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Original Article

Global, regional, and national burden of asthma from 1990 to 2021: A systematic analysis of the global burden of disease study 2021

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ABSTRACT

Background: Asthma is a prevalent non-communicable disease that affects individuals of all ages and has emerged as a significant global public health concern. This study aims to conduct a comprehensive assessment of the burden of asthma worldwide, as well as at regional and national levels, utilizing the Global Burden of Diseases (GBD) 2021 database for the years 1990 to 2021.

Methods: This study utilized the GBD 2021 database to report the prevalent cases and incident cases of asthma, alongside age-standardized prevalence rates (ASPR), age-standardized incidence rate (ASIR), the number of disability-adjusted life years (DALYs), age-standardized DALY rates (ASDR), the number of deaths, and age-standardized mortality rates (ASMR) at global, regional, and national levels for the year 2021. Additionally, it computed the estimated annual percentage change (EAPC) for these asthma burden indicators from 1990 to 2021. This study further analyzed the levels of the above indicators in different gender and age groups, and investigated the association between asthma ASDR/ASMR levels and socio-demographic index (SDI). It also provided an analysis of the contribution of four risk factors to the overall asthma burden.

Results: From 1990 to 2021, the global EAPC for asthma ASIR was −1.04 (95 % confidence interval [CI]:−1.18 to −0.89), the EAPC for ASPR was −1.59 (95 % CI:−1.74 to −1.43), the EAPC for ASDR was −1.91 (95 % CI:−1.98 to −1.84), and the EAPC for ASMR was −2.03 (95 % CI:−2.09 to −1.98). In 2021, the prevalent cases of asthma remained alarmingly high at 260.48 million (95 % UI: 227.21 million to 297.97 million). Developed countries, exemplified by the United States, exhibited elevated asthma ASPR. However, the burden of asthma-related mortality and DALYs predominantly afflicted low- and middle-income nations. In China, there has been a significant decline in ASIR, ASPR, ASDR and ASMR for asthma. In most age groups, the burden of asthma among women was markedly higher than that among men, particularly evident in prevalence and DALYs. Children and the elderly bore a heavier burden of asthma. In 2021, ASDR and ASMR levels varied across countries, generally exhibiting a negative correlation with SDI levels. A high body-mass index continued to be a primary risk factor for asthma on a global scale. Decomposition analysis reveals that population growth plays a significant role in exacerbating the burden of asthma-related deaths and DALYs.

Conclusions: From 1990 to 2021, the burden of asthma as measured by age-standardized rate (ASR) has shown a declining trend. However, the overall burden of asthma remains significantly high. Moreover, there is a notable inequality in the burden of asthma across different regions and populations worldwide. This highlights the urgent need for countries to prioritize asthma management and control strategies to address these disparities and improve health outcomes for affected individuals.

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Introduction

Asthma is one of the most prevalent chronic respiratory diseases, as well as a common chronic non-communicable ailment among both adults and children, characterized by variable respiratory symptoms and fluctuating airflow limitations.[1] According to the Global Initiative for Asthma (GINA) guidelines, over 300 million individuals worldwide are affected by asthma.[2] Due to the intricate interplay of genetic regulation and environmental influences on the onset of asthma, there are currently no clinical measures to completely eradicate the condition. Asthma imposes a significant burden worldwide, impacting both economic and health-related aspects.[3] A study from the United States projects that the direct costs associated with uncontrolled asthma could reach up to $300.6 billion over a 20-year period.[4] Researchers have utilized the Global Burden of Diseases (GBD) 2019 database to assess the global burden of asthma, finding that asthma results in significant loss of disability-adjusted life years (DALYs) and a high number of deaths worldwide.[5,6] Asthma imposes a substantial disease burden across all age groups. Previous studies have shown that the prevalence of asthma is particularly high among children aged 5 to 9 years. Additionally, the distribution of asthma-related DALYs exhibits a bimodal pattern: with a peak among young males in the 5–9-year age group and another peak among older females aged 60 to 64 years. There are notable gender differences in asthma incidence, as women over the age of 20 have a higher number of asthma-related DALYs compared with men.[5] Unlike many other illnesses, asthma has a higher prevalence rate in developed countries.[7] In many underdeveloped regions, it is associated with a significantly higher mortality rate and burden of disease, as measured by DALYs,[3] which underscores the universal nature of asthma as a significant public health burden. The GBD 2021 Diseases and Injuries Collaborators have released the latest GBD 2021 data, which provides a comprehensive analysis of the burden of 371 diseases worldwide.[8] Currently, there has been no research conducting a comprehensive analysis of the burden of asthma using the latest GBD 2021 data at the global, regional and national levels.

Although several studies related to GBD 2019 have previously analyzed the burden of asthma, it is imperative to update the assessment of its burden level, given asthma's significance as a public health issue. Prior evaluations assessing the burden of asthma in GBD studies have only calculated the percentage change in age-standardized rates (ASR) over the past three decade.[3,5] This study capitalizes on the asthma burden data from the intervening years between 1990 and 2021 by calculating the estimated annual percentage change (EAPC) of asthma ASR, thereby providing a more comprehensive portrayal of the overall trends in asthma ASR over the past 32 years. Furthermore, prior analyses of asthma risk factors have been predominantly limited to high body mass index (BMI), smoking, and occupational asthma, underscoring the necessity for a thorough examination of the burden attributed to currently reported asthma-related risk factors. This research also conducts a decomposition analysis of the driving forces behind the changes in mortality and DALYs associated with asthma, both globally and across 21 regions from 1990 to 2021. Additionally, this study places particular emphasis on the latest asthma burden in China, contrasting earlier studies that provided only a cursory overview using GBD 2019 data.[9,10] Although there has been a significant improvement in the burden of asthma-related diseases in China between 1990 and 2021, the sheer size of the population means that the loss of DALYs and the number of asthma-related deaths remain at a notably high level. Therefore, it is essential to focus on the latest burden of asthma in China. This study employs the GBD 2021 database to conduct a comprehensive analysis of asthma burden, aiming to provide updated epidemiological evidence to inform the formulation of relevant public health policies aimed at alleviating the burden of asthma.

Methods

Study data

All data for this study are sourced from the Global Burden of Diseases (GBD) database managed by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington. A comprehensive analysis was conducted using data on asthma incident cases/incidence, prevalent cases/prevalence, deaths/mortality, and DALYs numbers/rates across 21 regions and 204 countries and territories from 1990 to 2021. All data can be accessed at "https://vizhub.healthdata.org/gbd-results". Ethical approval was not required for this study, as it utilized publicly available data from the GBD 2021 dataset.

In GBD 2021, asthma is defined as a chronic pulmonary disease characterized by bronchospasm, often triggered by allergic reactions or hypersensitivity, typically manifesting as difficulty in breathing. It is classified under ICD-10 codes J45 and J46, and ICD-9 code 493.[8] The GBD 2021 provides a comprehensive description of the sources and specific definitions of asthma-related cases.[8]

In this study, data on asthma burden attributable to risk factors were also drawn from the GBD 2021 database.[8] GBD 2021 only reports the disease burden levels of four risk factors for asthma, including nitrogen dioxide (NO_2) pollution, occupational asthmagens, smoking, and high BMI. Exposure to NO_2 pollution is defined as the population-weighted annual average ambient concentration of NO_2 gas measured in parts per billion (ppb). The NO_2 exposure modelling process for the GBD Study 2021 combines multiple and varied input data sources. These include ground measurements, satellite column measurements and satellite-based surface concentration estimates, land-use regression-based surface concentration estimates, urbanicity data, and population estimates. Occupational asthmagens is defined as the proportion of the working population exposed to asthmagens, based on population distributions across nine occupational categories (legislators, senior officials, and managers; professionals; technicians and associate professionals; clerks; service workers and shop/market sales workers; skilled agricultural and fishery workers; plant and machine operators and assemblers; craft and related workers; elementary occupations). Primary input data were obtained from the International Labour Organization (ILO). GBD 2021 Collaborators estimated the prevalence of current smoking and the prevalence of former smoking using data from cross-sectional nationally representative household surveys. They defined current smokers as individuals who currently use any smoked tobacco product on a daily or occasional basis. They defined former smokers as individuals who quit using all smoked tobacco products for at least six months, where possible, or according to the definition used by the given survey. High BMI for adults (ages ≥20 years) is defined as BMI greater than 20 to 23 kg/m^2. High BMI for children and adolescents (ages 2–19 years) is defined as being overweight or obese based on International Obesity Task Force standards.[8] The GBD 2021 Collaborators provided a detailed description of the definition and statistical methods of the aforementioned risk factors in Supplementary Appendix 1 of the GBD 2021 research.[8]

The data sources for asthma mortality include vital registration systems and mortality surveillance data.[5] Years of life lost (YLLs) refer to the number of years of life lost due to premature death, calculated by multiplying the number of deaths at each age group by the global standard life expectancy at the age of death.[11] Years lived with disability (YLDs) represent the number of years lost due to health impairment caused by disability, calculated by multiplying the prevalence of a condition at each stage by the disability weight specific to that stage.[12] DALYs represent the total number of healthy years lost from the onset of disease to death, calculated by summing YLLs and YLDs.[13] The socio-demographic index (SDI) is a composite measure used to assess the development status of a country or region, ranging from 0 (least developed) to 1 (most developed). It evaluates this status by integrating data on the total fertility rate for

women under 25 years, the average educational attainment for individuals aged 15 years and older, and the lag-distributed income per capita.[14]

Statistical analysis

In GBD 2021, asthma data were primarily modeled using DisMod-MR 2.1, a Bayesian meta-regression tool for disease modeling that produces internally consistent estimates of prevalence, incidence, remission, and mortality rates by sex, location, year, and age group. The Cause of Death Ensemble Model (CODEm) was employed to analyze mortality data and evaluate asthma mortality rates across different locations, ages, sexes, and years.[8] We used the direct method with the GBD standard global population to produce age-standardized estimates. The GBD standard population is based on the population structure of all countries with populations greater than 5 million people. This study utilized the EAPC to assess the yearly changes in the burden of asthma from 1990 to 2021. The calculation of EAPC involves converting the age-standardized DALY rate (ASDR) or age-standardized mortality rate (ASMR) or age-standardized prevalence rate (ASPR) or age-standardized incidence rate (ASIR) to the common logarithm for different years, taking the geometric mean of these values, and fitting a straight line with these geometric means as the dependent variable. The formula is $Y = \alpha + \beta X + \epsilon$. Y refers to ln(ASR), α denotes the intercept, X signifies the calendar year, ϵ represents the error term, and β reflects a linear positive or negative trend in ASR. The EAPC and its 95% confidence interval (CI) were computed using this formula: $\text{EAPC} = 100 \times \left[\exp(\beta) - 1\right]$.[15] An EAPC and its 95 % confidence interval (CI) lower bound >0 indicate an increasing trend in incidence, prevalence, mortality or DALYs each year, whereas an EAPC and its 95 % CI upper bound <0 suggest the opposite trend.[16] In the GBD 2021 database, 95% uncertainty intervals (UIs) were generated for all final estimates as the 2.5th and 97.5th percentiles of 500 draws. Uncertainty was propagated at each step of the estimation process.[8] The rates presented in this study are expressed per 100,000 population. The correlation between SDI levels and age-standardized mortality and DALY rates was measured using the Spearman rank correlation test, and the expected values were visualized using locally weighted scatterplot smoothing curves.[17] This study employed Das Gupta's decomposition method to analyze and decompose the primary drivers of changes in global and regional asthma mortality rates and DALY rates from 1990 to 2021, focusing on factors such as aging, population growth, and changes in ASRs (epidemiological changes)[18] (Supplementary Material). The tools utilized for data analysis and graphical representation in this article are based on R Version 4.2.1 (https://www.r-project.org/).

Results

Global level

Globally, in 2021, the incident cases of asthma reached 37.86 million (95 % UI: 31.38 million to 46.92 million), with an ASIR of 516.70 (95 % UI: 425.36 to 646.13) per 100,000. The EAPC for ASIR from 1990 to 2021 was −1.04 (95 % CI: −1.18 to −0.89). In 2021, the prevalent cases of asthma reached 260.48 million (95 % UI: 227.21 million to 297.97 million), with an ASPR of 3340.12 (95 % UI: 2905.24 to 3832.24) per 100,000. The EAPC for ASPR from 1990 to 2021 was −1.59 (95 % CI: −1.74 to −1.43). In 2021, the number of DALYs attributed to asthma was 21.42 million (95 % UI: 16.96 million to 26.89 million), with an ASDR of 264.62 (95 % UI: 208.32 to 333.43) per 100,000. The EAPC for ASDR from 1990 to 2021 was −1.91 (95 % CI: −1.98 to −1.84). In 2021, the number of deaths due to asthma was 436,192.95 (95 % UI: 357,795.39 to 555,604.08), with an ASMR of 5.20 (95 % UI: 4.27 to 6.59) per 100,000. The EAPC for ASMR from 1990 to 2021 was −2.03 (95 % CI: −2.09 to −1.98) [Table 1, Supplementary Fig. 1].

Regional levels

The analysis of asthma burden across 21 global regions (Table 1) in 2021 shows that the highest incidences were in South Asia, East Asia, and High-income North America. The regions with the highest ASIR per 100,000 were High-Income North America, Caribbean and Central Europe. The regions with the lowest ASIR per 100,000 were Southern Sub-Saharan Africa, South Asia, and East Asia.

In 2021, the highest prevalences were in South Asia, High-Income North America, and East Asia. The regions with the highest ASPR per 100,000 were High-Income North America, Australasia, and the Caribbean. The regions with the lowest ASPR per 100,000 were Southern Sub-Saharan Africa, East Asia, and South Asia.

In terms of deaths due to asthma in 2021, the highest numbers were observed in South Asia, Southeast Asia, and East Asia. The regions with the highest ASMR per 100,000 were Oceania, South Asia, and Central Sub-Saharan Africa. Additionally, Southern Sub-Saharan Africa and Southeast Asia also had ASMRs exceeding 10 per 100,000, while Eastern Europe, High-Income Asia Pacific, and Western Europe had the lowest ASMRs.

For DALYs caused by asthma in 2021, the highest numbers were in South Asia, Southeast Asia, and East Asia. The regions with the highest ASDR were Oceania, Central Sub-Saharan Africa, and the Caribbean. Conversely, the regions with the lowest ASDR were East Asia, Eastern Europe, and High-Income Asia Pacific.

From 1990 to 2021, the ASIR for asthma declined in most global regions except High-Income North America; the ASPR for asthma showed a declining trend in 20 global regions. High-Income Asia Pacific, Eastern Europe, and Southern Sub-Saharan Africa experienced the largest absolute EAPC values for ASPR, indicating the most significant declines over 32 years. Only High-Income North America had a positive EAPC of 0.87 (95 % CI: 0.53 to 1.21), indicating an increasing trend in ASPR. Similarly, the ASMR for asthma showed a declining trend in all 21 regions from 1990 to 2021, with the largest negative EAPC values found in High-Income Asia Pacific, Eastern Europe, and Central Europe. The ASDR also declined in 20 regions except High-Income North America, with the highest negative EAPC values observed in High-Income Asia Pacific, Eastern Europe, and Central Latin America.

National/territorial level

At the national/territorial level, in 2021, the countries/territories with the highest ASIR of asthma per 100,000 population were Haiti, Poland, and Puerto Rico. In contrast, the countries/territories with the lowest ASPR in 2021 were Lesotho, Pakistan, and Bhutan (Supplementary Table 1).

In 2021, the countries with the highest ASPR of asthma per 100,000 population were Haiti, the United States of America, and the United Kingdom. All of these countries had an ASPR exceeding 10,000 per 100,000 population. In contrast, the countries/territories with the lowest ASPR in 2021 were Lesotho, American Samoa, and Guam (Supplementary Table 2).

For ASMR, Papua New Guinea, Fiji, and Kiribati had the highest rates. In contrast, over 50 countries and territories had an ASMR below 1 per 100,000, with Monaco, Ukraine, and Greece being the three countries with the lowest ASMR (Supplementary Table 3).

In terms of ASDR, the highest rates were found in Papua New Guinea, Fiji, and Haiti. The countries with the lowest ASDR were Armenia, China, and the Russian Federation (Supplementary Table 4).

From 1990 to 2021, asthma ASIR showed a declining trend in most countries/territories. The largest negative EAPC values for ASIR were observed in South Africa, Japan, and Guatemala, indicating the most significant declines in ASIR. However, some countries/territories showed a positive EAPC, indicating an increasing trend in ASIR over the 32 years, and the incidence rate of asthma in the United States has increased most

Table 1
Incidence, prevalence, deaths, and DALYs for asthma in 2021, and EAPC of ASRs per 100,000, by Global Burden of Disease region, from 1990 to 2021.

Items	Number of incident cases (million) (95% UI)	ASIR (per 100,000) (95% UI)	EAPC of incidence from 1990 to 2021 (95% CI)	Number of prevalent cases (million) (95% UI)	ASPR (per 100,000) (95% UI)	EAPC of prevalence from 1990 to 2021 (95% CI)	Number of deaths (95% UI)	ASMR (per 100,000) (95% UI)	EAPC of ASMR from 1990 to 2021 (95% CI)	Number of DALYs (95% UI)	ASDR (per 100,000) (95% UI)	EAPC of ASDR from1990 to 2021 (95% CI)
Global	37.86 (31.38 to 46.92)	516.70 (425.36 to 646.13)	−1.04 (−1.18 to −0.89)	260.48 (227.21 to 297.97)	3340.12 (2905.24 to 3832.24)	−1.59 (−1.74 to −1.43)	436,192.95 (357,795.39 to 555,604.08)	5.20 (4.27 to 6.59)	−2.03 (−2.09 to −1.98)	21,422,859.89 (16,956,877.71 to 26,887,091.72)	264.62 (208.32 to 333.43)	−1.91 (−1.98 to −1.84)
Western Sub-Saharan Africa	3.75 (2.97 to 4.77)	606.89 (502.78 to 741.36)	−0.70 (−0.75 to −0.65)	18.66 (15.70 to 22.29)	3650.77 (3218.15 to 4137.05)	−0.93 (−0.99 to −0.88)	18,898.82 (15,091.91 to 23,345.29)	9.52 (7.82 to 11.7)	−1.63 (−1.70 to −1.57)	1,407,732.74 (1,119,316.34 to 1,805,847.68)	380.91 (313.80 to 467.14)	−1.51 (−1.56 to −1.46)
Western Europe	1.56 (1.32 to 1.92)	498.8 (404.7 to 632.59)	−0.72 (−0.87 to −0.56)	25.52 (21.96 to 29.23)	5886.78 (4943.98 to 6943.63)	−1.52 (−1.70 to −1.34)	6740.73 (5747.58 to 7304.26)	0.67 (0.59 to 0.71)	−5.40 (−5.89 to −4.92)	1,105,870.45 (759,089.03 to 1,544,548.45)	248.26 (161.28 to 359.54)	−1.93 (−2.12 to −1.73)
Tropical Latin America	1.66 (1.29 to 2.17)	894.57 (682.86 to 1191.46)	−1.41 (−1.54 to −1.28)	9.56 (7.84 to 11.68)	4751.69 (3833.54 to 5918.81)	−1.86 (−1.98 to −1.74)	2688.83 (2444.76 to 2839.61)	1.09 (0.99 to 1.16)	−3.64 (−3.94 to −3.34)	451,820.22 (308,650.23 to 653,273.09)	219.3 (147.61 to 319.39)	−2.25 (−2.37 to −2.12)
Southern Sub-Saharan Africa	0.27 (0.22 to 0.34)	340.03 (278.42 to 423.88)	−1.91 (−2.12 to −1.69)	1.47 (1.28 to 1.72)	1875.86 (1645.57 to 2166.61)	−2.11 (−2.34 to −1.89)	7580.28 (6808.77 to 8414.52)	13.89 (12.43 to 15.40)	−1.15 (−1.66 to −0.65)	287,850.96 (252,760.81 to 322,121.90)	425.56 (377.10 to 471.90)	−1.43 (−1.88 to −0.98)
Southern Latin America	0.39 (0.32 to 0.48)	669.63 (534.12 to 860.67)	−0.19 (−0.27 to −0.11)	4.17 (3.59 to 4.88)	6030.14 (5072.85 to 7192.86)	−0.76 (−0.82 to −0.69)	755.85 (685.74 to 804.61)	0.87 (0.79 to 0.92)	−3.60 (−3.88 to −3.31)	179,155.36 (121,013.42 to 255,622.26)	257.29 (170.66 to 375.59)	−1.20 (−1.26 to −1.14)
Southeast Asia	3.08 (2.63 to 3.66)	484.15 (410.27 to 580.20)	−1.19 (−1.27 to −1.12)	19.54 (17.39 to 21.69)	2924.63 (2602.99 to 3254.73)	−1.45 (−1.52 to −1.37)	65,397.93 (58,052.46 to 74,920.29)	11.37 (10.01 to 12.98)	−2.08 (−2.20 to −1.95)	2,562,177.31 (2,230,743.15 to 2,989,405.56)	390.32 (340.44 to 453.86)	−1.94 (−2.01 to −1.87)
South Asia	6.16 (5.07 to 7.69)	358.65 (297.33 to 445.06)	−1.31 (−1.63 to −0.99)	39.01 (33.79 to 45.12)	2264.21 (1980.33 to 2598.62)	−1.52 (−1.76 to −1.28)	232,839.13 (167,862.40 to 348,208.11)	17.68 (12.55 to 26.32)	−1.25 (−1.38 to −1.12)	7,155,537.61 (5,526,770.05 to 9,866,148.76)	465.02 (357.17 to 648.94)	−1.67 (−1.73 to −1.60)
Oceania	0.07 (0.06 to 0.08)	484.35 (423.68 to 549.28)	−1.38 (−1.48 to −1.28)	0.37 (0.34 to 0.41)	2878.06 (2664.96 to 3120.11)	−1.72 (−1.83 to −1.61)	2047.03 (1436.86 to 3075.59)	33.98 (24.05 to 51.08)	−1.12 (−1.17 to −1.06)	76,217.83 (57,057.50 to 106,237.10)	847.59 (626.75 to 1212.54)	−1.23 (−1.29 to −1.18)
North Africa and Middle East	3.28 (2.74 to 4.00)	541.22 (457.04 to 654.65)	−1.07 (−1.10 to −1.03)	20.75 (18.11 to 23.77)	3486.37 (3091.70 to 3959.27)	−1.41 (−1.47 to −1.36)	24,989.70 (21,799.47 to 28,676.08)	6.48 (5.65 to 7.36)	−3.19 (−3.28 to −3.09)	1,438,121.56 (1,142,506.92 to 1,850,525.62)	269.87 (219.66 to 338.46)	−2.67 (−2.73 to −2.61)
High-income North America	3.99 (3.37 to 4.83)	1403.64 (1137.64 to 1766.66)	0.65 (0.35 to 0.95)	35.31 (31.59 to 39.43)	9717.74 (8485.10 to 11,226.93)	0.87 (0.53 to 1.21)	4062.03 (3733.98 to 4246.43)	0.78 (0.74 to 0.81)	−2.93 (−3.26 to −2.60)	1,488,360.68 (1,017,655.34 to 2,132,562.26)	411.94 (280.02 to 602.95)	0.49 (0.19 to 0.80)

(*continued on next page*)

Table 1 (*continued*)

Items	Number of incident cases (million) (95% UI)	ASIR (per 100,000) (95% UI)	EAPC of incidence from 1990 to 2021 (95% CI)	Number of prevalent cases (million) (95% UI)	ASPR (per 100,000) (95% UI)	EAPC of prevalence from 1990 to 2021 (95% CI)	Number of deaths (95% UI)	ASMR (per 100,000) (95% UI)	EAPC of ASMR from 1990 to 2021 (95% CI)	Number of DALYs (95% UI)	ASDR (per 100,000) (95% UI)	EAPC of ASDR from1990 to 2021 (95% CI)
High-income Asia Pacific	0.66 (0.56 to 0.80)	506.95 (397.10 to 661.02)	−2.04 (−2.31 to −1.77)	6.01 (5.27 to 6.85)	3299.82 (2706.15 to 4053.50)	−3.22 (−3.43 to −3.00)	4165.77 (3222.09 to 5205.50)	0.66 (0.53 to 0.84)	−8.86 (−9.32 to −8.40)	285,743.91 (201,191.79 to 389,779.44)	143.21 (94.06 to 209.45)	−4.29 (−4.56 to −4.02)
Eastern Sub-Saharan Africa	3.76 (3.05 to 4.69)	687.17 (568.56 to 836.7)	−1.00 (−1.06 to −0.94)	19.87 (16.75 to 23.04)	4199.27 (3674.62 to 4771.13)	−1.33 (−1.39 to −1.27)	17,340.12 (12,493.90 to 26,617.60)	9.42 (6.67 to 15.60)	−1.90 (−1.95 to −1.84)	1,474,135.98 (1,128,871.35 to 1,947,523.58)	420.17 (323.24 to 574.53)	−1.88 (−1.91 to −1.84)
Eastern Europe	0.68 (0.55 to 0.86)	460.11 (360.84 to 601.68)	−1.75 (−1.82 to −1.67)	4.87 (4.12 to 5.76)	2622.05 (2124.97 to 3234.01)	−2.65 (−2.75 to −2.54)	1558.16 (1441.99 to 1667.04)	0.46 (0.43 to 0.50)	−8.34 (−8.79 to −7.89)	227,918.67 (158,590.93 to 316,405.98)	116.52 (76.32 to 169.50)	−3.92 (−4.13 to −3.72)
East Asia	4.19 (3.40 to 5.42)	373.08 (291.39 to 504.20)	−1.14 (−1.51 to −0.77)	27.18 (22.84 to 32.83)	2036.50 (1638.37 to 2582.26)	−1.52 (−1.85 to −1.20)	28,333.85 (22,816.64 to 33,772.81)	1.52 (1.23 to 1.82)	−4.70 (−4.93 to −4.48)	1,594,034.94 (1,167,031.93 to 2,112,126.53)	108.13 (75.87 to 150.96)	−2.92 (−3.15 to −2.70)
Central Sub-Saharan Africa	0.81 (0.66 to 1.01)	487.01 (406.36 to 584.51)	−1.08 (−1.18 to −0.99)	3.99 (3.41 to 4.68)	2809.86 (2505.27 to 3185.93)	−1.29 (−1.39 to −1.20)	8075.96 (5009.81 to 16,737.05)	15.79 (8.99 to 37.27)	−1.22 (−1.30 to −1.14)	441,135.83 (317,609.39 to 683,848.39)	491.68 (337.41 to 909.34)	−1.50 (−1.57 to −1.42)
Central Latin America	1.29 (1.02 to 1.63)	567.65 (448.44 to 726.23)	−1.53 (−1.75 to −1.31)	7.43 (6.11 to 9.00)	3077.88 (2518.31 to 3750.27)	−1.95 (−2.15 to −1.75)	2611.24 (2320.02 to 2923.27)	1.08 (0.96 to 1.21)	−6.09 (−6.28 to −5.90)	369,767.35 (255,083.67 to 519,105.71)	152.57 (105.11 to 213.98)	−3.10 (−3.31 to −2.89)
Central Europe	0.75 (0.63 to 0.90)	898.73 (725.29 to 1136.93)	0.02 (−0.18 to 0.22)	6.12 (5.38 to 6.98)	5642.95 (4722.71 to 6691.58)	−0.93 (−1.14 to −0.72)	1823.65 (1658.00 to 1977.25)	0.79 (0.72 to 0.86)	−6.35 (−6.86 to −5.84)	270,349.75 (185,646.45 to 376,319.49)	239.11 (156.47 to 350.46)	−1.64 (−1.92 to −1.37)
Central Asia	0.39 (0.32 to 0.49)	409.26 (338.42 to 509.61)	−0.62 (−0.66 to −0.57)	2.42 (2.09 to 2.80)	2577.21 (2227.15 to 2979.19)	−1.09 (−1.17 to −1.01)	3215.21 (2779.74 to 3765.49)	4.34 (3.78 to 5.09)	−3.90 (−4.43 to −3.37)	176,623.81 (139,781.58 to 221,096.73)	198.84 (158.89 to 245.61)	−2.97 (−3.32 to −2.63)
Caribbean	0.50 (0.42 to 0.60)	1193.84 (1000.88 to 1445.97)	−0.25 (−0.31 to −0.20)	3.36 (2.97 to 3.74)	7638.48 (6722.22 to 8563.44)	−0.67 (−0.72 to −0.62)	2032.19 (1576.84 to 2834.59)	4.02 (3.09 to 5.63)	−1.87 (−2.03 to −1.71)	210,878.66 (159,211.81 to 279,815.95)	468.60 (349.60 to 628.75)	−1.04 (−1.11 to −0.97)
Australasia	0.13 (0.11 to 0.17)	588.51 (457.79 to 769.61)	−1.31 (−1.53 to −1.09)	2.25 (1.93 to 2.58)	7747.21 (6479.30 to 9107.51)	−1.93 (−2.13 to −1.73)	580.40 (505.34 to 638.76)	1.14 (1.02 to 1.24)	−4.23 (−4.93 to −3.52)	101,308.89 (69,965.57 to 145,094.00)	340.71 (227.37 to 493.21)	−2.21 (−2.36 to −2.05)
Andean Latin America	0.49 (0.37 to 0.63)	772.86 (588.02 to 1010.83)	−1.51 (−1.66 to −1.36)	2.61 (2.09 to 3.30)	4048.92 (3233.66 to 5118.23)	−1.91 (−2.11 to −1.70)	456.08 (345.54 to 575.99)	0.78 (0.59 to 0.99)	−5.22 (−5.45 to −4.99)	118,117.37 (75,886.50 to 176,635.71)	184.46 (119.17 to 276.05)	−3.01 (−3.30 to −2.71)

ASR: Age-standardized rate; ASDR: Age-standardized DALY rate; ASIR: Age-standardized incidence rate; ASMR: Age-standardized mortality rate; ASPR: Age-standardized prevalence rate; DALYs: Disability-adjusted life years; EAPC: Estimated annual percentage change.

significantly, showing the highest EAPC value (0.73, 95% UI: 0.40 to 1.06) (Supplementary Table 1).

From 1990 to 2021, asthma ASPR showed a declining trend in most countries/territories. The largest negative EAPC values for ASPR were observed in Japan, Turkmenistan, and the Russian Federation, indicating the most significant declines in ASPR. However, the United States of America, Oman and Barbados showed a positive EAPC, indicating an increasing trend in ASPR over the 32 years (Supplementary Table 2).

Regarding ASMR, from 1990 to 2021, it declined in most countries/territories. The largest negative EAPC values were in Singapore, the Republic of Korea, and Belarus. Only Zimbabwe and Lesotho showed a positive EAPC for ASMR, indicating an increasing trend in these two countries over the period (Supplementary Table 3).

Asthma ASDR also showed a declining trend in most countries/territories from 1990 to 2021. The largest negative EAPC values were in the Republic of Korea, Guatemala, and the Maldives. In contrast, Zimbabwe, Lesotho, and the United States of America were the only three countries with a positive EAPC for ASDR (Supplementary Table 4).

Focusing on China in 2021, the ASIR for asthma was 364.17 (95 % UI: 283.22 to 494.10) per 100,000, the ASPR for asthma was 1956.49 (95 % UI: 1566.68 to 2491.87) per 100,000, the ASDR was 103.76 (95 % UI: 72.50 to 145.46) per 100,000, and the ASMR was 1.47 (95 % UI: 1.15 to 1.79) per 100,000. From 1990 to 2021, all four indicators in China showed a declining trend, with the EAPC for ASIR being −1.17 (95 % CI: −1.56 to −0.78), EAPC for ASPR being −1.57 (95 % CI: −1.92 to −1.22), the EAPC for ASDR −2.98 (95 % CI: −3.21 to −2.74), and the EAPC for ASMR −4.69 (95 % CI: −4.93 to −4.45) (Supplementary Tables 1, 2, 3, 4).

Age and sex pattern

In the analysis by gender and age groups, the age group with the highest global asthma incident cases in 2021 was children aged 5–9 years, with 4,351,871.07 cases among males (95 % UI: 2,094,706.84 to 7,569,067.94) and 3,217,212.26 cases among females (95 % UI: 1,541,011.65 to 5,678,234.79) (Supplementary Fig. 2).

The age group with the highest global asthma prevalent cases in 2021 was children aged 5–9 years, with 21,231,103.57 cases among males (95 % UI: 15,286,393.23 to 30,156,658.36) and 16,056,573.47 cases among females (95 % UI: 11,534,484.15 to 23,010,188.04). Among those under 20 years of age, the prevalent cases of asthma was higher in males than females, whereas in age groups over 20 years, females exhibited higher prevalent cases than males. The global ASPR of asthma in 2021 displayed a distribution pattern characterized by higher rates at the extremes of age, with the highest ASPR per 100,000 population observed in individuals aged 95 years and older—9366.12 (95 % UI: 7663.72 to 11,465.88) per 100,000 for females and 7882.51 (95 % UI: 6512.99 to 9642.39) per 100,000 for males. Males had a higher ASPR than females only in the 2–19 and 80–89 age groups (Supplementary Fig. 3).

Asthma-related deaths in 2021 were predominantly concentrated among those aged 55–89 years. The age group with the highest number of asthma-related deaths among females was 80–84 years (31,884.09, 95 % UI: 24,064.35 to 44,654.87), while among males, it was the 70–74 age group (27,947.31, 95 % UI: 22,114.01 to 46,009.79). The asthma ASMR per 100,000 population in 2021 increased with age, peaking among males aged 90–94 years (98.18, 95 % UI: 82.75 to 142.31) per 100,000 and among females aged 95 years and older (104.62, 95 % UI: 73.18 to 150.85) per 100,000 (Supplementary Fig. 4).

The number of DALYs due to asthma in 2021 was primarily concentrated in the 2–14 and 55–74 age groups, with the highest DALYs among males in the 5–9 age group (924,212.19, 95 % UI: 548,235.91 to 1,549,471.69) and among females in the 55–59 age group (856,216.05, 95 % UI: 665,805.56 to 1,111,149.6). The global ASDR per 100,000 population in 2021 followed a U-shaped distribution, with rates declining initially and then rising sharply in older age groups. The highest ASDR was observed among females aged 95 years and older (1155.87, 95 % UI: 890.65 to 1578.02) per 100,000 and among males aged 90–94 years (1071.92, 95 % UI: 917.09 to 1433.75) per 100,000 (Fig. 1).

Relations to the SDI

On a global scale, from 1990 to 2021, asthma ASDR and ASMR were generally negatively correlated with SDI levels (Fig. 2, Supplementary Fig. 5). At the regional level, only in high-income North America did asthma ASDR levels show a positive correlation with increasing SDI. In all 21 regions, ASMR levels were negatively correlated with SDI. Regions such as Oceania, Southeast Asia, the Caribbean and Australasia, consistently had asthma ASDR levels higher than those predicted by their SDI levels from 1990 to 2021. Similarly, Oceania, Southern Sub-Saharan Africa, and Southeast Asia consistently exhibited asthma ASMR levels above the SDI-predicted levels during the same period.

At the national level, in 2021, asthma ASDR and ASMR generally showed a negative correlation with SDI, particularly when SDI exceeded 0.5, where a rapid decline in ASDR and ASMR levels was observed. Notably, Fiji and Papua New Guinea had significantly higher asthma ASDR and ASMR levels in 2021 than predicted by their SDI levels. Conversely, China's asthma ASDR and ASMR levels in 2021 were notably lower than what would be expected based on its SDI.

Risk factors

This study provides a comprehensive analysis of the proportion of asthma DALYs lost due to four attributable risk factors reported in GBD 2021: nitrogen dioxide pollution, occupational asthmagens, smoking, and high BMI.

In 2021, on a global scale, high BMI accounted for 15.36 % of asthma DALYs loss, ranking first among the four reported risk factors, followed by occupational asthmagens at 8.24 %, smoking at 6.56 %, and nitrogen dioxide pollution at 0.82 % (Fig. 3A).

At the regional level in 2021, High-income North America saw the highest proportion of asthma DALYs attributable to high BMI, reaching 27.56 %. Smoking accounted for the highest proportion of asthma DALYs in Central Europe (9.29 %). Southeast Asia had the highest proportion of asthma DALYs attributable to occupational asthmagens (10.70 %). Nitrogen dioxide pollution, while the least impactful among the four risk factors, still accounted for 4.15 % of asthma DALYs in Andean Latin America (Fig. 3, Supplementary Table 5).

At the national/territorial level, in over 110 countries or territories, high BMI accounted for over 20 % of asthma DALYs in 2021, with the United Arab Emirates (37.83 %), Nauru (36.25 %), and American Samoa (35.90 %) ranking the highest (Supplementary Table 6). Smoking accounted for >10 % of asthma DALYs in over 25 countries or territories, with Kiribati (14.65 %), Micronesia (Federated States of) (13.63 %), and Greenland (13.41 %) at the top (Supplementary Table 7). Occupational asthmagens accounted for >10 % of asthma DALYs in over 40 countries or territories, with Zimbabwe (16.54 %), Cameroon (15.76 %), and the United Arab Emirates (15.74 %) leading (Supplementary Table 8). In 2021, nitrogen dioxide pollution caused 7.55 % of asthma DALYs in Lebanon (Supplementary Table 9).

In China in 2021, nitrogen dioxide pollution, occupational asthmagens, smoking, and high BMI respectively accounted for 1.42 %, 8.82 %, 9.12 %, and 14.95 % of asthma DALYs loss (Supplementary Tables 6, 7, 8, 9).

Gender analysis of the four risk factors for asthma DALYs loss in 2021 revealed that high BMI was the leading risk factor for both males and females globally, accounting for 13.59 % and 17.01 % respectively. In China, however, smoking was the leading risk factor for asthma DALYs loss in males in 2021, accounting for 14.66 % (Supplementary Tables 6, 7, 8, 9).

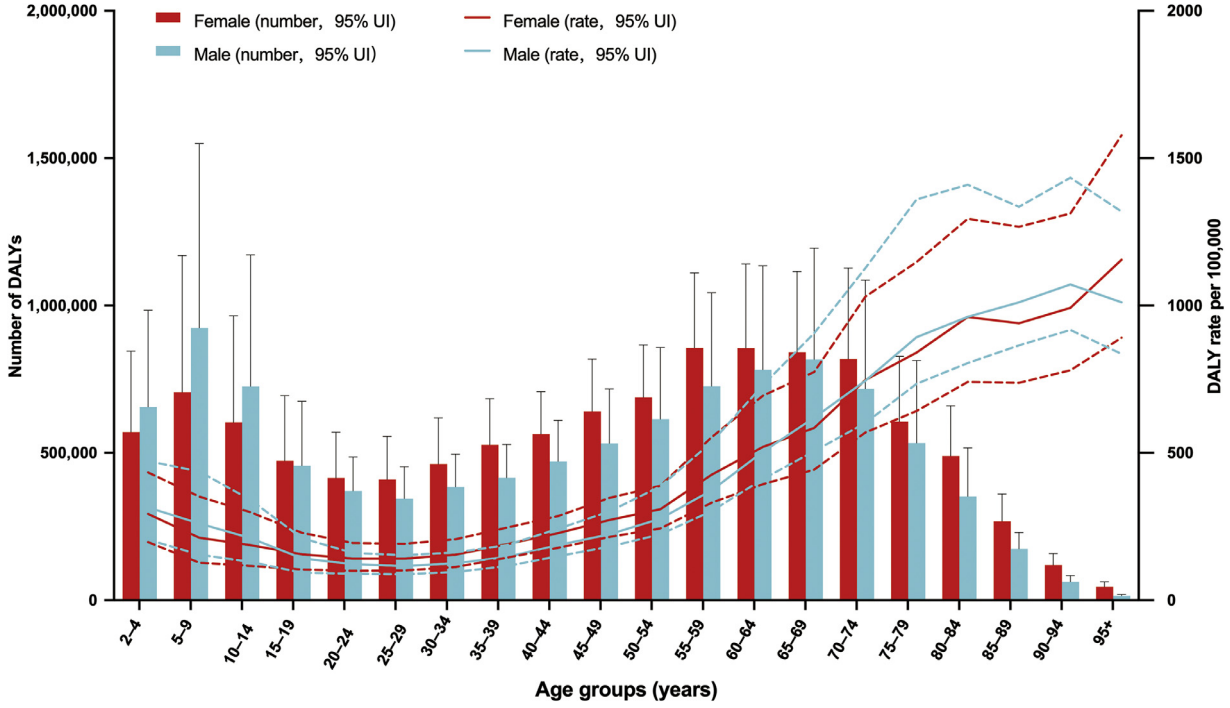

Fig. 1. The number of DALYs and DALY rate of asthma per 100,000 population, by age and sex in 2021 globally. Bar chart represents the number of DALY with 95 % uncertainty intervals (UIs) (error bars) for men and women. Line chart represents DALY rates with 95 % UIs (dashed line) for men and women. DALY: Disability adjusted life year.

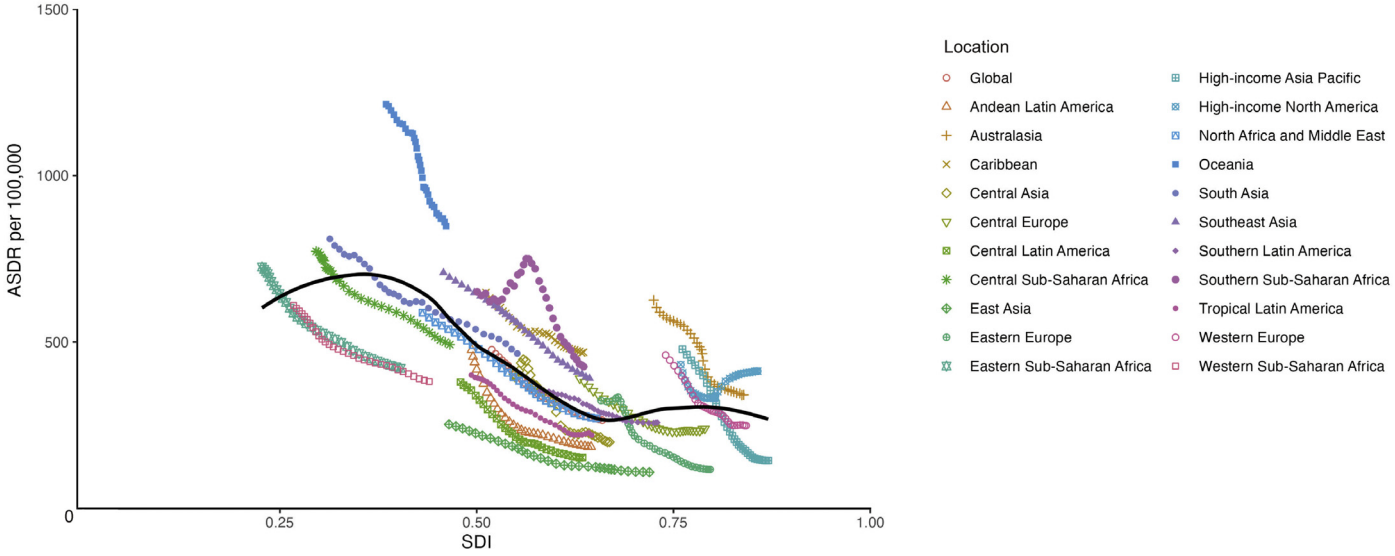

Fig. 2. The association between ASDRs of asthma and the SDI levels in different regions from 1990 to 2021. ASDR: Age-standardized disability-adjusted life years rate; SDI: Sociodemographic index.

Age subgroup analysis of the four risk factors for asthma DALYs loss in 2021 showed that the proportion attributable to high BMI increased and then decreased with age, particularly rising rapidly after age 20 years, peaking in the 40–44 age group, and then gradually declining. The proportion of asthma DALYs attributable to smoking was reported only for those aged 30 years and above, with the proportion exceeding 10 % in the 30–64 age group. The proportion of asthma DALYs attributable to occupational asthmagens was reported only for those aged 15–84, with the 20–64 age group having the highest proportion (11.47–16.00 %). The proportion of asthma DALYs attributable to nitrogen dioxide pollution was reported only for those aged 2–19 years (2.81–3.57 %). In China, the distribution trend of DALYs loss attributable to four risk factors for asthma was similar to that globally (Fig. 3B, Supplementary Tables 10, 11).

Decomposition analysis

This study conducted a decomposition analysis to assess the contributions of three population-related factors to the changes in asthma DALYs and mortality burden from 1990 to 2021 (Supplementary Fig. 6, Supplementary Table 12). At both the global level and across the 21 regions, epidemiological changes played a role in reducing the burden of

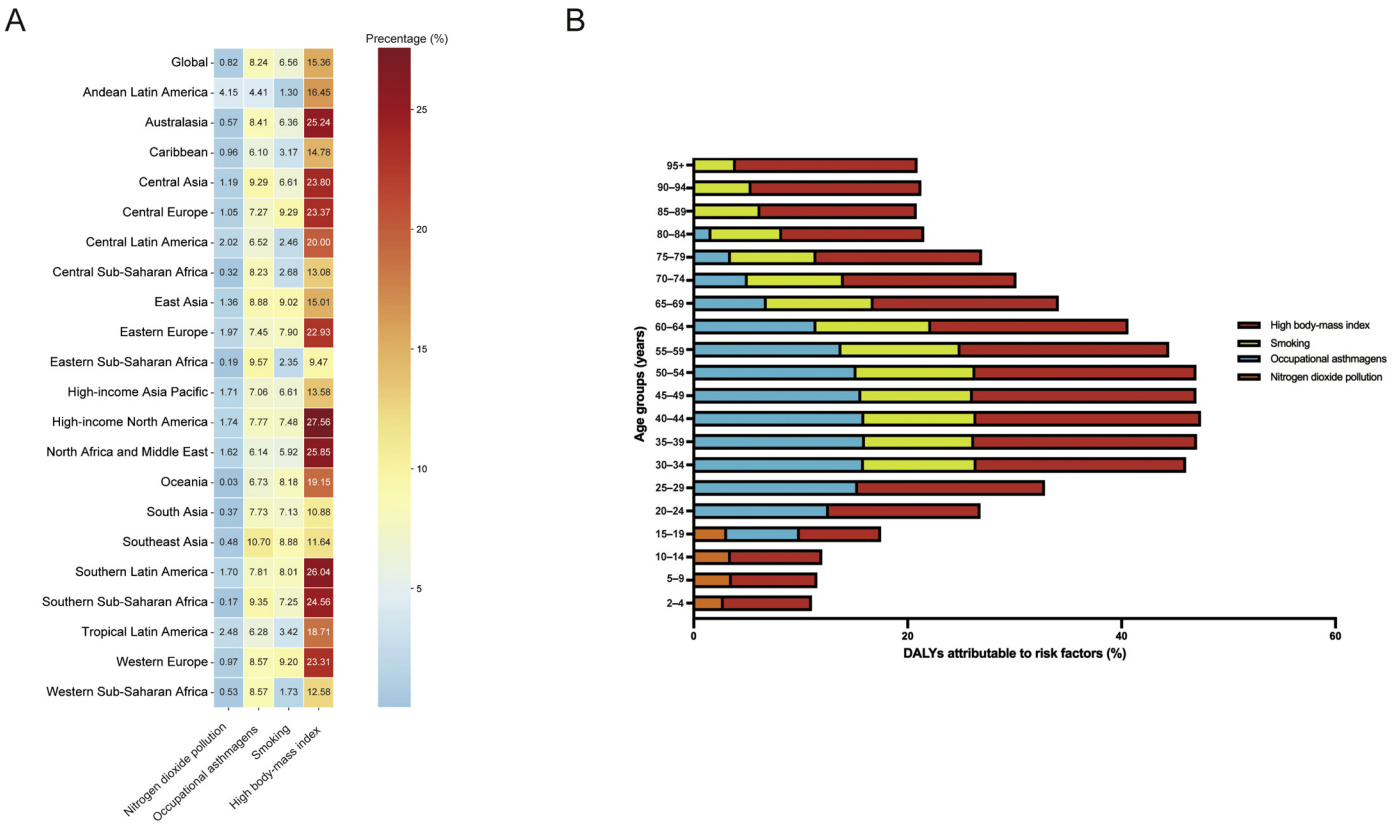

Fig. 3. Percentage of risk factors causing DALYs burden of asthma in 2021. (A) Percentage of asthma DALYs attributable to four risk factors for the 21 Global Burden of Disease regions in 2021. (B) Percentage of asthma DALYs attributable to four risk factors in different age subgroups at the global level. DALY: Disability-adjusted life year.

asthma mortality and DALYs. Conversely, population aging contributed to an increased burden of asthma DALYs and mortality globally and in most regions. Population growth, however, was a consistent factor across most regions except East Europe, leading to an increase in the asthma DALYs and mortality burden. In low- and middle-income areas, such as Sub-Saharan Africa and Oceania, the impact of population growth on increasing asthma DALYs and mortality burden offset the reducing effect of epidemiological changes.

Notably, in China, the influence of epidemiological changes outweighed the effects of population growth and aging, ultimately reducing the burden of asthma mortality and DALYs.

Discussion

This study utilizes the latest GBD 2021 data to update the global burden of asthma. From 1990 to 2021, the global burden of asthma has markedly declined, as evidenced by significant decreases in ASIR, ASPR, ASDR, and ASMR. This trend is consistent with the results of the GBD 2019 study.[3,5] However, due to the large population affected, the incident cases, prevalent cases, mortality, and DALYs associated with asthma remain at substantial levels. In developed regions, such as High-income North America, asthma prevalence is notably high, while the burden of DALYs and mortality is predominantly concentrated in low- and middle-income nations. As a chronic airway disease, asthma mortality rates have been maintained at relatively low levels, partly due to advancements in healthcare. Among different age groups, the disease burden of asthma is heavier in population aged 2–14 and in adults over 55 years. In terms of gender, the prevalent cases of asthma in females surpasses those in males over the age of 20. In terms of risk factors, a high BMI remains the leading reported attributable risk factor for asthma. Occupational asthmagens and smoking also contribute significantly to asthma-related DALYs, with smoking causing considerable DALYs loss in certain countries like China. Additionally, nitrogen dioxide pollution is another risk factor that should not be overlooked.

This study, compared to previous assessments based on the GBD 2019 database, introduces the EAPC to evaluate the changes in asthma burden between 1990 and 2021. This approach allows for a more comprehensive utilization of data from the intervening years.[16] This study reveals that while the overall trends for asthma ASIR, ASPR, ASDR, and ASMR show a significant decline, some countries exhibit contrary trends. For instance, the United States of America, Oman, and Barbados have shown an upward trend in ASPR, with the United States also experiencing an increase in ASDR between 1990 and 2021. The high prevalence of asthma in developed nations is now a widely acknowledged concern.[7] This may be attributed to the fact that developed regions often have better medical facilities, which enhance the diagnosis rate of the disease.[19] Additionally, the dietary habits in Western developed countries are often associated with higher obesity rates, and obesity is a significant risk factor for asthma.[20] In lower-middle-income countries such as Papua New Guinea, Fiji, Haiti, and Kiribati, there is a higher burden of asthma mortality and DALYs. The lower economic development levels significantly impede disease diagnosis and treatment, particularly as essential inhaled medications for asthma are often unavailable in these regions.[21] Thus, low-income countries experience a high burden of asthma deaths and DALYs, which also suggests that the true prevalence of asthma in these countries is severely underestimated.[22]

This study, by calculating the EAPC of asthma ASR from 1990 to 2021 and utilizing data from intermediate years, more comprehensively illustrates the overall trend in asthma burden over the past 32 years, offering more convincing insights compared to merely calculating percentage changes in ASR. In terms of asthma prevalence and DALYs, the bur-

den is significantly higher in females than in males. In individuals over 20 years of age, female asthma prevalent cases consistently exceed those of males, and male asthma prevalence rates are lower in most age groups compared to females. While genetic differences, airway anatomical variations, hormonal differences, and lifestyle factors such as smoking have been proposed to explain the disparity in asthma burden between genders,[23,24] reliable evidence supporting these theories remains lacking. This study also found that among individuals aged 15 and older, the number of DALYs for asthma in females surpasses that in males. Compared with the GBD 2019 study, the age at which female asthma DALYs exceed those of males has advanced even further.[5] In the age subgroup analysis, we observed that the prevalent cases of asthma was the highest among children aged 5–9 years, while the burden of asthma DALYs exhibited a bimodal distribution, with peaks among young children and the elderly. This indicates a need to focus on the asthma burden within the pediatric population. The heterogeneity of asthma and the unique characteristics of children present ongoing challenges in both the treatment and diagnosis of pediatric asthma.[25,26] As with many diseases, the burden of asthma mortality is predominantly concentrated among the elderly, particularly those over the age of 70. Age-related changes in pulmonary structure and the immune system, as well as the frequent presence of comorbid conditions in older adults, may contribute to the increased burden of asthma DALYs and mortality.[27]

In the analysis of asthma risk factors reported by GBD 2021, a high BMI emerges as the most significant risk factor globally. From 1990 to 2021, the proportion of asthma DALYs attributed to high BMI has been increasing. In over half of the countries and territories, a high BMI accounts for >20 % of asthma-related DALYs. Extensive research has confirmed that obesity is a major risk factor for asthma.[28–30] Although further research is needed to elucidate the mechanisms between them, weight loss undoubtedly holds significant importance for asthma management. Occupational asthmagens and smoking are also notable risk factors for asthma, each contributing significantly to asthma-related DALYs in 2021. Occupational asthmagens often have clear triggers, yet some studies report that a considerable proportion of diagnosed occupational asthma patients, fearing job loss, continue to be exposed to allergens, thereby exacerbating the burden of asthma caused by occupational asthmagens.[31] Therefore, governments need to implement appropriate welfare policies to protect such patients. Smoking remains a significant risk factor for asthma, and its reduction has benefited from the support of the World Health Organization and numerous government initiatives.[32] The implementation of smoking cessation policies has yielded significant results, leading to a decline in the asthma DALYs burden attributable to smoking. However, it is noteworthy that the proportion of asthma DALYs loss due to smoking varies significantly across different countries. For example, in China, smoking accounts for a higher proportion of asthma DALYs loss compared to the global average. In particular, among Chinese men, smoking remains the leading factor for asthma DALYs loss in 2021. Despite the clear goals set by China's Healthy China 2030 initiative to control smoking,[33] stricter tobacco control measures are still needed to further reduce the disease burden associated with smoking. This study also highlights the impact of nitrogen dioxide pollution on asthma DALYs loss, which is a risk factor that has not been reported in the GBD 2019 study. Although its proportion is lower compared with other risk factors, it should not be overlooked due to the large number of asthma patients. Notably, among the 2–19 age group, the proportion of asthma DALYs loss attributable to nitrogen dioxide pollution is high, indicating a substantial impact of this risk factor on asthma in children and adolescents.[34] Additionally, this study utilizes decomposition analysis to examine the impact of three demographic factors (aging, population growth, and epidemiological changes) on asthma DALYs and mortality burden from 1990 to 2021. We found that epidemiological changes have generally reduced the asthma burden globally and across all regions, while population growth has been a major driver of increased asthma mortality and DALYs, particularly in low- and middle-income regions such as Sub-Saharan Africa and Oceania, where population growth has counteracted the reductions due to epidemiological changes. Research suggests that future population growth will be concentrated in low- and middle-income countries over the next 30 years,[35] exacerbating local health inequities. Therefore, implementing measures to control population growth is also crucial for reducing the asthma burden.

This study updates the asthma burden levels from 1990 to 2021 using the latest GBD 2021 data. However, due to inherent limitations in the GBD database, several constraints must be acknowledged. Primarily, due to data limitations, asthma data are largely estimated through standardized Bayesian regression tools,[8] particularly in some underdeveloped countries, where original data are inaccessible. Moreover, although the GBD team has employed mathematical modeling to enhance accuracy, there remains a lack of a universal gold standard for asthma diagnosis worldwide. Currently, the use of spirometry, the primary diagnostic tool, varies significantly across regions, which affects the true diagnostic rates of asthma.[36] Therefore, implementing standardized training and uniform diagnostic criteria for asthma is of paramount importance. Furthermore, although this study has incorporated the impact of nitrogen dioxide pollution, the effects of this factor on asthma burden are only reported for certain age ranges. Similarly, smoking, which can be subdivided into active and passive smoking, lacks detailed data on its specific effects.

In conclusion, from 1990 to 2021, the burden of asthma as measured by ASR has shown a declining trend. However, the overall burden of asthma remains significantly high. The mortality and DALYs burden of asthma are mainly concentrated in low-income countries. Analysis at the age level shows that the burden of asthma is mainly concentrated in children and the elderly. Women have a heavier burden of asthma. In addition to the high BMI, nitrogen dioxide pollution, occupational asthmagens, and smoking, as risk factors for asthma, also contribute to a significant disease burden. Decomposition analysis of asthma ASRs suggests that population growth is a key factor contributing to the burden of asthma.

CRediT authorship contribution statement

Zhenyu Mao: Writing – original draft, Writing – review & editing, Conceptualization. **Xiaoyan Zhu:** Writing – original draft. **Pengdou Zheng:** Writing – review & editing. **Lingling Wang:** Writing – review & editing, Methodology. **Fengqin Zhang:** Writing – review & editing, Visualization. **Lixiang Chen:** Writing – review & editing, Visualization. **Ling Zhou:** Writing – review & editing, Visualization. **Wei Liu:** Writing – review & editing, Conceptualization. **Huiguo Liu:** Writing – review & editing, Project administration, Conceptualization.

Data availability

Data used in the analyses of this manuscript are available publicly to download. Please visit the Global Health Data Exchange GBD 2021 website: https://www.healthdata.org/research-analysis/gbd.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.pccm.2025.02.005.

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