1990 (95% UI)	ASIR per 100,000 population, 1990 (95% UI)	Number of cases, 2021 (95% UI)	ASIR per 100,000 population, 2021 (95% UI)	EAPC 1990–2021 (95% CI)
Low-middle SDI	23,147 (17,451 to 33,472)	3.8 (2.8 to 5.6)	8544 (7235 to 10,016)	1.1 (0.9 to 1.4)	−3.67% (−3.77 to −3.58)
Low SDI	11,426 (7686 to 18,063)	3.7 (2.5 to 5.9)	9170 (6739 to 12,092)	1.5 (1.1 to 2.1)	−2.98% (−3.09 to −2.87)
Regions					
East Asia	12,901 (11,303 to 14,972)	2.9 (2.4 to 3.5)	1540 (1235 to 1869)	0.5 (0.4 to 0.6)	−5.78% (−5.98 to −5.59)
Southeast Asia	7450 (5730 to 10,184)	3.5 (2.6 to 4.9)	3348 (2868 to 3814)	1.5 (1.2 to 1.8)	−2.52% (−2.59 to −2.46)
Oceania	106 (63 to 166)	3.1 (1.6 to 5.3)	167 (112 to 237)	2.5 (1.4 to 3.9)	−0.38% (−0.75 to −0.01)
Central Asia	243 (217to 276)	0.8 (0.7 to 0.9)	105 (88 to 123)	0.3 (0.3 to 0.4)	−3.20% (−3.52 to −2.88)
Central Europe	391 (368 to 424)	1.1 (1 to 1.2)	49 (43 to 55)	0.2 (0.2 to 0.2)	−4.86% (−5.14 to −4.58)
Eastern Europe	322 (311 to 336)	0.5 (0.5 to 0.5)	93 (87 to 99)	0.2 (0.2 to 0.2)	−3.09% (−3.97 to −2.21)
High-income Asia Pacific	457 (393 to 522)	0.9 (0.8 to 1.1)	52 (48 to 58)	0.2 (0.1 to 0.2)	−5.69% (−5.94 to −5.44)
Australasia	21 (20 to 23)	0.3 (0.3 to 0.4)	5 (5 to 6)	0.1 (0.1 to 0.1)	−5.08% (−5.43 to −4.72)
Western Europe	654 (635 to 672)	0.7 (0.6 to 0.7)	101 (94 to 108)	0.1 (0.1 to 0.1)	−5.66% (−5.78 to −5.54)
Southern Latin America	279 (263 to 295)	1.5 (1.3 to 1.6)	69 (61 to 76)	0.3 (0.3 to 0.4)	−3.88% (−4.28 to −3.49)
High-income North America	463 (451 to 473)	0.6 (0.6 to 0.6)	225 (208 to 240)	0.3 (0.2 to 0.3)	−3.02% (−3.32 to −2.72)
Caribbean	605 (426 to 870)	4 (2.7 to 6.3)	369 (254 to 519)	2.5 (1.5 to 3.8)	−1.09% (−1.42 to −0.76)
Andean Latin America	675 (588 to 821)	3.6 (2.9 to 4.6)	268 (221 to 325)	1.1 (0.9 to 1.4)	−3.29% (−3.44 to −3.13)
Central Latin America	1174 (1107 to 1252)	1.4 (1.3 to 1.6)	522 (435 to 621)	0.6 (0.5 to 0.7)	−2.24% (−2.52 to −1.97)
Tropical Latin America	769 (692 to 871)	1.2 (1 to 1.4)	337 (302 to 372)	0.5 (0.4 to 0.6)	−1.98% (−2.18 to −1.77)
North Africa and Middle East	16,175 (12,539 to 24,503)	9.1 (6.6 to 13.8)	3778 (3057 to 4685)	1.6 (1.2 to 2.2)	−5.13% (−5.24 to −5.03)
South Asia	11,900 (8021 to 17,949)	2.2 (1.4 to 3.4)	4927 (4018 to 6085)	0.8 (0.6 to 1)	−3.28% (−3.40 to −3.16)
Central sub-Saharan Africa	1844 (903 to 3079)	5.3 (2.5 to 9.1)	814 (498 to 1160)	1.1 (0.6 to 1.8)	−5.26% (−5.59 to −4.93)
Eastern sub-Saharan Africa	3401 (2490 to 4776)	2.9 (2.1 to 4.2)	2457 (2070 to 2904)	1.1 (0.9 to 1.3)	−3.48% (−3.57 to −3.39)
Southern sub-Saharan Africa	295 (227 to 388)	1.1 (0.8 to 1.6)	234 (189 to 291)	0.7 (0.6 to 1)	−0.71% (−1.10 to −0.31)
Western sub-Saharan Africa	4536 (3030 to 7097)	3.8 (2.4 to 6)	5335 (3269 to 7729)	1.9 (1.1 to 2.8)	−2.16% (−2.43 to −1.89)

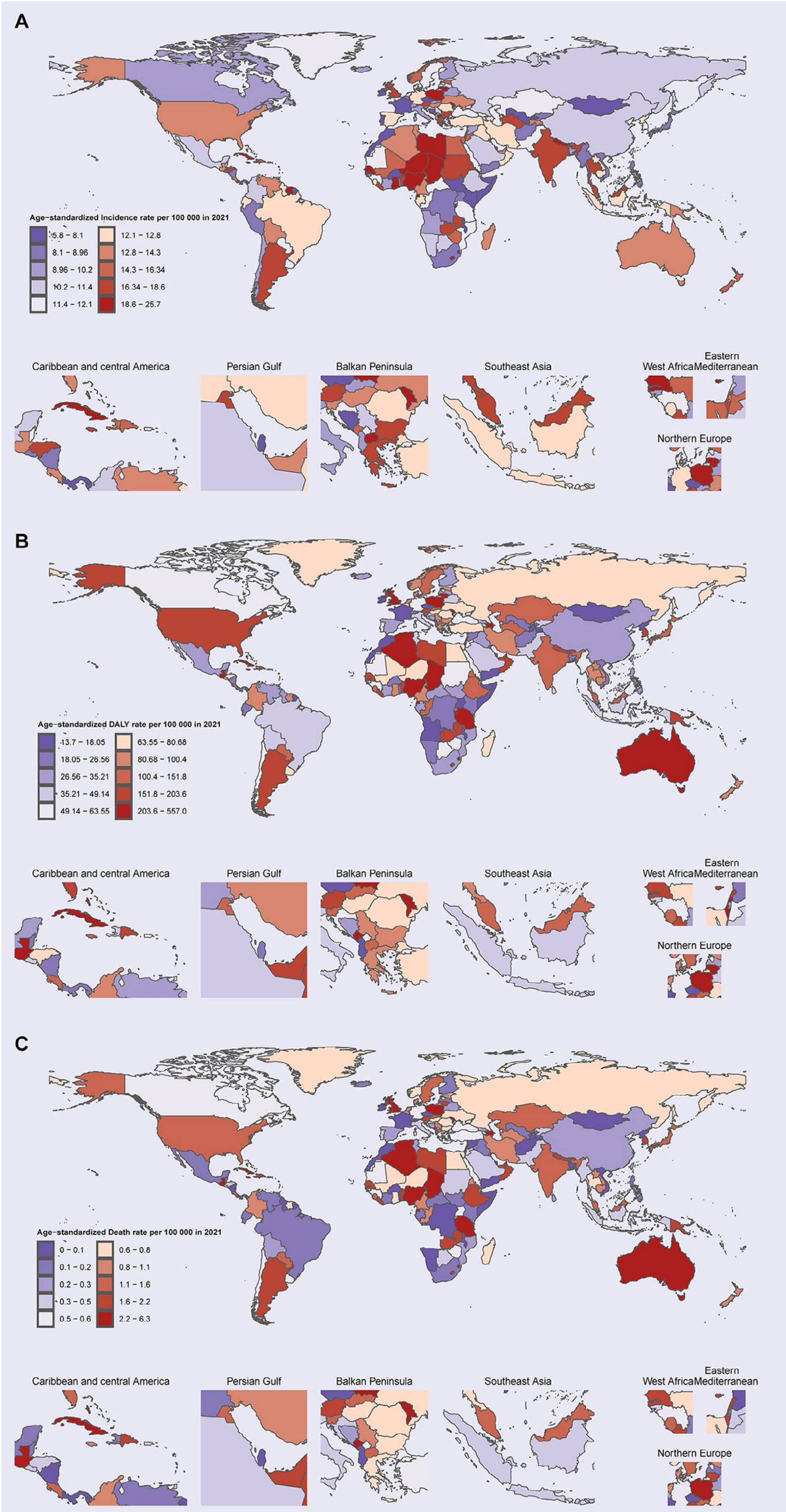

FIGURE 1 | Legend on next page.

FIGURE 1 | Age-standardized point incidence, DALYs, and death of stroke per 100,000 population in 2021 by country. DALY, disability-adjusted life years.

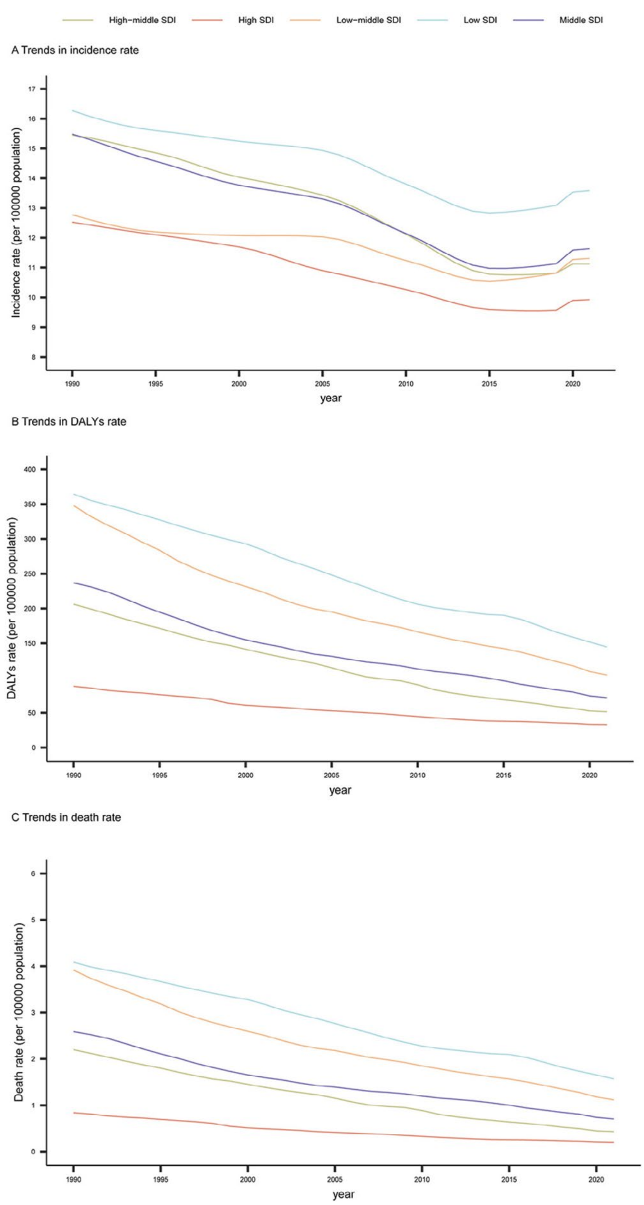

FIGURE 2 | Epidemiologic trends of incidence, disability-adjusted life years (DALYs), and mortality rates in five sociodemographic index (SDI) regions for childhood stroke from 1990 to 2021.

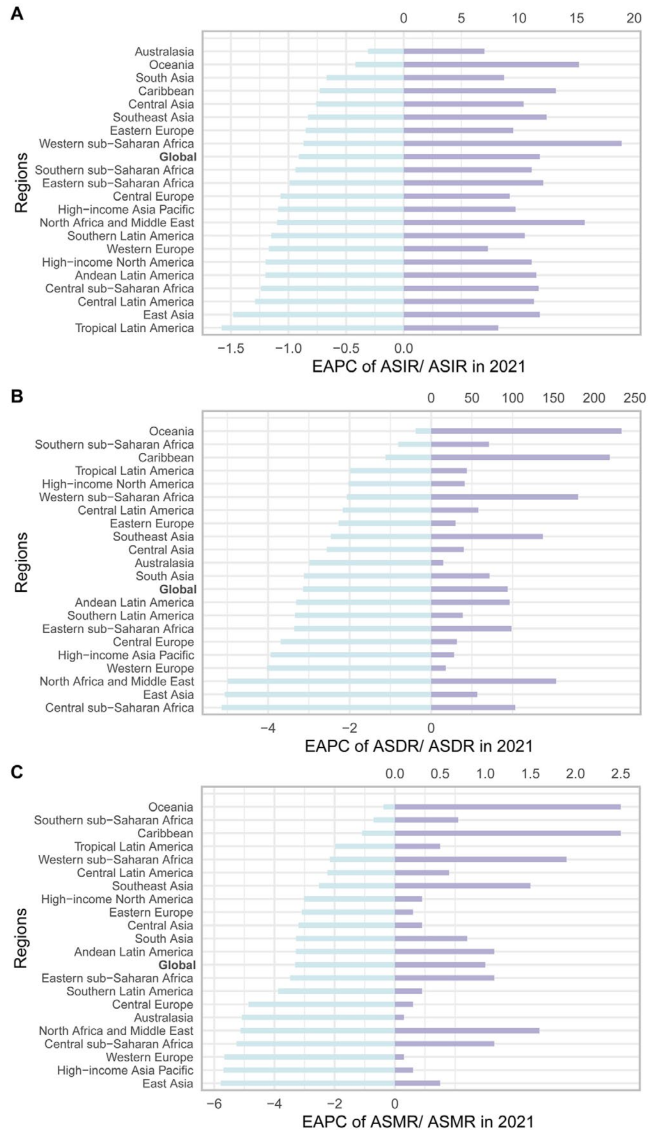

FIGURE 3 | ASRs and EAPCs of the ASRs for stroke globally and in 21 regions. (A) ASIR and EAPCs of the ASIR for stroke in 21 regions. (B) ASDR and EAPCs of the ASDR for stroke in 21 regions. (C) ASMR and EAPCs of the ASMR for stroke in 21 regions. ASDR, age-standardized disability-adjusted life-year rate; ASIR, age-standardized incidence rate; ASMR, age-standardized mortality rate; ASR, age-standardized rate; EAPC, estimated annual percentage change.

reductions in Tropical Latin America (EAPC: −1.58%; 95% CI: −1.74 to 1.42), followed by East Asia (EAPC: −1.48%; 95% CI: −1.60 to −1.36) and Central Latin America (EAPC: −1.29%; 95% CI: −1.39 to −1.20) (Table 1; Figure 3).

3.3 | Stroke Burden Based on SDI

Regionally, a reversed V-shaped association was observed between SDI and stroke ASDR from 1990 to 2021, with ASDR rising exponentially with SDI up to 0.45, then declining. North Africa, the Middle East, Central Asia, and High-income North America showed higher-than-expected DALY rates, while Central, Tropical, and Southern Latin Americas, Central Asia, and Australasia had lower-than-expected burdens from 1990 to 2019 (Figure 4A). Nationally, in 2021, stroke burden generally decreased with socioeconomic development. Countries including Haiti, Libya, Sierra Leone, Niue, Tokelau, Nauru, Papua New Guinea, Guinea, Chad, Myanmar, and Lao People's Democratic Republic had higher-than-expected burdens. Contrastingly, Nepal, Ethiopia, Mozambique, Burundi, the Democratic Republic of Congo, Malawi, and Rwanda had lower-than-expected burdens (Figure 4B). Stroke ASIR and

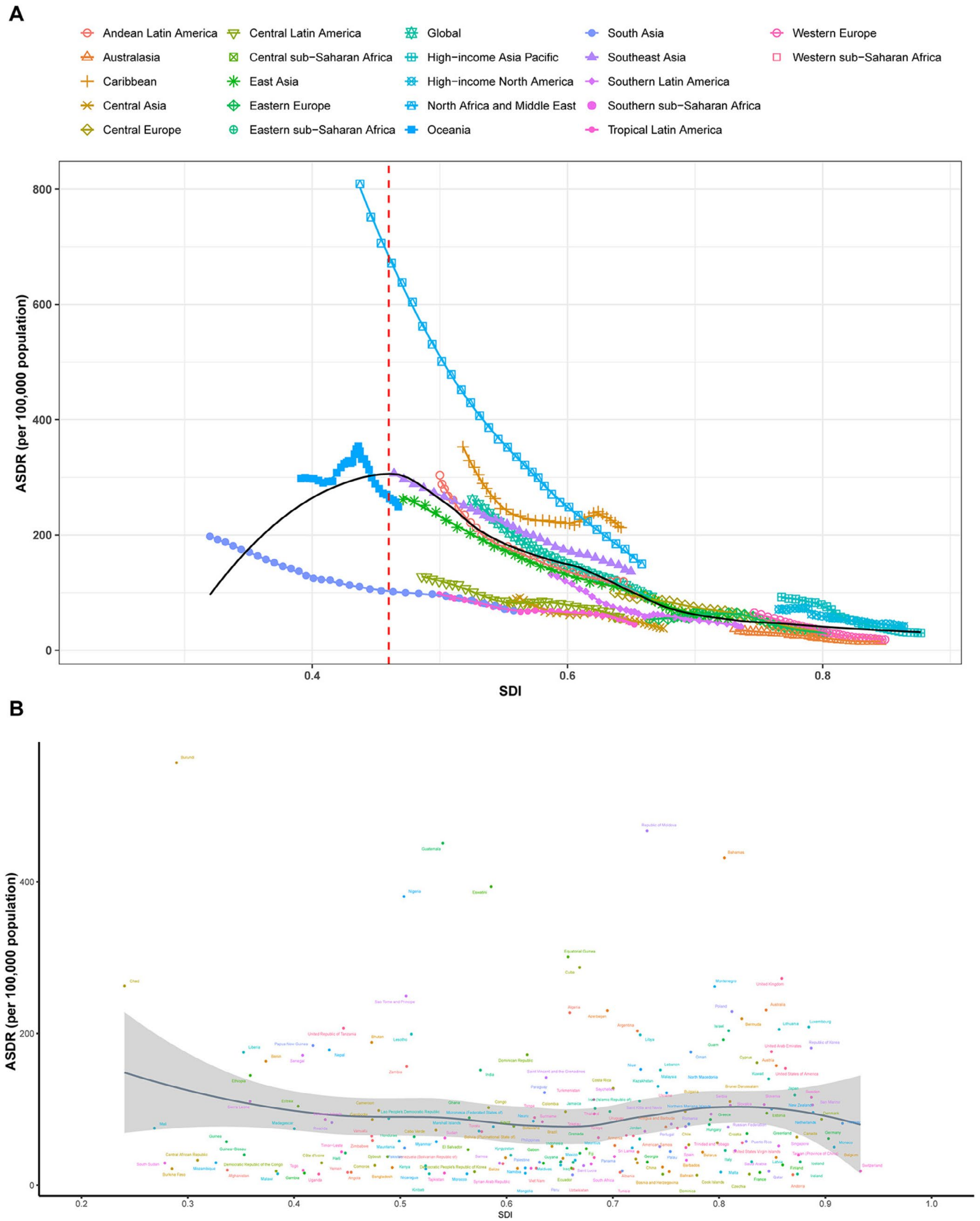

FIGURE 4 | ASDRs for stroke in 21 regions and 204 countries and territories by SDI. (A) ASDRs for stroke in 21 regions from 1990 to 2021 according to the SDI. (B) ASDRs for stroke in 204 countries and territories in 2021 according to the SDI. ASDR, age-standardized disability-adjusted life-year rate; ASIR, age-standardized incidence rate; SDI, sociodemographic index.

ASMR also exhibited a reversed V-shaped association with SDI, peaking at 0.45 (Figures S10–S18).

3.4 | Cross-Country Social Inequalities

Significant absolute and relative income-related inequality existed in DALY burden due to stroke, disproportionately affecting poorer countries. Over time, these inequalities reduced alongside a global decrease from 264.4 DALYs/100,000 (95% UI: 209.7 to 360.7) in 1990 to 93.9 DALYs/100,000 (95% UI: 76.9 to 113.5) in 2021. The SII showed an excess of 345.65 DALYs/100,000 (95% UI: 390.70 to 300.60) between the lowest and highest income countries in 1990, decreasing to 136.42 DALYs/100,000 (95% UI: 153.86 to 118.99) in 2021 (Figure 5A).

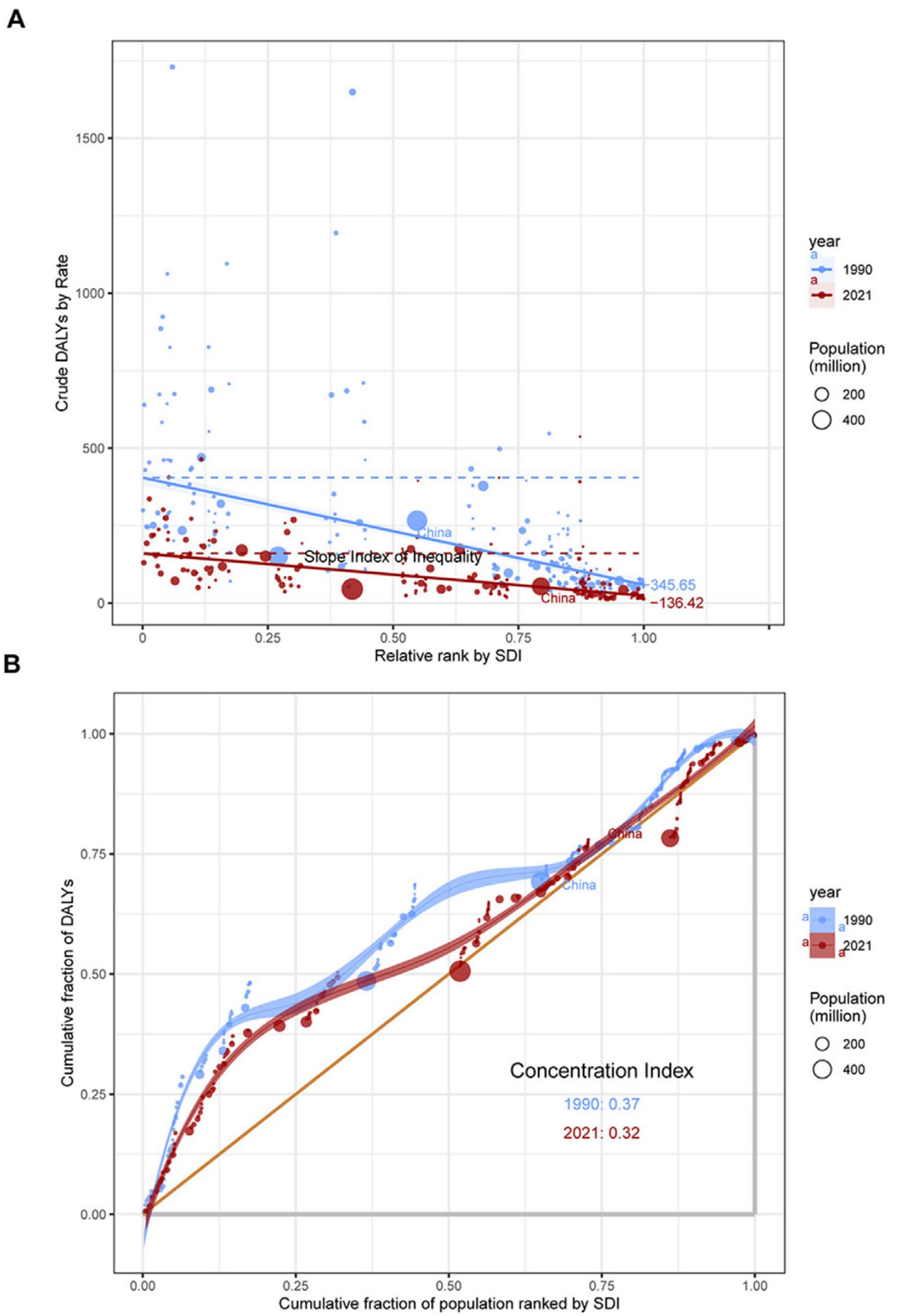

FIGURE 5 | Absolute and relative cross-country inequality in ASDR and rankings of total stroke, 1990–2021. (A) Health inequality regression curves for ASDR of total stroke. (B) Concentration curves for ASDR of total stroke. ASDR, age-standardized disability-adjusted life-year rate.

Relative inequality, per the health inequality concentration index, dropped from 0.37 (95% UI: 0.30 to 0.44) in 1990 to 0.32 (95% UI: 0.25 to 0.39) in 2021, reflecting reduced inequality across SDI regions (Figure 5B).

By 2021, DALYs were more evenly distributed across SDI regions, with decreases in both the concentration index and SII, indicating progress in reducing health inequality. However, childhood stroke burden remains persistently higher in low-SDI regions.

3.5 | Stroke Type Burden Based on Age

In 2021, stroke incidents (IS, ICH, and SAH) were predominantly observed in children > 5 years, accounting for 71.4% of all stroke cases in children and adolescents, although the ASIR was higher in children < 5 years. Furthermore, ASIR decreased most in children < 5 years across all stroke types from 1990 to 2021, with the largest reduction in those < 1 year: EAPC −1.40% (95% CI: −1.52 to −1.28) for stroke, −0.90% (95% CI: −1.00 to −0.80) for IS, −1.94% (95% CI: −2.10 to −1.78) for ICH, and −1.31% (95% CI: −1.42 to −1.20) for SAH. Hemorrhagic stroke was most common in children < 1 year, while IS was highest among adolescents aged 15–19 years. Both groups showed higher DALYs and death counts, as well as ASDR and ASMR, across all stroke types than other age groups. From 1990 to 2021, children < 5 years experienced a more significant decrease in ASDR and ASMR across all stroke types, with the largest reduction in 1-year-old children. Overall, stroke burden was highest in children < 1 year and adolescents 15–19 years (Tables S6–S8; Figure 6).

3.6 | Attributable Risk Factors for Stroke in Children and Adolescents

In 2021, high temperature accounted for 1.99% (95% UI: 0.69 to 3.8) of global stroke-related DALYs, while low temperature accounted for 2.31% (1.63 to 3.11). DALYs associated with high and low temperatures were higher in males (2.02% vs. 1.94% in females and 2.41% vs. 2.23% in females, respectively). High-temperature stroke burden ranged from 3.59% (95% UI: 0.66 to 7.76) in North Africa and the Middle East to −0.04% (95% UI: −0.3 to 0.19) in Eastern Europe. Low-temperature stroke burden ranged from 6.29% (95% UI: 5.38 to 7.72) in Central Europe to 0.27% (95% UI: 0.14 to 0.4) in the Caribbean (Tables S9 and S10; Figures S19–S27).

In 2021, high temperatures accounted for 2.50% (95% UI: 0.86 to 4.72) of global stroke-related deaths, while low temperatures accounted for 2.76% (95% UI: 1.94 to 3.73). Deaths attributed to high temperatures were higher in females at 2.59% (vs. males at 2.41%), while males had a slightly higher risk for low temperature at 2.79% (vs. 2.76% in females). High-temperature stroke burden ranged from 4.27% (95% UI: 0.79 to 9.03) in North Africa and the Middle East to −0.09% (95% UI: −0.62 to 0.4) in Eastern Europe. Low-temperature stroke burden ranged from 9.6% (95% UI: 8.59 to 11.34) in Central Europe to 0.30% (95% UI: 0.17 to 0.45) in the Caribbean (Tables S9 and S10; Figures S19–S27).

3.7 | Stroke Over Time DALYs: 1990–2021, and 2050 Forecasts

Between 2021 and 2050, the global ASDR of stroke in children and adolescents under 20 years is expected to decrease by 89.9%, from 93.9 (95% UI: 76.9 to 113.5) to 10.0 (95% UI: 0.6 to 19.5) per 100,000, resulting in 2,824,404 (95% UI: 16,994 to 550,688) people living with disability by 2050. Compared to other stroke types, ICH will have the highest ASDR, with rates of 56.3/100,000 (95% UI: 44.4 to 71.5) in 2021 and 6.0/100,000 (95% UI: 0.7 to 11.3) in 2050. Children under 1 year and adolescents aged 15–19 years will still bear the highest stroke burden in 2050 (Figure 7).

In 2050, Oceania (123.0/100,000; 95% UI: 11.8 to 234.2) is estimated to have the highest ASDR, while East Asia (0.4/100,000 95% UI: −0.3 to 1.2) will have the lowest (Table S11; Figures S28 and S33). Oceania and the Caribbean will have a higher SAH-related stroke burden, while Southern and Western Sub-Saharan Africa will have a higher IS-related burden (Tables S11–S17; Figures S34–S38).

4 | Discussion

Globally, the ASRs of stroke declined significantly from 1990 to 2021 among children and adolescents under 20 years; however, the stroke burden remains high. This study provided an in-depth analysis of stroke in individuals under 20 years using the latest 2021 data, expanding our understanding and highlighting the urgent need to prevent stroke, reduce stroke-related mortality, and improve clinical outcomes in this age group.

This study revealed disparities in stroke burden by the GBD region, country, and SDI quintiles, alongside an overall decline in ASIR, DALYs, and death rates from 1990 to 2021 in children and adolescents under 20 years. The global ASIR for stroke decreased from 14.6 in 1990 to 12.4 in 2021. The incidence in this study aligns with previous reports (1.3–13/100,000) [4]. This decline occurred across all SDI regions, with the highest ASIR in 2021 in the low-SDI region and the lowest in the high-SDI region, highlighting disparities between regions of different socioeconomic development. Similarly, deaths and DALYs attributed to stroke declined, with the low-SDI region showing the highest ASDR and ASMR and the high-SDI region the lowest. Improved socioeconomic conditions and better access to and quality of healthcare likely contributed to lower stroke burden in high-SDI regions. Advancements in medical technology, imaging, genetic screening, and family history assessments also played a role. For instance, early screening in high-income countries coupled with timely intervention were key factors contributing to the early detection of stroke-related diseases and improved stroke outcomes. The high incidence of stroke in children with sickle cell disease (SCD) contributed to global health disparities. SCD, which primarily affects individuals of African descent, increases childhood stroke risk by over 200 times. Primary stroke prevention strategies—such as transcranial Doppler ultrasound (TCD) screening and chronic blood transfusion therapy for high-risk patients—have successfully reduced stroke rates in Western populations; however, stroke rates remain elevated in resource-limited regions like Sub-Saharan Africa [15–17].

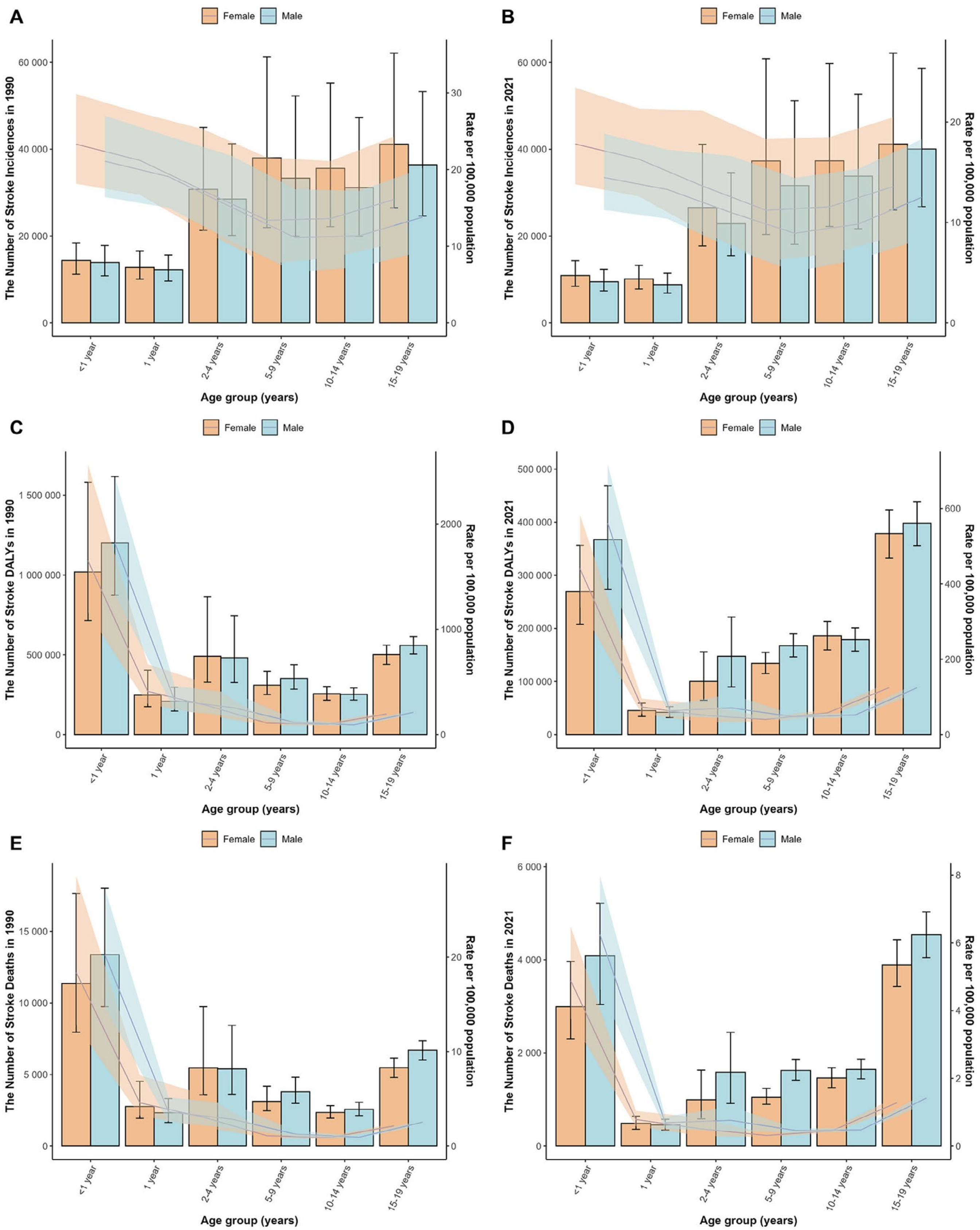

FIGURE 6 | Age-specific rates of stroke and stroke numbers by age subgroups and sex in 1990 and 2021. (A) Age-specific incidence rates of stroke and incident numbers by age subgroups and sex in 1990. (B) Age-specific incidence rates of stroke and incident numbers by age subgroups and sex in 2021. (C) Age-specific DALY rates of stroke and incident numbers by age subgroups and sex in 1990. (D) Age-specific DALY rates of stroke and incident numbers by age subgroups and sex in 2021. (E) Age-specific death rates of stroke and incident numbers by age subgroups and sex in 1990. (F) Age-specific death rates of stroke and incident numbers by age subgroups and sex in 2021 DALY disability-adjusted life year.

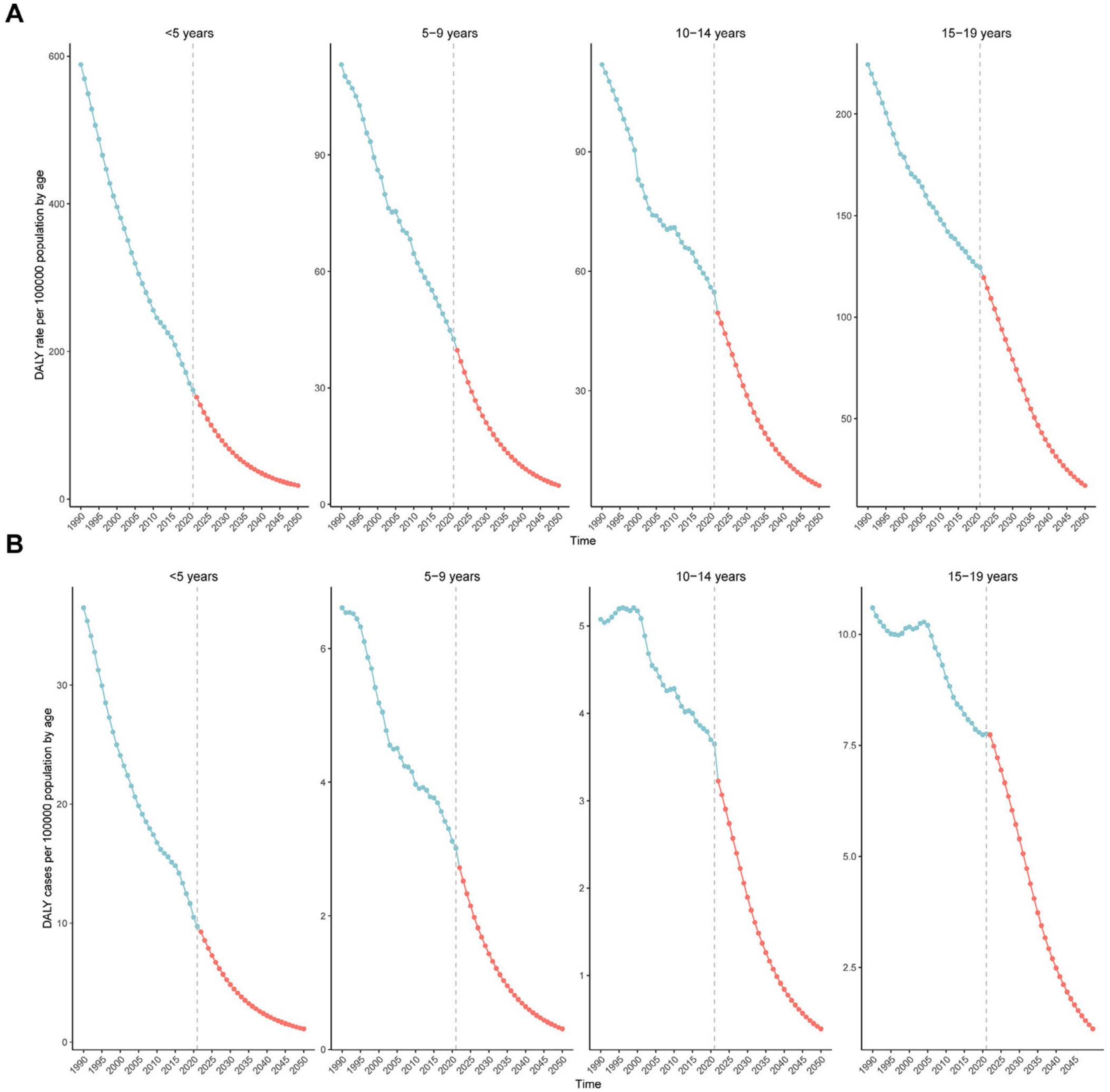

FIGURE 7 | Projections of DALYs to 2050. (A) Global age-standardized DALY rate per 100,000 population of stroke from 1990 through 2050 forecasted by age subgroups. (B) Global DALY cases per 100,000 population of stroke from 1990 through 2050 forecasted by age subgroups DALY disability-adjusted life years.

Certain populations, such as children of East Asian descent (Japanese, Korean, Chinese), are at higher risk of moyamoya disease, a common cause of stroke in this population. Genetic screening for moyamoya disease, combined with imaging techniques such as TCD and angiography, for children with early symptoms such as headache and transient ischemic attack, enables prompt surgical intervention. These timely approaches are crucial for reducing stroke risk, improving prognosis, and reducing DALYs and mortality.

Regionally, stroke incidence, DALYs, and deaths varied significantly. Tropical Latin America experienced the largest decrease, while Australasia showed a slight decline. Oceania had the highest ASDR and ASMR, with the lowest decrease in both, while Australasia had the lowest ASDR and ASMR with a larger decrease. These disparities underscore the complex interaction of genetic, environmental, and healthcare factors affecting stroke incidence. Age pattern analysis revealed a decline in ASIR across all age groups under 20 years since 1990, with a slower reduction with increasing age. The highest global stroke incidence, DALYs, and death rates were in children under 1 year, generally declining with age. Stroke types followed this trend, with IS affecting more children and adolescents under 20 years and hemorrhagic stroke occurring more frequently than in adults, leading to more severe outcomes [18, 19]. These trends across different age groups offer valuable insights for tailoring screening and prevention strategies. Therefore, regions and countries with varying social development levels must implement evidence-based and context-specific interventions to reduce stroke incidence, DALYs, and deaths. Preventive measures for children under 1 year should be more comprehensive, given their limited ability to express discomfort and frequent crying; therefore, it is essential to develop appropriate assessment scales to better evaluate symptoms and facilitate timely interventions.

This GBD study identified temperature as the primary attributable risk factor for stroke. According to previous studies, in the framework of climate change, most regions of the world are affected by strokes attributed to high temperatures [20, 21]. This emphasizes the urgent need for increased attention and strategies to protect human health from the effects of non-optimal temperatures. In 2021, approximately 2,414,655 children were living with stroke-related disability [2], a number projected to decrease by 89.9% to 282,404 people by 2050, with Oceania having the highest and East Asia having the lowest ASDR. ICH had the highest ASDR in 2021 and is expected to remain the leading cause of disability by 2050.

Unlike adults whose stroke risk often centers on modifiable risk factors such as high blood pressure and diabetes, childhood stroke primarily revolves around hereditary factors that increase susceptibility and acquired factors that trigger stroke events [22, 23]. Hence, public policies should focus on preventing childhood stroke and improving the management of ICH-related disabilities in children and adolescents.

This study provided the most comprehensive analysis to date of stroke burden trends in children and adolescents under 20 years. For children and adolescents with stroke and their families, the decreasing mortality and DALYs associated with this disease are encouraging. For policymakers, stroke still imposes a substantial burden due to its high disability and mortality rates despite a declining incidence, particularly in low and lower-middle SDI regions. Therefore, it is essential to strengthen healthcare resource preparedness. For clinicians, further studies are needed to uncover the potential mechanisms of stroke to take proactive measures to prevent stroke in children and adolescents. However, our study has certain limitations. First, the estimates were based on available data sources, and the precision of the GBD data is influenced by the quality of the existing epidemiological data. The reporting and forecasting of stroke data for 204 countries may be insufficient, potentially affecting the accuracy of the results. Second, no system has been established to classify types of childhood stroke; future studies on childhood stroke should include information that could aid in developing such a classification. Therefore, further high-quality, real-world research is needed to validate our findings.

In conclusion, the stroke burden among children and adolescents (< 20 years) decreased considerably from 1990 to 2021. Both were higher in those living in middle-to-low-SDI regions, those younger than 1 year, and those with ICH. Management of non-optimal temperature remains a key challenge for children and adolescents, and targeted clinical assessment methods among pediatricians are needed. Numbers are expected to decrease until the year 2050 for all stroke types; thus, further efforts are needed in the future to strengthen the primary prevention of stroke in children and adolescents. Additionally, stroke prevention strategies tailored to specific national contexts are needed to reduce regional disparities in stroke burden.

Author Contributions

Jing-Jie Li: conceptualization, writing – original draft, writing – review and editing, supervision, methodology, investigation, validation, visualization, project administration, formal analysis, software, data curation, resources. **Xiao-Peng Wang:** conceptualization, writing – original draft. **Qian-Nan Wang:** methodology, writing – original draft, funding acquisition. **Zi-Qing Kong:** writing – original draft, conceptualization, methodology. **Cong Han:** data curation. **Qing-Bao Guo:** data curation. **Min-Jie Wang:** data curation. **Si-Meng Liu:** data curation. **Jin-Huan Huang:** data curation. **Zhang-Wei Zeng:** data curation. **Cheng Chen:** data curation. **Shuai-Nan Ning:** data curation. **Xuan Fang:** data curation. **Xiang-Yang Bao:** data curation. **Lian Duan:** writing – review and editing, funding acquisition.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated or analyzed in this study are accessible through GBD 2021. Public datasets used in the study are available at GBD Results Tool. Additionally, analyzed data can be provided by the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.