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Global trends and burden of idiopathic epilepsy: regional and gender differences from 1990 to 2021 and future outlook

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Abstract

Background Idiopathic epilepsy (IE) remains a significant neurological disorder, contributing to substantial global morbidity and mortality. This study aims to comprehensively evaluate the global burden of IE from 1990 to 2021, focusing on trends in incidence, mortality, and disability-adjusted life years (DALYs) across different geographic regions. Additionally, the study projects IE burden trends through 2036, providing insights for future public health interventions.

Methods Data were extracted from the Global Burden of Disease Study 2021 (GBD 2021). IE incidence, mortality, and DALYs were analyzed by age, sex, year, and geographic location. Age-standardized rates were computed to facilitate comparisons across countries and regions. Temporal trends in IE burden were evaluated using Joinpoint regression, while future trends were projected using the Bayesian age-period-cohort (BAPC) model.

Results In 2021, there were approximately 3.27 million new cases of IE globally (95% uncertainty interval [UI]: 2.4 to 4.13 million) and 140,000 deaths (95% UI: 120,000 to 150,000). Total DALYs reached 13.88 million (95% UI: 10.73 to 17.62 million). The global age-standardized incidence rate increased from 38.12 per 100,000 in 1990 to 42.82 per 100,000 in 2021. The Andean and Central Latin American regions exhibited the highest incidence rates, while East Asia and Oceania reported the lowest. Despite a decrease in the global age-standardized mortality rate from 2.07 per 100,000 in 1990 to 1.74 per 100,000 in 2021, mortality rates remained elevated in low- and middle-income countries, particularly in sub-Saharan Africa. Male patients showed consistently higher incidence, mortality, and DALY rates compared to females, with the highest burden observed in children under 5 years and adults over 60 years.

Conclusion Over the past three decades, global IE incidence has steadily increased, while mortality and DALY rates have declined, especially in high-income countries. However, low- and middle-income regions continue to face significant challenges due to limited access to healthcare. Public health efforts must prioritize enhancing early diagnosis and treatment capabilities in these resource-limited areas.

Keywords Idiopathic epilepsy, Disease burden, Global trends, Socio-demographic differences

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Introduction

Epilepsy is a prevalent chronic neurological disorder that affects approximately 50 million people worldwide, ranking among the most burdensome neurological conditions [1, 2]. It is characterized by recurrent seizures, which are caused by abnormal electrical discharges in the brain's neurons [3]. According to the International League Against Epilepsy (ILAE), epilepsy is classified into structural, genetic, infectious, metabolic, immune, or unknown causes [4]. Idiopathic epilepsy (IE), a key subtype, is defined by the absence of structural abnormalities or metabolic causes and typically manifests in childhood or adolescence [5, 6]. Patients with IE experience various types of seizures, the most common being generalized tonic-clonic and absence seizures [7, 8]. While epilepsy can occur at any age, the incidence of IE is lower in elderly populations and higher in younger individuals [9].

The Global Burden of Disease (GBD) study provides comprehensive epidemiological data on IE, covering key health indicators such as incidence, prevalence, mortality, and disability-adjusted life years (DALYs). GBD data reveal significant regional and population-based disparities in the global burden of IE. Low- and middle-income countries bear a particularly heavy burden due to limited healthcare resources and diagnostic tools. These regions demonstrate notably higher incidence and mortality rates, primarily resulting from delayed medical interventions and inadequate treatment [10]. Beyond the medical challenges, the burden of IE also significantly impacts patients' social, economic, and psychological well-being. Epilepsy patients often face societal stigma and discrimination, and experience higher rates of comorbidities such as depression and anxiety, which further exacerbate the overall disease burden [11, 12].

Since the onset of the COVID-19 pandemic in 2020, substantial healthcare resources have been diverted to combat the virus, leading to disruptions in the diagnosis, treatment, and management of other diseases [13]. In LMICs, these disruptions have delayed epilepsy management and increased treatment interruptions, resulting in a rise in seizure frequency and worsened patient outcomes.

Given epilepsy's long-term impact on patients' health and quality of life—particularly among vulnerable populations such as children and adolescents—it is essential to systematically study global epidemiological trends in IE. This study utilizes the GBD database to analyze the global burden of IE, with a focus on incidence, mortality, and DALYs across different regions and age groups. Through this comprehensive analysis, the study provides evidence to inform global health policies, optimize resource allocation, and implement targeted public health strategies to reduce the burden of IE, particularly in low- and middle-income countries.

Methods

Study population and data collection

This study utilizes data from the GBD 2021, incorporating cross-sectional data collected between 1990 and 2021. The dataset encompasses the burden of 371 diseases and injuries across 21 global regions and 204 countries, including IE [14]. IE is defined following the 1985 proposal by the ILAE and classified under code G40.0 in the 10th edition of the International Classification of Diseases (ICD-10) [15]. The study population includes patients of all ages diagnosed with IE, with key metrics such as incidence, mortality, and DALYs evaluated. Data were stratified by age, sex, and geographic location, with uncertainty intervals (95% UIs) provided for each metric. DALYs, representing the disease burden, were calculated as the sum of years of life lost (YLLs) and years lived with disability (YLDs) [16]. The study adhered to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) [17].

The GBD 2021 data underwent several processing steps, including the use of a Bayesian meta-regression model (DisMod-MR 2.1) to estimate global data, addressing issues of data incompleteness across regions.[15] This model enabled analysis of data from various sources, including scientific literature, survey microdata, and insurance claims, estimating both non-fatal and fatal outcomes of IE. Spatio-temporal Gaussian process regression was applied to smooth the raw data and account for differences in age, time, and geographic regions for global analysis [18].

Definition of idiopathic epilepsy

IE is defined as recurrent, unprovoked seizures for which no identifiable structural or metabolic causes are found, and it is presumed to have a strong genetic basis. Cases included in this study are those with at least one seizure within the last five years, regardless of treatment. Data sources primarily include medical records and epidemiological surveys to ensure the accuracy and consistency of case identification.

Data analysis

We conducted descriptive analyses to assess global trends in the incidence, mortality, and DALYs of IE from 1990 to 2021. Joinpoint regression analysis was applied to identify annual percentage changes (APC) and average annual percentage changes (AAPC) over specific periods [19]. This approach enabled identification of inflection points in incidence and mortality rates, allowing for the calculation of the rate of change across each period.

Regional comparisons were made to evaluate differences in the burden of IE across 21 GBD regions and different sociodemographic index (SDI) groups. SDI is a composite measure of a country's socioeconomic

development and serves as an important health predictor, incorporating factors such as per capita income, average educational attainment, and fertility rate [20]. Stratified analyses by sex and age group were also conducted to examine the burden across demographic segments. Uncertainty intervals were calculated based on 1,000 draws from input data, adjusting for measurement error and residual non-sampling errors [21].

A Bayesian age-period-cohort (BAPC) model was employed to predict trends in incidence, mortality, and DALYs of IE from 2022 to 2036. This model considers the influence of age, time period, and birth cohort on the disease burden, offering a reliable basis for future projections.

Statistical analysis

All statistical analyses were performed using R software (version 4.4.0) and Joinpoint regression software. The BAPC analysis was conducted using the BAPC and INLA packages in R [22]. Descriptive results are presented with 95% confidence intervals (CIs), while uncertainty intervals (95% UIs) were calculated to evaluate the robustness of the findings. Temporal trends were evaluated through APC and AAPC calculations, with a two-tailed P-value < 0.05 considered statistically significant.

Patient and public involvement

This study used secondary open-access data from the GBD 2021 database, where all data were anonymized. As a result, direct patient involvement was not required, and ethical committee approval was not necessary.

Results

Global trends

From 1990 to 2021, the global incidence of IE increased by approximately 54%, rising from 2.12 million cases to 3.27 million. The ASIR grew from 38.12 per 100,000 in 1990 to 42.82 per 100,000 in 2021, reflecting an average annual growth of 0.37% (Table 1; Fig. 1). In 2021, IE-related deaths increased by 40%, from 100,000 in 1990 to 140,000, although the age-standardized mortality rate decreased from 2.07 to 1.74 per 100,000, with an average annual decline of -0.54% (Supplementary Table 1, Supplementary Fig. 1). Similarly, the global number of DALYs caused by IE rose to 13.88 million in 2021, a 22% increase from 11.38 million in 1990. Despite this rise, the age-standardized DALY rate decreased from 208.8 per 100,000 in 1990 to 177.84 per 100,000 in 2021, averaging an annual decline of -0.52% (Supplementary Table 2, Supplementary Fig. 2).

Regional trends

In 2021, the highest age-standardized incidence rates were recorded in Andean Latin America (71.71 per 100,000) and Central Latin America (69.69 per 100,000), while East Asia (28.18 per 100,000) and Oceania (29.71 per 100,000) had the lowest rates (Table 1; Fig. 2A). The largest annual increase in incidence rates occurred in East Asia (AAPC 0.75%) and High-Income North America (AAPC 0.46%), whereas the most significant declines were seen in Eastern Europe (AAPC – 0.39%) and Tropical Latin America (AAPC – 0.32%) (Table 1; Fig. 2B). The highest mortality rates in 2021 were in Eastern Sub-Saharan Africa (7.49 per 100,000) and Central Sub-Saharan Africa (3.91 per 100,000), with the lowest rates in Southeast Asia (0.56 per 100,000) and Eastern Europe (0.63 per 100,000) (Supplementary Table 1, Supplementary Fig. 3A). Western Europe (AAPC 0.69%) and High-Income North America (AAPC 0.65%) saw the largest annual increases in mortality rates, while East Asia (AAPC – 2.58%) and Andean Latin America (AAPC – 1.92%) experienced the greatest decreases (Supplementary Table 1, Supplementary Fig. 3B). In terms of DALY rates, Western Sub-Saharan Africa (299.71 per 100,000) and Central Asia (280.70 per 100,000) had the highest rates in 2021, while Eastern Europe (87.13 per 100,000) and High-Income Asia Pacific (92.92 per 100,000) had the lowest (Supplementary Table 2, Supplementary Fig. 4A). The largest increases in DALY rates were seen in High-Income North America (AAPC 0.26%) and Oceania (AAPC 0.13%), while East Asia (AAPC – 1.76%) and Eastern Europe (AAPC – 1.41%) had the greatest reductions (Supplementary Table 2, Supplementary Fig. 4B).

National trends

In 2021, Ecuador (94.94 per 100,000) and Germany (91.82 per 100,000) had the highest ASIR, while North Korea (21.74 per 100,000) and Bangladesh (25.74 per 100,000) recorded the lowest rates (Supplementary Table 3, Fig. 3A). The most significant increases were in Equatorial Guinea (AAPC 1.47%) and Cape Verde (AAPC 0.92%), while Belarus (AAPC – 0.54%) and Burundi (AAPC – 0.48%) saw the largest decreases (Supplementary Table 3, Fig. 3B). Zambia (0.08 per 100,000) and Somalia (10.32 per 100,000) had the highest mortality rates in 2021, while Vietnam (0.56 per 100,000) and San Marino (0.12 per 100,000) had the lowest (Supplementary Table 4, Supplementary Fig. 5A). Italy (AAPC 2.49%) and Japan (AAPC 0.65%) had the largest annual increases in mortality rates, while the United Arab Emirates (AAPC – 2.95%) and Qatar (AAPC – 2.83%) saw the largest declines (Supplementary Table 4, Supplementary Fig. 5B). In terms of DALY rates, Zambia (746.45 per 100,000) and Somalia (505.54 per 100,000) recorded the highest, while San Marino (66.98 per 100,000) and Russia (72.78 per 100,000) had the lowest rates (Supplementary Table 5, Supplementary Fig. 6A). The largest increases in DALY rates were in Lesotho (AAPC 1.02%) and Zambia

Table 1 Age-standardized incidence rates and AAPC of idiopathic epilepsy globally and by region from 1990 to 2021

location	1990		2021		AAPC (95%CI)
	Number (95%UI)	ASIR (95%UI)	Number (95%UI)	ASIR (95%UI)	
Global	2121188.68 (1515389.47 to 2784665.28)	38.12 (27.91 to 49.48)	3272733.66 (2403802.43 to 4125118.75)	42.82 (31.24 to 53.72)	0.37 (0.34 to 0.39)
High-income Asia Pacific	67592.04 (42835.16 to 91926.57)	41.83 (26.26 to 57.00)	71299.06 (44655.59 to 98719.58)	45.04 (27.44 to 62.64)	0.23 (0.2 to 0.25)
High-income North America	96534.69 (64181.37 to 130220.74)	36.53 (24.65 to 49.71)	143833.84 (90670.21 to 199907.84)	42.17 (26.95 to 59.59)	0.46 (0.41 to 0.52)
Western Europe	213651.95 (141218.86 to 284516.85)	60.18 (39.83 to 81.61)	260298.49 (164172.29 to 344964.91)	65.28 (41.25 to 89.06)	0.24 (0.12 to 0.36)
Australasia	9705.92 (3717.75 to 14839.17)	49.72 (18.96 to 76.11)	13634.20 (5442.31 to 21148.86)	48.85 (19.76 to 75.95)	-0.06 (-0.1 to -0.03)
Andean Latin America	28861.83 (13752.90 to 43604.48)	70.31 (33.90 to 105.82)	47503.11 (25464.12 to 68779.91)	71.71 (38.67 to 103.62)	0.02 (-0.13 to 0.18)
Tropical Latin America	99702.03 (62033.16 to 138528.97)	61.07 (38.36 to 84.02)	121092.55 (81539.28 to 161143.31)	55.23 (37.05 to 73.69)	-0.32 (-0.41 to -0.23)
Central Latin America	131059.12 (87881.57 to 180478.71)	72.38 (49.82 to 97.29)	173731.44 (121135.08 to 229075.20)	69.69 (48.39 to 92.19)	-0.13 (-0.15 to -0.11)
Southern Latin America	23701.51 (10904.44 to 36220.33)	47.08 (21.61 to 71.81)	32871.23 (15908.75 to 49490.64)	51.77 (25.01 to 78.40)	0.32 (0.27 to 0.37)
Caribbean	19527.72 (12174.72 to 27001.39)	52.57 (33.26 to 72.61)	24075.25 (15127.53 to 33911.63)	52.51 (32.89 to 73.75)	0 (-0.04 to 0.05)
Central Europe	47504.58 (31841.06 to 64463.59)	40.55 (27.07 to 55.46)	40009.64 (26683.69 to 53769.27)	41.92 (27.96 to 58.95)	0.12 (0.1 to 0.14)
Eastern Europe	78797.25 (55522.17 to 104605.53)	37.21 (26.12 to 49.80)	59542.98 (39814.79 to 81362.44)	33.15 (22.04 to 45.28)	-0.39 (-0.42 to -0.36)
Central Asia	33719.93 (20902.72 to 48052.21)	44.40 (27.70 to 62.05)	45658.96 (26279.14 to 63771.66)	47.45 (27.54 to 66.25)	0.14 (0.08 to 0.19)
North Africa and Middle East	167811.94 (105397.63 to 237699.79)	42.98 (27.55 to 59.61)	298247.03 (202461.21 to 422106.32)	47.37 (32.28 to 66.75)	0.3 (0.28 to 0.32)
South Asia	362106.76 (223755.19 to 517303.18)	30.80 (19.05 to 43.33)	602049.79 (428444.26 to 784538.10)	33.10 (23.43 to 42.49)	0.19 (0.05 to 0.32)
Southeast Asia	162701.85 (111437.38 to 229022.66)	31.97 (22.49 to 44.24)	248332.00 (170940.21 to 336053.27)	37.14 (25.44 to 50.84)	0.44 (0.41 to 0.47)
East Asia	274895.30 (185204.90 to 376907.58)	22.55 (15.41 to 31.19)	372849.14 (259684.14 to 491425.13)	28.18 (19.18 to 37.38)	0.75 (0.63 to 0.86)
Oceania	2180.01 (1006.73 to 3731.87)	30.12 (13.86 to 50.39)	4420.43 (1714.02 to 7277.26)	29.71 (11.89 to 48.40)	-0.04 (-0.05 to -0.03)
Western Sub-Saharan Africa	120691.58 (75211.17 to 173255.84)	53.45 (33.48 to 75.54)	323994.41 (220101.26 to 431751.75)	59.26 (42.17 to 77.35)	0.33 (0.3 to 0.36)
Eastern Sub-Saharan Africa	113423.74 (62874.73 to 167901.46)	50.54 (28.52 to 74.33)	258133.00 (167482.70 to 358826.42)	54.02 (35.99 to 73.18)	0.22 (0.2 to 0.24)
Central Sub-Saharan Africa	35246.19 (12865.48 to 62096.14)	54.87 (20.05 to 95.23)	85154.93 (34157.98 to 138874.12)	55.60 (22.40 to 88.94)	0 (-0.14 to 0.14)
Southern Sub-Saharan Africa	31772.75 (20748.69 to 44050.62)	55.81 (36.38 to 76.44)	46002.18 (29385.54 to 63985.67)	56.65 (36.76 to 78.63)	0.05 (-0.1 to 0.19)

Abbreviations: ASIR: age-standardized incidence rate; AAPC: average annual percentage change; CI: confidence interval; UI: uncertainty interval

(AAPC 0.97%), while the largest decreases were observed in Turkey (AAPC −1.95%) and Qatar (AAPC −1.94%) (Supplementary Table 5, Supplementary Fig. 6B).

Age and gender patterns

In 2021, IE cases peaked in the under-5 age group and then gradually declined, reaching the lowest in the ≥95 age group. Among individuals under 79 years old, the number of male cases exceeded female cases, but in the ≥80 age group, female cases outnumbered male cases (Fig. 4). Incidence rates were highest in the youngest age groups (under 5 years old), then declined with age, before rising again in the over-60 age group and peaking at 95 and older (Fig. 4). In 2021, deaths peaked among middle-aged individuals before gradually declining with age, with the lowest number of deaths in the ≥95 age group. Male mortality exceeded female mortality in individuals under 79, while female mortality surpassed male mortality in

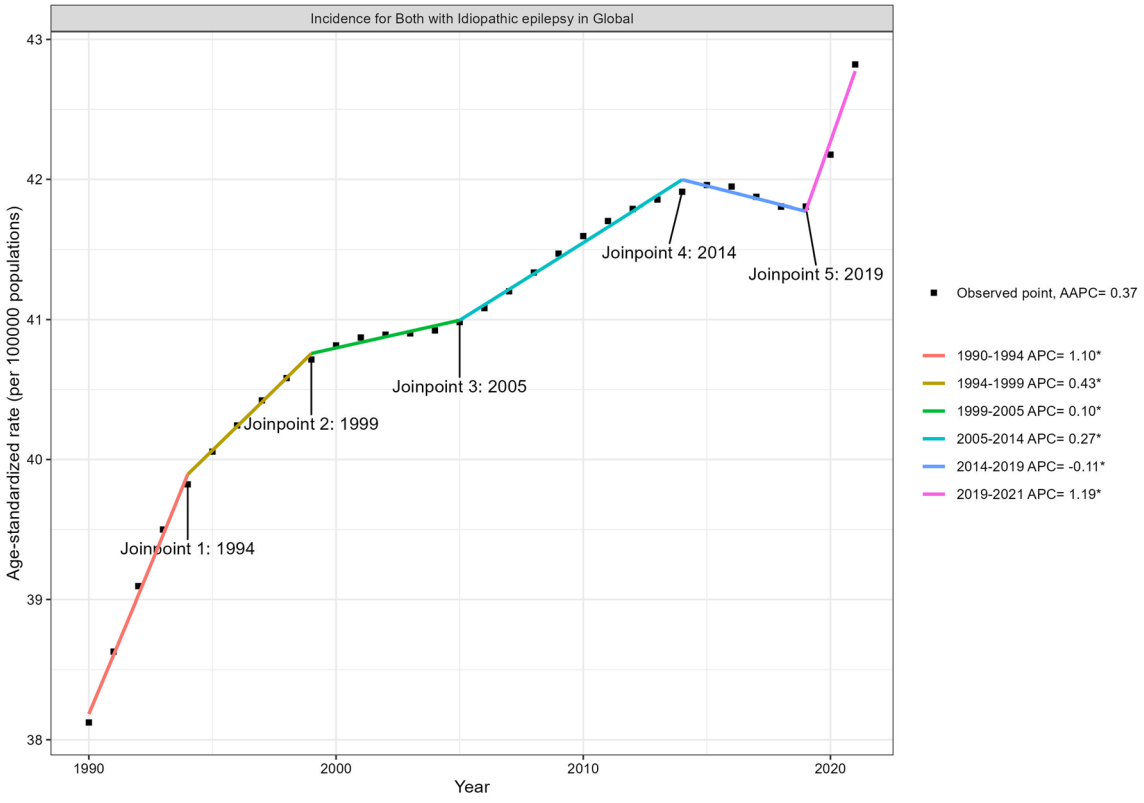

Fig. 1 Global trends in age-standardized incidence rates (per 100,000) of idiopathic epilepsy from 1990 to 2021

those aged ≥ 80 (Supplementary Fig. 7). Mortality rates increased significantly with age, particularly in those aged 80 and above (Supplementary Fig. 7). The highest number of DALYs in 2021 was seen in children under 5, with fluctuations in the 5–19 age group. DALYs remained relatively high in the 20–39 age group before decreasing, reaching the lowest levels in the ≥ 95 age group (Supplementary Fig. 8). DALY rates started high in the younger age groups, dropped in the 5–9 age group, and then rose again, peaking in the 15–19 age group before declining and reaching a low in the 50–54 age group. Rates then increased after the age of 55, peaking at 95 and older (Supplementary Fig. 8). IE showed significant gender differences, with males having consistently higher incidence, mortality, and DALY rates than females.

Association with SDI

At the regional level, a "W" shaped association was observed between the SDI and age-standardized incidence rates of IE from 1990 to 2021. Age-standardized DALY rates declined with rising SDI, increased when SDI reached about 0.4, dropped again at 0.6, and rose once more when SDI exceeded 0.67 (Fig. 5). Conversely, both age-standardized mortality and DALY rates decreased with increasing SDI (Supplementary Figs. 9 and 10).

At the national level, age-standardized incidence rates of IE increased with socioeconomic development in 2021, although fluctuations were noted in the 0.5–0.75 SDI range (Supplementary Fig. 11). In contrast, age-standardized mortality and DALY rates decreased with higher SDI (Supplementary Figs. 12 and 13).

Decomposition analysis of IE across 21 GBD regions (1990–2021)

Our decomposition analysis examined the relative contributions of aging, population growth, and epidemiological changes (adjusted for demographic factors) to the incidence, mortality, and DALYs of IE across 21 GBD regions. Notably, Eastern Europe and Central Europe showed a modest decline in overall incidence of IE between 1990 and 2021 (Fig. 6). In contrast, South Asia exhibited the largest increase in incidence, primarily driven by population growth. During the same period, regions such as East Asia and Eastern Europe—where epidemiological changes were adjusted for demographic factors—experienced declines in both overall mortality and DALY rates of IE. However, South Asia demonstrated the most significant rise in incidence, largely attributed to population dynamics (Supplementary Figs. 14 and 15).

Projections of IE (2022–2036)

To investigate the future trends of age-standardized incidence, mortality, and DALY rates of IE post-2021, we employed the BAPC model, stratifying projections by

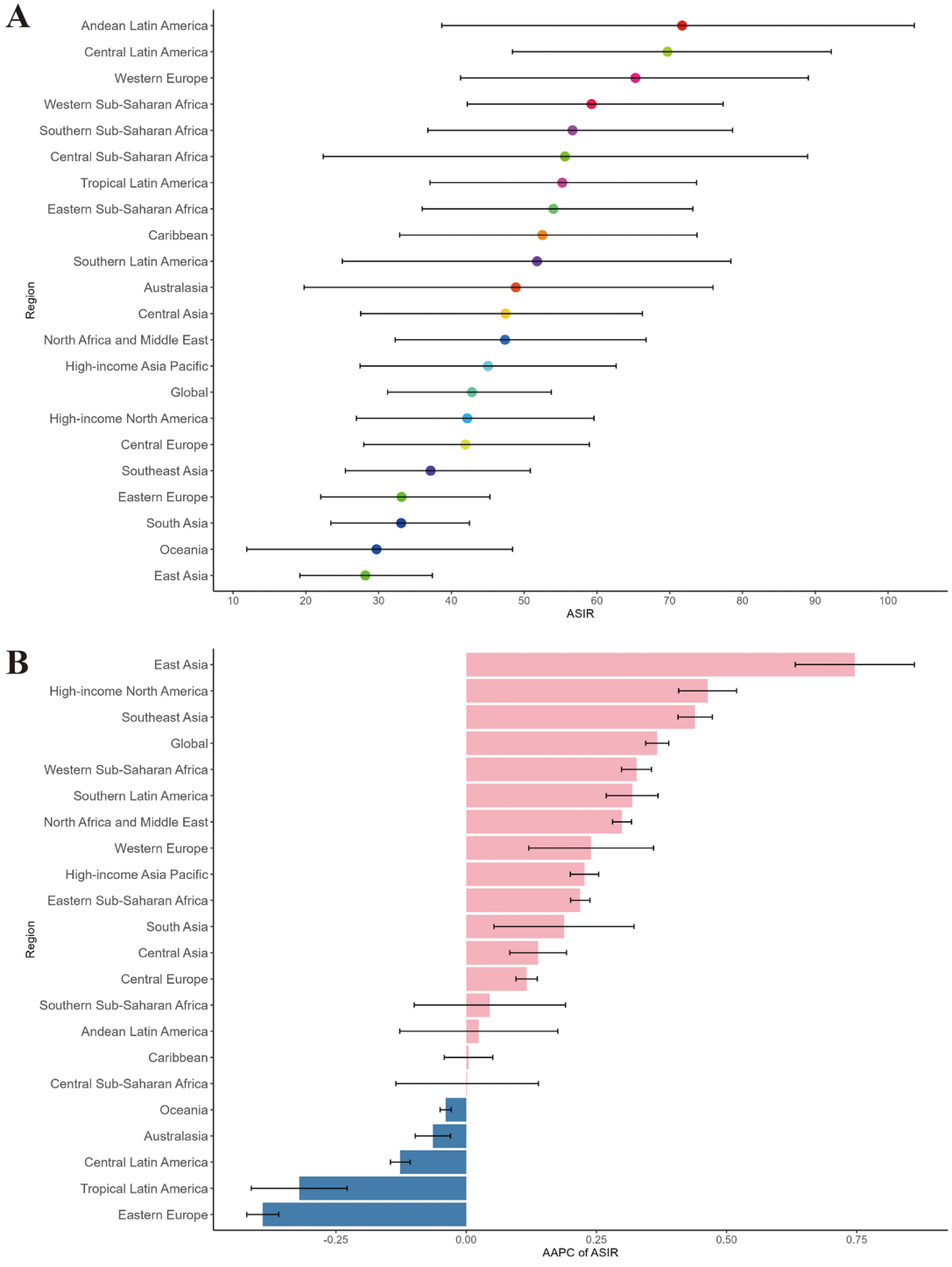

Fig. 2 Age-Standardized incidence rate of idiopathic epilepsy in 2021 and trends in Age-Standardized incidence rates from 1990 to 2021 across 21 regions. (**A**) Age-Standardized incidence rate of idiopathic epilepsy in 2021 across 21 regions. (**B**) Age-standardized incidence rate changes of idiopathic epilepsy across 21 regions from 1990 to 2021

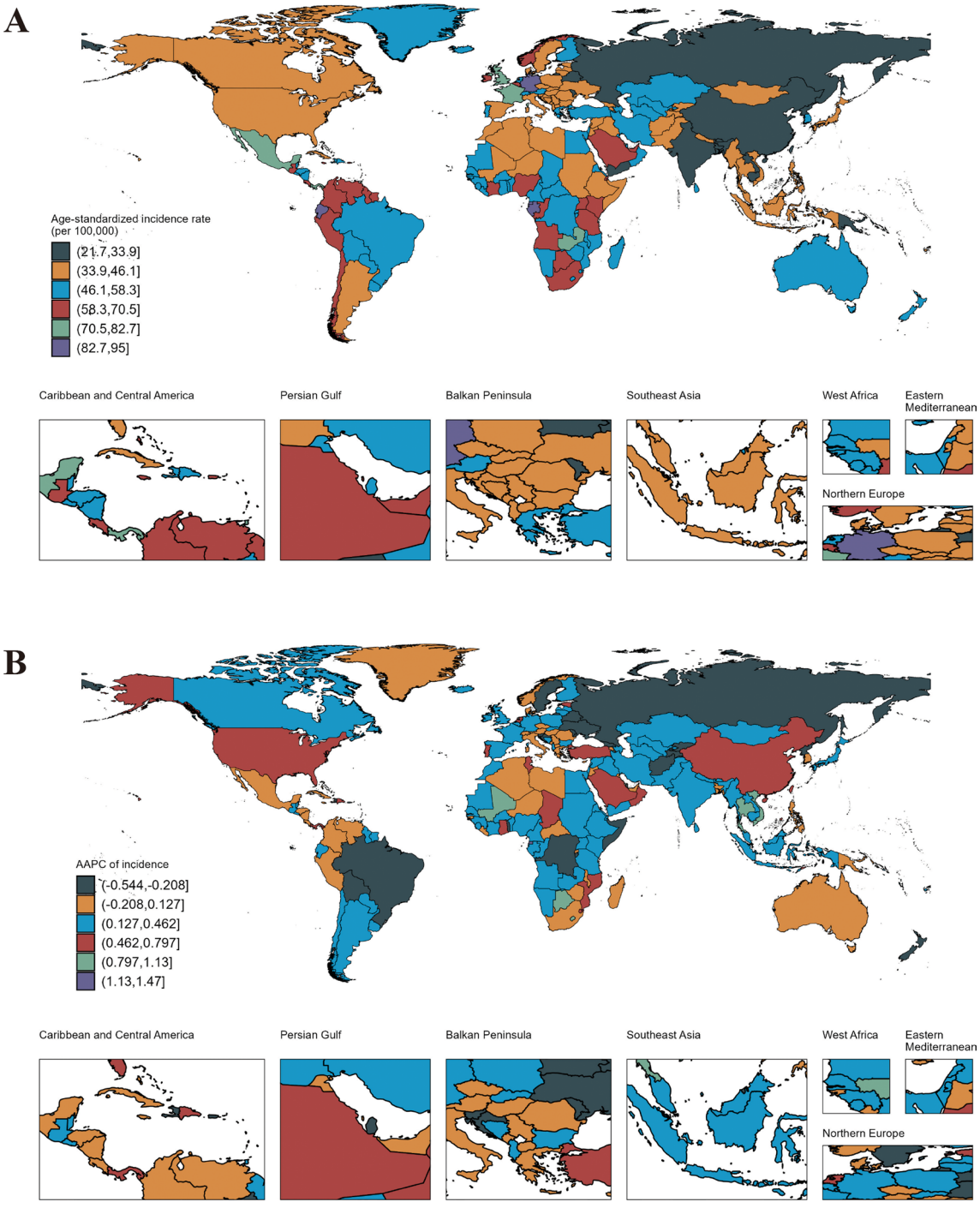

Fig. 3 Map of age-standardized incidence rates of idiopathic epilepsy at the national level in 2021 and map of the average annual percentage change of idiopathic epilepsy from 1990 to 2021. (**A**) Map of age-standardized incidence rates of idiopathic epilepsy at the national level in 2021. (**B**) Map of the average annual percentage change of idiopathic epilepsy from 1990 to 2021

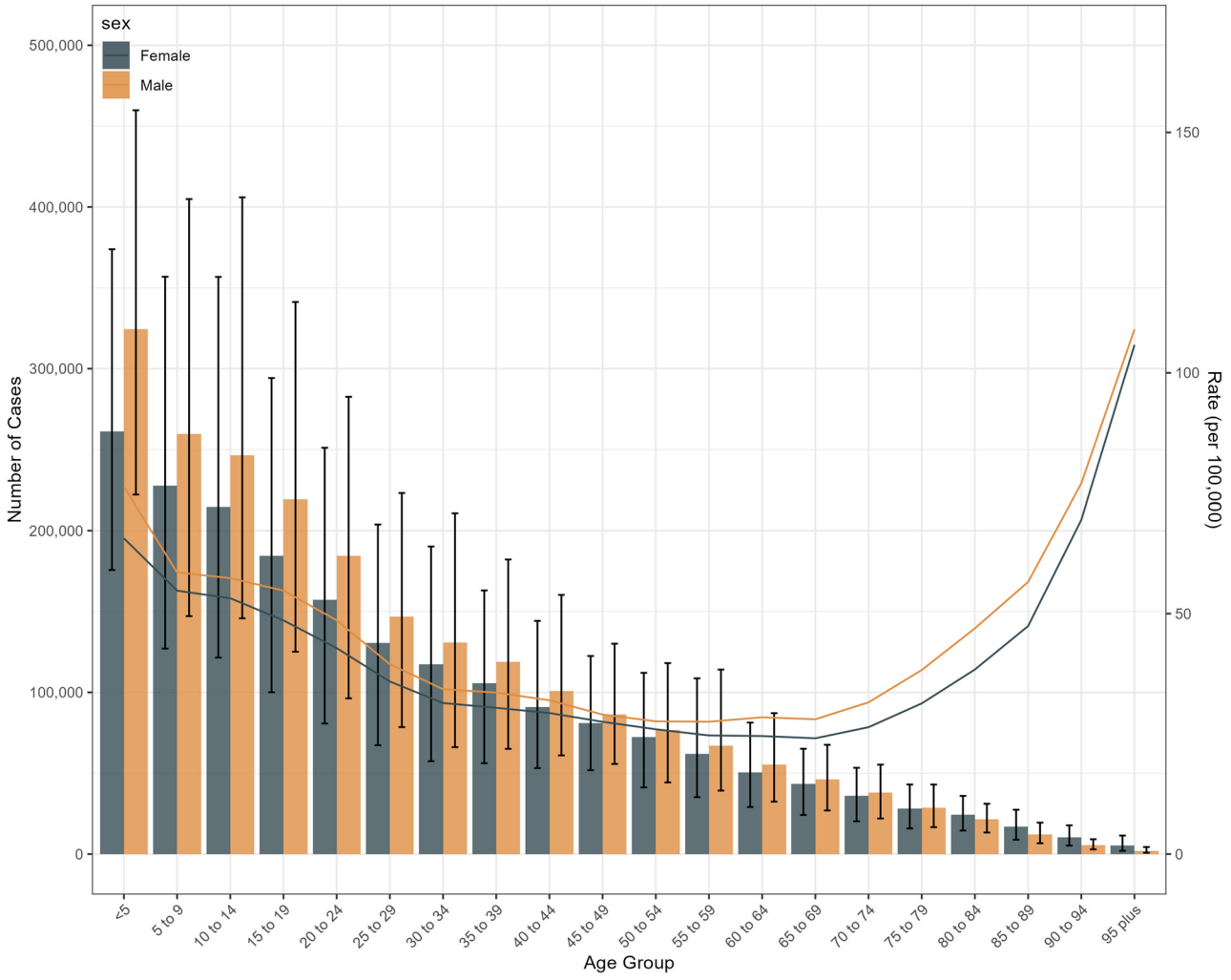

Fig. 4 The global number of incident cases and incidence rate per 100,000 population of idiopathic epilepsy in 2021, stratified by age and gender

gender from 2022 to 2036. The results suggest that the age-standardized incidence rate of IE will continue to rise annually beyond 2021, with men consistently exhibiting higher incidence rates than women (Fig. 7). Conversely, age-standardized mortality and DALY rates are projected to decline after 2021, though men are expected to maintain higher mortality and DALY rates compared to women (Supplementary Figs. 16 and 17).

Discussion

This study, utilizing the GBD 2021 database, offers a comprehensive epidemiological analysis of IE at a global scale, focusing on trends in incidence, mortality, and DALYs across various regions and sociodemographic contexts. Through comparisons with previous studies and detailed analysis, we reveal the dynamic changes in the global disease burden and the multifaceted factors driving them. Our study not only updates the global IE burden but also identifies distinctive patterns across regions, genders, and age groups, offering insights into potential health interventions.

Compared to earlier studies, our findings highlight notable regional differences in the global IE burden. For instance, the GBD2019 report showed a significantly higher epilepsy incidence in low- and middle-income countries, aligning with our observations of regional disparities [23]. However, our study further refines these differences, demonstrating that, in 2021, the highest age-standardized incidence rates were in Andean and Central Latin America, while East Asia and Oceania had the lowest. These variations reflect the complex interplay between healthcare resource allocation, health policies, socioeconomic development, and cultural factors. Since the COVID-19 pandemic began in early 2020, IE management has been severely impacted, especially in low- and middle-income countries where healthcare resources have been redirected to address the virus, disrupting the management of chronic diseases. The existing evidence suggests that delays in diagnosis and treatment, as well as

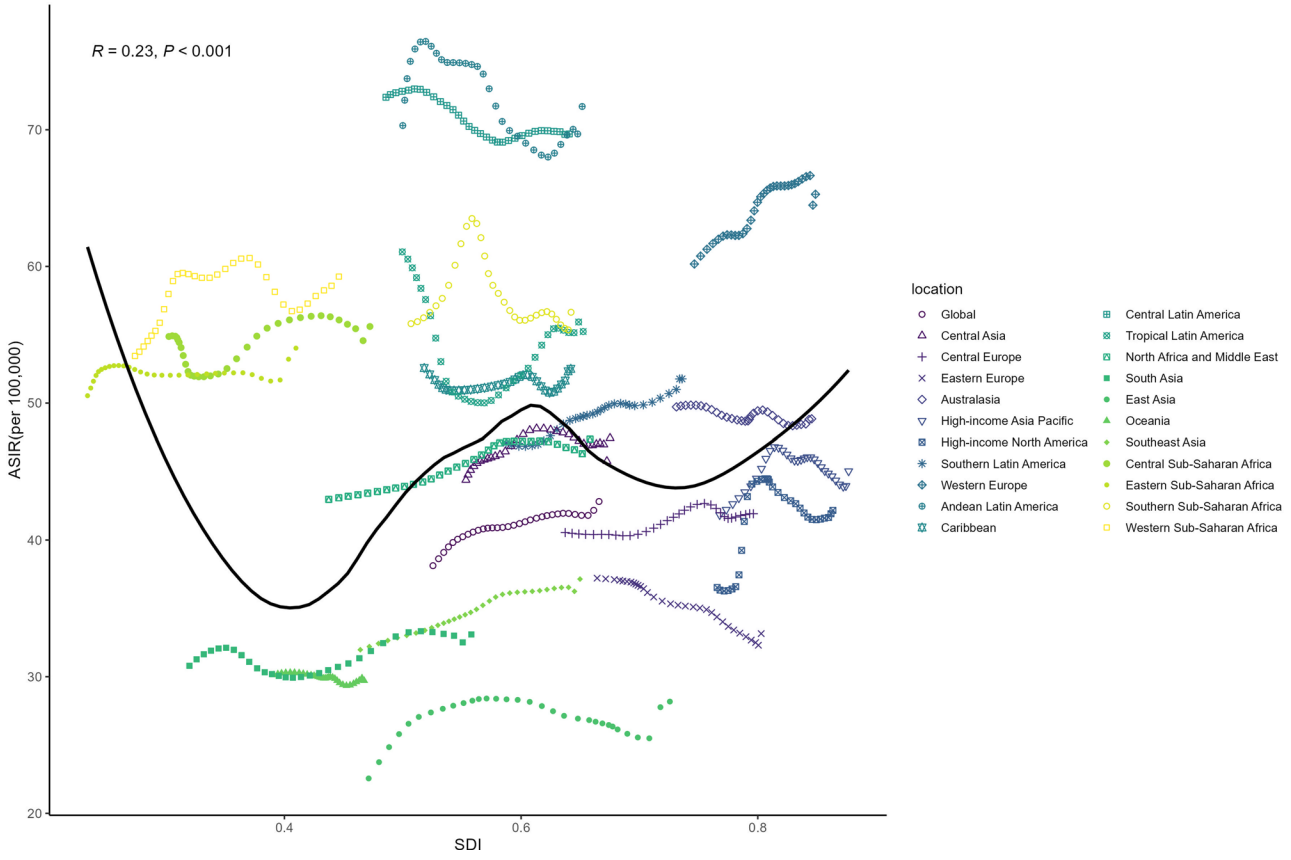

Fig. 5 The age-standardized incidence rates of idiopathic epilepsy by the Socio-demographic Index (SDI) across 21 Global Burden of Disease regions from 1990 to 2021. Each region is represented by 32 points, showing the observed age-standardized incidence rates from 1990 to 2021. The expected values, based on the SDI and incidence rates across all locations, are indicated by a solid line

limitations in healthcare resources, may affect the management of epilepsy [24].

Unlike previous studies, we incorporated the SDI to further clarify the socioeconomic drivers of epilepsy burden. Previous research primarily focused on healthcare resource shortages in low-income countries [11], but our study reveals a complex bidirectional relationship between SDI and disease burden. While economic development improves healthcare and reduces mortality, epilepsy incidence often rises with lifestyle changes and improved diagnostics.

Gender and age differences in IE burden were further explored and expanded in our study. Consistent with prior findings, males had higher incidence, mortality, and DALY rates than females, particularly in young and middle-aged populations. The higher burden among males may be related to gender-specific genetic susceptibility and environmental factors (e.g., lifestyle and occupational risks). These factors may partially explain the persistent differences in the burden observed between male and female patients [25]. Males are also more prone to trauma, with the increased accident frequency further elevating their mortality risk [26]. Social and behavioral factors, including stress, lifestyle, and occupational hazards, may also exacerbate epilepsy in male patients [27]. These factors collectively explain the higher burden in males.

Our study also elucidates life-cycle patterns of IE burden. Consistent with previous literature, we observed higher incidence rates in children under five, particularly those with neurodevelopmental disorders like intellectual disability and autism spectrum disorder [28]. However, epilepsy incidence decreases after adolescence but rises sharply in the elderly, particularly those over 60. This trend is associated with the high prevalence of neurodegenerative conditions like cerebrovascular disease, which heightens epilepsy risk in older adults [9, 29]. The incidence of IE demonstrates a distinctive double-peak distribution, with the first peak occurring in children under 5 years old and the second peak emerging in populations over 60 years old. The second peak is likely closely associated with aging populations, who are at increased risk of IE due to age-related comorbidities such as cerebrovascular and neurodegenerative diseases. This trend will not only challenge healthcare systems but also significantly increase the health economic burden in aging

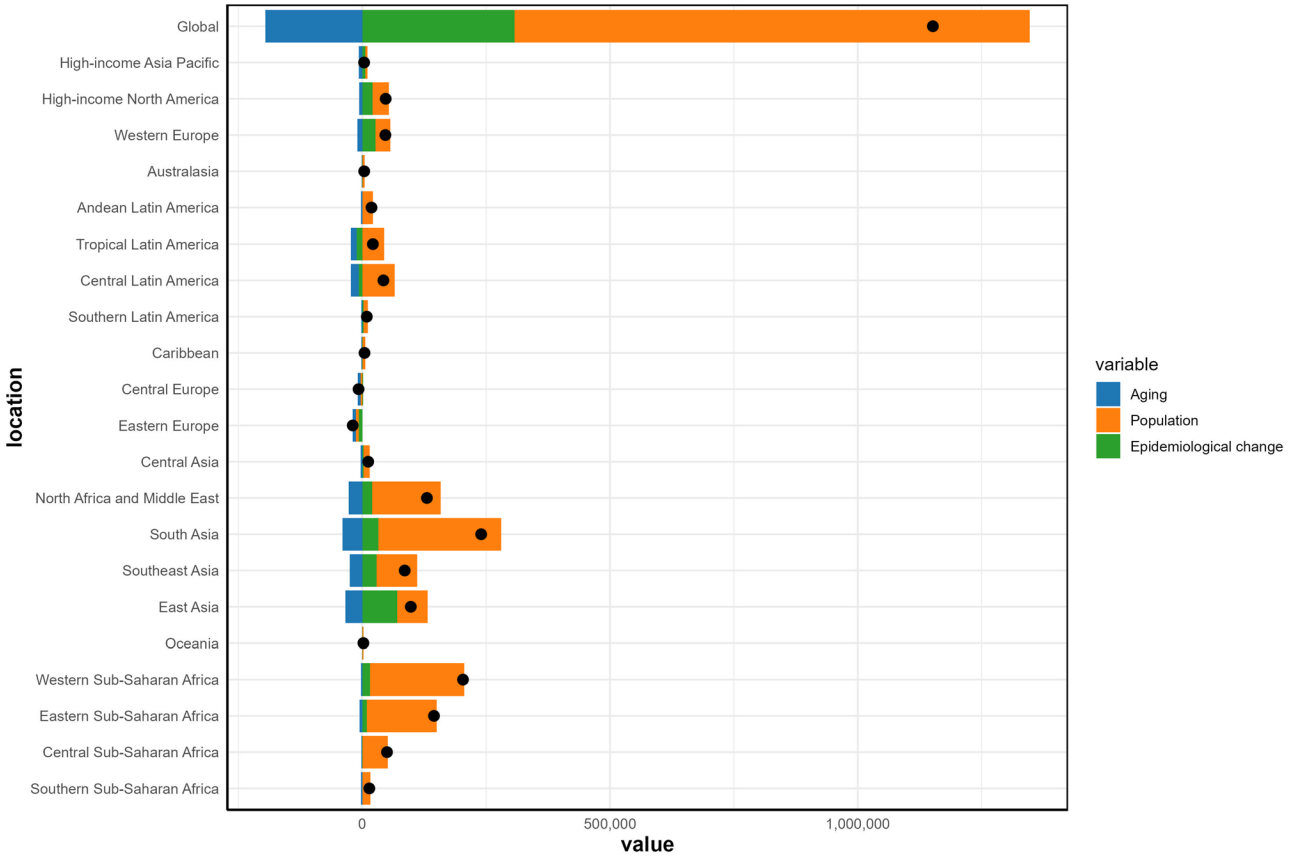

Fig. 6 Decomposition analysis of the incidence of idiopathic epilepsy across 21 Global Burden of Disease regions from 1990 to 2021

populations, particularly in rapidly aging regions like East Asia, where age-standardized incidence rates have shown the most notable growth over the years. This reflects the combined impact of population aging and improved diagnostic capabilities. To alleviate this growing burden, targeted public health strategies are needed, such as enhancing early diagnosis, improving treatment accessibility, and implementing health policies that address both the medical and economic impacts of IE, particularly in regions with aging populations and a high prevalence of neurodegenerative diseases.

Furthermore, using the BAPC model, we projected IE burden over the next 15 years (2022–2036). While mortality and DALY rates are expected to decline, incidence will continue to rise globally. These projections align with previous epidemiological findings but offer clearer insight into future trends. Our refined predictive modeling provides early warnings for policymakers, particularly in regions with lower SDI, highlighting the importance of enhancing early diagnosis and sustained treatment to mitigate the global epilepsy burden.

This study provides new insights by analyzing the burden of IE across different regions, age groups, and genders, while incorporating the dynamic impact of the SDI. We utilized DisMod-MR 2.1 and spatio-temporal Gaussian process regression models to effectively address data gaps and inconsistencies. However, data limitations in certain regions, particularly in countries with incomplete health records, may lead to underestimation. Additionally, the reliance on multinational data sources may introduce variability in data quality and accuracy. Although trend projections were made, these need to be validated with actual data. Therefore, enhancing epilepsy monitoring and data collection in low- and middle-income countries is crucial. The study also highlights significant regional and gender differences in the prevalence and burden of idiopathic epilepsy, particularly in resource-limited areas. Future research could further explore the trends in idiopathic epilepsy (especially the newly defined IGE types) from 1990 to 2021 through systematic reviews and meta-analyses. It is also important to investigate comorbidities such as depression and anxiety in epilepsy patients and to evaluate the effectiveness of medical interventions and health policies in different regions. This will help develop more effective public health strategies to alleviate the global epilepsy burden.

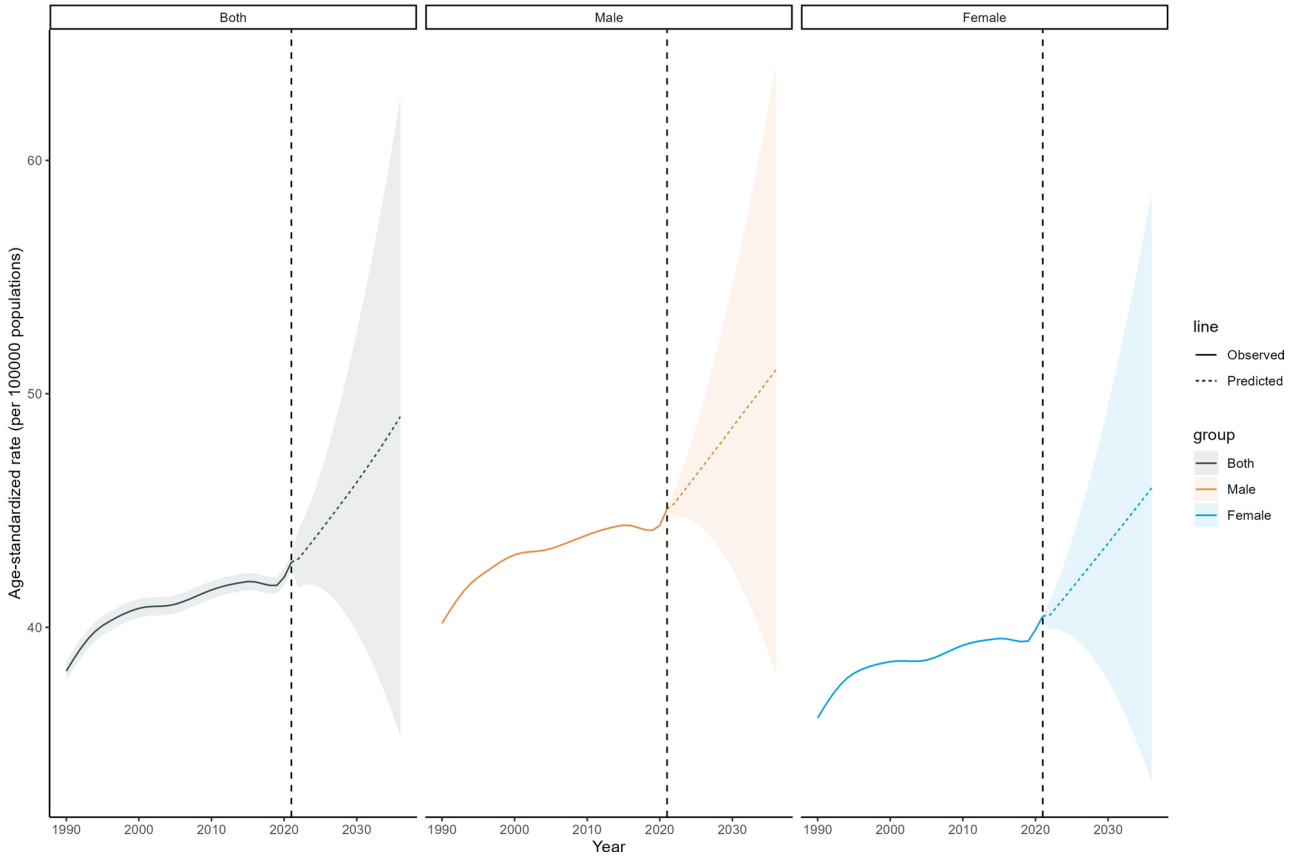

Fig. 7 BAPC model predictions of the age-standardized incidence rate of idiopathic epilepsy for the next 15 years, with shaded areas representing the 95% confidence intervals

Conclusion

By providing extensive data from the GBD 2021 database, this study highlights IE burden variations across regions, genders, and age groups, offering valuable insights for future health policy and resource allocation. The high incidence and mortality rates in low- and middle-income countries underscore the need to prioritize improvements in epilepsy diagnosis and care. Post-pandemic, the focus should be on restoring epilepsy management to mitigate the global burden and ensure effective resource distribution in response to evolving global health challenges.

Supplementary Information

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Supplementary Material 1

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Author contributions
LBX and QSL designed the research; LBX, ML and ZHW collected the data and verified the accuracy of the data. ML and ZHW verified the accuracy of the data; LBX, ML and ZHW contributed to data interpretation; LBX, ML and ZHW performed the statistical analysis and visualization; LBX and QSL wrote the manuscript. All authors read, critically reviewed, and approved the final manuscript.

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Data availability
The data supporting the findings of this study are based on the Global Burden of Disease (GBD) 2021 database. The GBD data is publicly available and can be accessed through the Institute for Health Metrics and Evaluation (IHME) platform at https://vizhub.healthdata.org/gbd-results/.

Declarations

Ethics approval and consent to participate
The use of the 2021 Global Burden of Disease database in this study was in compliance with the ethical standards of the database's governing body. As this study involved analysis of publicly available, de-identified data, no additional ethical approval was required.

Consent for publication
This study utilized data from publicly available databases, which do not contain identifiable personal information. Therefore, consent for publication is not applicable.

Competing interests
The authors declare no competing interests.

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