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The Evolution Characteristics and Trend Prediction of the Disease Burden of Asthma in China and Globally

Yuting Yang[1#], Xiaofei Yin[2#], Fuming He[1*] and Jing Yang[2*]
1 Thoracic Surgery, Nanbu County People's Hospital, Nanchong, Sichuan, 637300, China.
2 Demonstration Center for Experimental Teaching in Biomedicine, Chengdu Medical College, Chengdu, 610500, China.
# These authors contributed equally to this work.
* Authors to whom correspondence should be addressed.
Email addresses: 15281703505@139.com (Yuting Yang), 18190871235@163.com (Xiaofei Yin), 13699681739@163.com (Fuming He), jingyang@cmc.edu.cn (Jing Yang).

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Abstract

Background: Asthma is a common chronic inflammatory airway disease. This study assessed the disease burden of asthma in China and globally from 1990 to 2021 and predicted future trends, aiming to provide a evidence for prevention and control strategies.

Methods: Using the GBD database, a descriptive analysis of asthma burden data was conducted in China and globally, covering the changing trends of incidence, prevalence, mortality and disability-adjusted life years (DALYs), as well as the distribution characteristics in terms of age and gender. Joinpoint regression analysis was employed to further explore the epidemiological characteristics, and eight machine learning algorithms were fitted to predict the future trends.

Results: From 1990 to 2021, the overall burden in both China and globally decreased. However, the global number of deaths increased by 16.51%. In terms of age, children, adolescents, and the elderly (≥60 years) all faced an extremely high burden. Regarding gender, the burden on males in most age groups in China was higher than that on females, while the pattern was reversed globally. Among the eight algorithms, the Autoregressive Integrated Moving Average algorithm performed the best. Predictions show that by 2050, the age-standardized rate of incidence, prevalence, and DALYs of asthma globally will show an upward trend, while the age-standardized mortality rate will decline. In China, the situation is contrary to that of the global trend.

Conclusion: Over the past 32 years, although the asthma burden in China and globally has declined, the burden remains substantial. This study recommends strengthening attention to asthma management in children, adolescents, the elderly, and women during critical life stages, optimizing healthcare resources, enhancing international cooperation, and increasing investment in increasing investment in resource-limited regions to alleviate the asthma burden.

Keywords: asthma, disease burden, China, global, machine learning, GBD2021

1 Introduction

Asthma is a heterogeneous disease characterized by chronic airway inflammation. It is usually accompanied by symptoms such as wheezing, dyspnea, chest tightness, and cough [1]. Its pathogenesis is complex, and different phenotypes are shaped by various factors such as different environmental triggers, age, obesity, and genetic factors [2]. As a prevalent chronic inflammatory airway disease, asthma imposes a substantial burden on global health. According to the Global Burden of Disease 2021 (GBD2021) data, it is estimated that approximately 260 million people globally suffer from asthma, and the number of deaths due to asthma reaches 430,000 [3]. Many asthma patients also have multiple comorbidities, including rhinitis and sinusitis, chronic obstructive pulmonary disease, sleep disorders, and mood disorder [4],[5]. These comorbidities not only further increase the burden of asthma but also lead to a significant decline in the quality of life of patients. In the United States, the direct or indirect personal costs incurred by patients with asthma exceed $3,000 per year, and the total annual medical expenditure on asthma exceeds $50 billion [6]. In China, 15.5% of asthma patients have had at least one emergency room visit in the past year, and 7.2% of patients have been hospitalized at least once due to the deterioration of respiratory symptoms [7]. However, these data may be underestimated, and the levels of diagnosis and treatment of asthma are relatively low globally [7],[8]. In addition, with the acceleration of the urbanization process and the intensification of climate change and environmental pollution, the risks of new-onset asthma, asthma exacerbation, or other adverse asthma-related outcomes have been significantly increased [9],[10]. Therefore, enhancing the awareness of asthma and understanding its epidemiological characteristics are necessary steps to reduce the burden of asthma.

In recent years, the burden of asthma has received widespread attention. Yuan et al. systematically analyzed the global trends in asthma burden from 1990 to 2021 and assessed the associated risk factors [11]. Another study explored the epidemiological characteristics of asthma in China and its attributable burden [12]. While these studies have offered valuable insights into the global and regional trends of asthma burden, their scope remains somewhat limited. Based on data from the GBD 2021 study, this research systematically analyzes the evolving characteristics of asthma burden in China and worldwide from the perspectives of age, sex, and time, offering a comparative analysis. Additionally, it employs multiple machine learning algorithms to predict trends in asthma burden by 2050. The purpose of this study is to elaborate on the epidemiological characteristics of asthma in greater depth and raise public awareness of asthma. It intends to help the government optimize the allocation of medical resources through age - gender stratification, and directly compare the trends in China with those globally to reveal regional specificities, thereby providing a scientific basis for formulating targeted asthma prevention and control strategies and the rational allocation of health resources.

2 Methods

2.1 Data Source

This study utilizes the GBD 2021 database (https://ghdx.healthdata.org/gbd-2021) as the primary data source. The GBD 2021 database provides comprehensive estimates for 204 countries and regions, covering 371 diseases and injuries, as well as 88 risk factors. Asthma was selected as the focus of this study, and data on incidence, prevalence, deaths, and disability-adjusted life years (DALYs) were extracted for the period from 1990 to 2021. The data include both absolute numbers and age-standardized rates (ASR, per 100,000 population). Population classifications include the total population across all age groups (both sexes), as well as stratifications by sex (male and female) [][][][15].

2.2 Disease Definition

According to the disease classification system of the GBD 2021 study, asthma is classified as a third-level disease under chronic respiratory diseases, which fall within the first-level category of non-communicable diseases. In accordance with the International Classification of Diseases, 10th Revision (ICD-10), asthma is coded as J45, while under the 11th Revision (ICD-11), it is coded as CA23 [14],[15].

2.3 Descriptive Analysis

We conducted a descriptive analysis of the data on the disease burden of asthma in China and globally during the period from 1990 to 2021, including the annual changing trends of incidence, prevalence, death, and DALYs, as well as the distribution characteristics across different age groups and genders.

2.4 Joinpoint Regression Analysis

In order to identify the significant turning points in the changing trends of the disease burden indicators of asthma, we adopted the Joinpoint regression model for analysis. The Bayesian Information Criterion is adopted for model selection, and the model parameters are set as follows: a minimum time interval of 2 years, a maximum number of joinpoints of 6, and a significance level of $\alpha = 0.05$. This model can explore the turning points (joinpoints) in the epidemic trends of the disease, and calculate the Annual Percent Change (APC) between the turning points as well as the Average Annual Percent Change (AAPC) throughout the study period.

2.5 Prediction of the Disease Burden of Asthma from 2022 to 2050 Using Eight Machine Learning Algorithms

Our study adopted a structured three-stage approach to predict the disease burden of asthma from 2022 to 2050. In the data preparation stage, we integrated the global age-standardized rate data from 1990 to 2021 provided by the GBD database and the population data from 1990 to 2050 from the literature. To enhance the predictive ability of the model, we carried out comprehensive feature engineering, including the standardization of time and population data, the construction of lag features of the disease rates for the previous year and the previous two years, the calculation of the 3-year moving average to smooth out short-term fluctuations, and the creation of interaction terms between the population and the year to explore the combined effect of these two factors.

In the model construction stage, we employed eight advanced time series prediction methods and machine learning algorithms. The Prophet model optimized parameters through grid search and applied data scaling techniques; the ARIMA model introduced nonlinear external regression variables and used the Box-Cox transformation to increase its nonlinear capability; the TBATS model used a simplified ETS model as the basis and adopted a damped trend to prevent divergence in long-term predictions; the Elastic Net model integrated Ridge and Lasso regression and used nonlinear features to enhance its expressive ability; the ETS model added nonlinear adjustments to the basic predictions and applied smoothing constraints; the VAR model introduced logarithmic transformations, squared terms, and interaction terms to enhance its nonlinear expression; the Holt-Winters model combined quadratic curve fitting and exponential smoothing to achieve nonlinear predictions; the improved Theta model added periodic fluctuations and random growth trends on the basis of the standard model. All models used the cross-validation method to evaluate their predictive performance.

In the model evaluation stage, we adopted a rigorous cross-validation method and a comprehensive evaluation index system. We used the data from 1990 to 2010 as the training set, the data from 2011 to 2021 as the validation set, and the data from 2022 to 2050 as the final prediction set, ensuring that historical data are fully utilized for model training, the short-term prediction ability is verified through recent data, and the long-term prediction performance is ultimately evaluated. To comprehensively evaluate the model performance, we employed six evaluation indicators: the Mean Squared Error (MSE) is used to measure the squared difference between the predicted values and the actual values; the Mean Absolute Percentage Error (MAPE) provides a measure of the relative prediction error; the Root Mean Squared Error (RMSE) provides an error measure in the same unit as the original data; the Coefficient of Determination (R^2) measures the degree to which the predicted values explain the variation of the observed values; the Cross-Validation Mean Absolute Percentage Error (CV_MAPE) evaluates the generalization ability of the model's predictions through cross-validation. This evaluation system examines the prediction performance of each model from multiple perspectives.

2.6 Data Visualization

All data processing, statistical analysis, and visualization were completed using the R programming language (Version 4.4.1). The main R packages used included: dplyr, tidyr, stringr, and arrow for data manipulation and analysis.

3 Results

3.1 Overall Trends of the Disease Burden of Asthma Globally and in China from 1990 to 2021

As shown in Figure 1A and Table 1, compared with 1990, the age-standardized mortality rate (ASMR), age-standardized incidence rate (ASIR), age-standardized DALYs rate (ASDR), and age-standardized prevalence rate (ASPR) of asthma in both China and globally significantly decreased in 2021. As shown in Figure 1B and Table 1, compared with 1990, the numbers of deaths, incidence cases, DALYs, and prevalence cases in China all decreased in 2021. According to the global data, the number of deaths increased by 16.51%, while other indicators decreased.

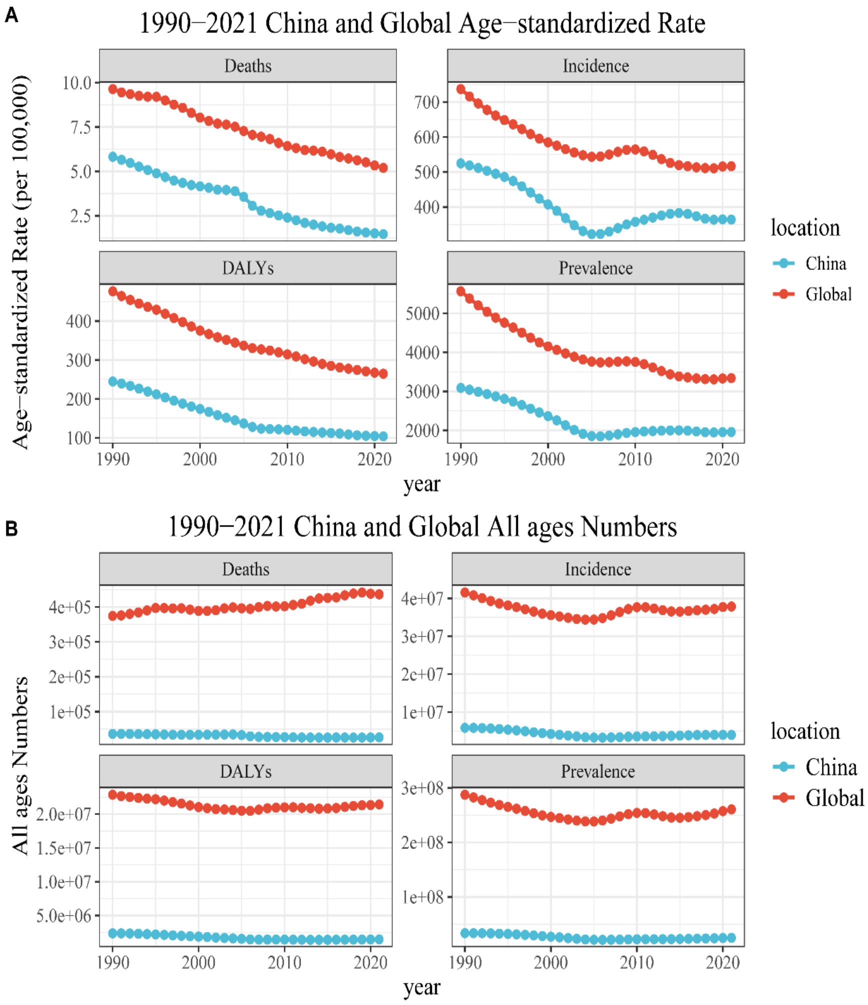

Figure 1 Long-term Trends of the Disease Burden Indicators of Asthma in China and Globally (from 1990 to 2021)

A: The changing trends of the age-standardized rates of the incidence, prevalence, deaths, and DALYs of asthma in China and globally from 1990 to 2021.

B: The changing trends of the absolute numbers of the incidenc, prevalence, deaths, and DALYs of asthma in China and globally from 1990 to 2021.

Table 1 The Disease Burden of Asthma in China and Globally in 1990 and 2021

measure	location	ASRs 1990_per 100 000 (95% UI)	ASRs 2021_per 100 000(95% UI)	ASRs Percentage change in ASRs (100%)	Number 1990_numbers (95% UI)	Number 2021_numbers (95% UI)	Number Percentage change in case (100%)
Deaths	Global	9.64 (7.76, 12.80)	5.20 (4.27, 6.59)	-46.08	374,377 (304,600, 492,653)	436,193 (357,795, 555,604)	16.51
Deaths	China	5.82 (4.46, 8.50)	1.47 (1.15, 1.79)	-74.81	36,252 (28,567, 51,942)	26,233 (20,582, 31,840)	-27.64
DALYs	Global	476.48 (386.56, 587.84)	264.62 (208.32, 333.43)	-44.46	22,862,050 (18,306,873, 28,768,792)	21,422,860 (16,956,878, 26,887,092)	-6.3
DALYs	China	244.58 (191.12, 316.63)	103.76 (72.50, 145.46)	-57.58	2,359,935 (1,825,916, 3,115,161)	1,467,418 (1,072,756, 1,947,203)	-37.82
Incidence	Global	736.99 (615.03, 905.18)	516.70 (425.36, 646.13)	-29.89	41,555,628 (34,158,823, 51,705,168)	37,864,175 (31,381,241, 46,919,994)	-8.88
Incidence	China	524.81 (421.31, 672.76)	364.17 (283.22, 494.10)	-30.61	5,826,101 (4,640,624, 7,504,883)	3,934,875 (3,183,311, 5,136,133)	-32.46
Prevalence	Global	5,568.25 (4,899.64, 6,349.80)	3,340.12 (2,905.24, 3,832.24)	-40.01	287,300,888 (250,369,955, 331,080,711)	260,479,187 (227,209,547, 297,967,237)	-9.34
Prevalence	China	3,087.89 (2,583.55, 3,782.05)	1,956.49 (1,566.68, 2,491.87)	-36.64	33,522,406 (27,438,105, 41,409,093)	25,015,668 (20,898,414, 30,448,108)	-25.38

3.2 Age and Sex Distribution of Asthma Burden in China and Globally in 1990 and 2021

As shown in Figure 2A, the overall trend of asthma ASMR in both China and globally increases with age, with the lowest ASMR observed in the 5–9 age group in 2021. The number of deaths was primarily concentrated among middle-aged and elderly populations, with the highest death numbers recorded in the 80–84 age group in China and the 70–74 age group globally in 2021.

As illustrated in Figures 2B and 2C, the ASIR and ASDR of asthma in China and globally both exhibit a declining-then-rising trend. However, notable differences exist: the ASIR was highest in the <5 age group, while the ASDR was more prominent among the elderly. In terms of incidence numbers, the highest count was observed in the <5 age group, followed by a decline and subsequent increase, though numbers slightly decreased in later life stages. The trend in DALYs numbers was similar to that of incidence numbers, but in 2021, the DALYs numbers in the 5–9 age group exceeded those in the <5 age group. Specifically, the highest DALYs count was recorded in the 5–9 age group in China, whereas globally, it peaked in the 65–69 age group.

As shown in Figure 2D, asthma in both China and globally exhibits a high ASPR at younger ages, with a peak observed in the 5–9 age group, followed by a declining-then-rising trend with increasing age. In 2021, the highest ASPR in China was recorded in the 5–9 age group, whereas globally, it peaked in the 95+ age group. In terms of prevalence numbers, the peak was consistently observed in the 5–9 age group.

As illustrated in Figure 3, the sex distribution of asthma burden differs between China and the global population. In China, the disease burden was generally higher in males across most age groups, whereas globally, females experienced a higher burden in most age groups. Notably, among the extremely elderly population in China, females tended to bear a greater burden. As shown in Figure 3A, the number of deaths among females exceeded that of males in the 90+ age group. Conversely, at the global level, young males had a higher burden. As depicted in Figure 3E, the number of deaths among males was greater than that of females in the 0–9 age group.

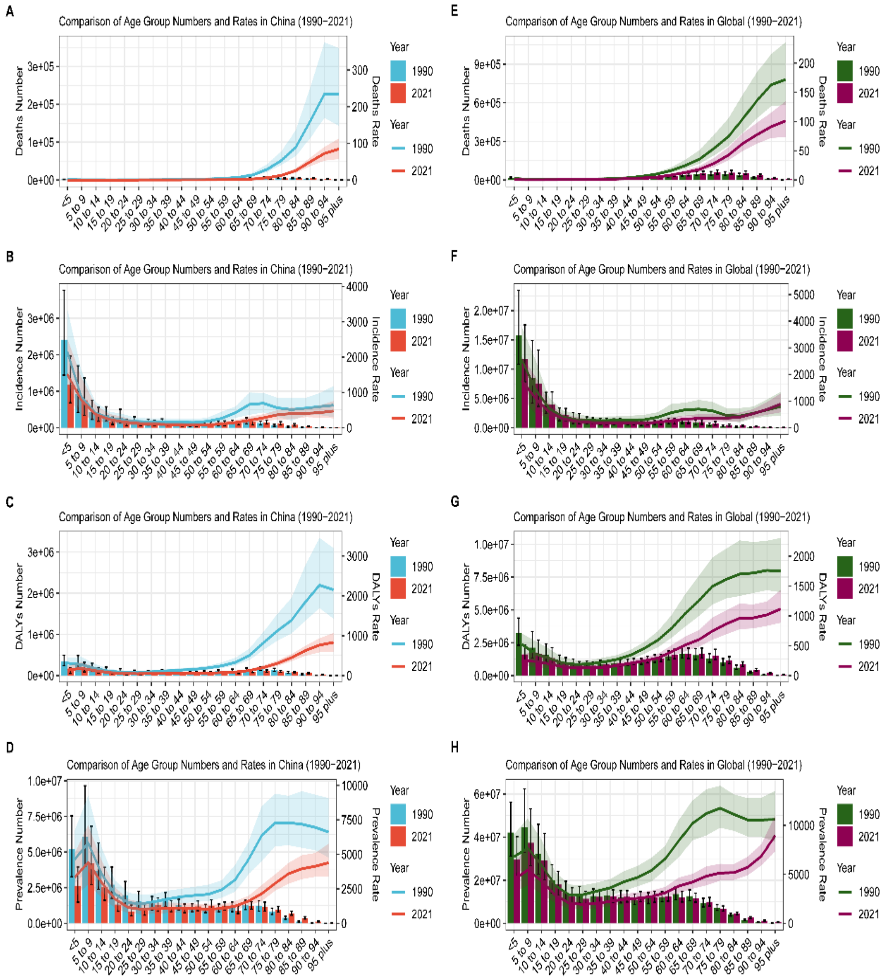

Figure 2. Age Distribution Characteristics of Asthma Burden in China and Globally (1990 vs. 2021)

A–D: The number and age-standardized rates of asthma deaths (A), incidence (B), DALYs (C), and prevalence (D) across different age groups in China for the years 1990 and 2021. Bar charts represent absolute numbers, while line graphs indicate age-standardized rates.

E–H: The number and age-standardized rates of asthma deaths (E), incidence (F), DALYs (G), and prevalence (H) across different age groups globally for the years 1990 and 2021. Bar charts represent absolute numbers, while line graphs indicate age-standardized rates.

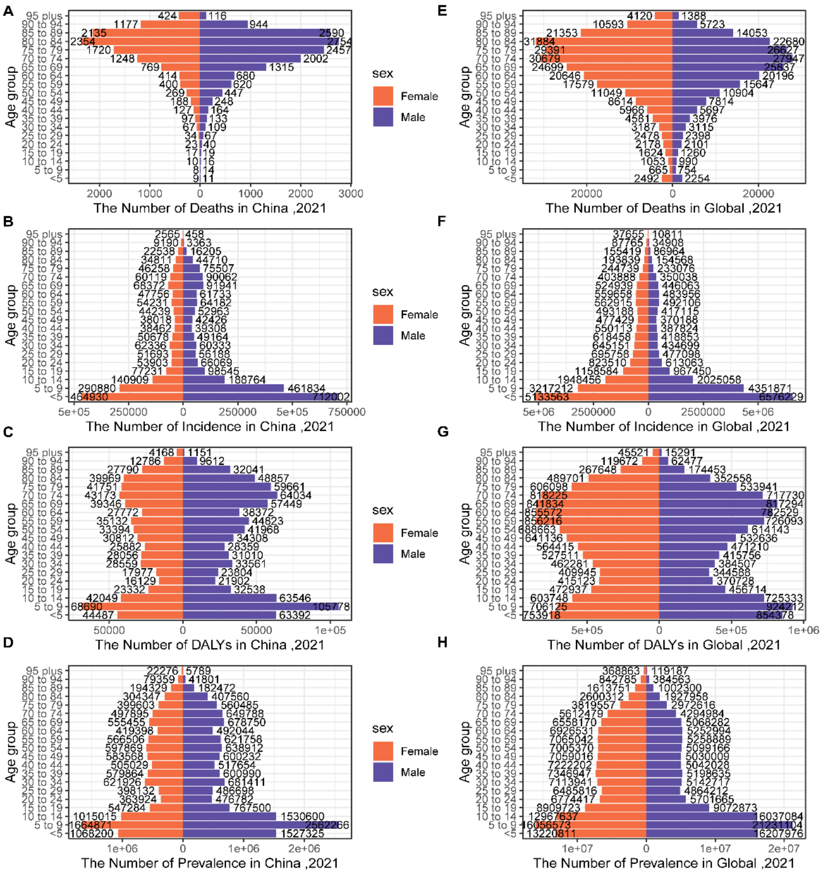

Figure 3. Sex and Age Distribution Characteristics of Asthma Burden in China and Globally in 2021

A–D: Population pyramid charts illustrating the distribution of asthma deaths (A), incidence (B), DALYs (C), and prevalence (D) across different age groups and sexes in China in 2021.

3.3 Temporal Trends of Asthma Burden in China and Globally from 1990 to 2021

As shown in Figure 4, from 1990 to 2021, the deaths, incidence, DALYs, and prevalence of asthma exhibited a declining trend in both China and globally. However, the global decline was relatively smaller, and the rates of change varied across different periods. Notably, there were phase-specific increases in incidence and prevalence after 2005. For instance, the incidence increased significantly in China from 2005 to 2014 and globally from 2005 to 2010. Similarly, the prevalence in China showed a marked increase from 2005 to 2012.

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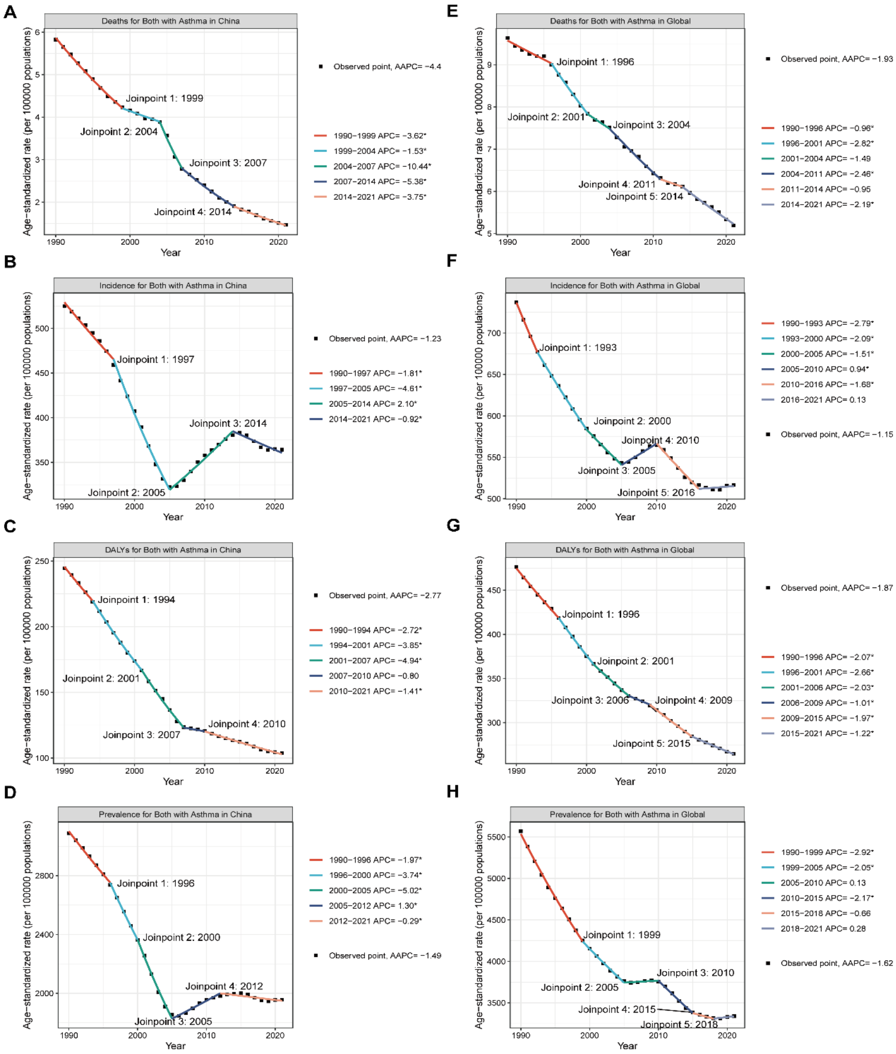

Figure 4. Joinpoint Regression Analysis of Asthma Burden Indicators in China and Globally (1990–2021)
A–D: Joinpoint regression analysis results for asthma deaths (A), incidence (B), DALYs (C), and prevalence (D) in China from 1990 to 2021.
E–H: Joinpoint regression analysis results for asthma deaths (E), incidence (F), DALYs (G), and prevalence (H) globally from 1990 to 2021.

3.4 Future Trend Prediction of Asthma Burden in China and Globally

As shown in Figure 5A and Figure 6A, we evaluated the predictive performance of each model using five metrics: MSE, MAPE, RMSE, R^2, and CV_MAPE, with ARIMA demonstrating the best overall performance. According to ARIMA's prediction results, the future trends of asthma burden in China and globally show opposite patterns. As illustrated in Figure 5B, from 2022 to 2050, the global ASIR, ASPR, and ASDR are projected to gradually increase, whereas ASMR is expected to decline. In contrast, as shown in Figure 6B, China's ASIR, ASPR, and ASDR are predicted to decrease by 2050 compared to 2021, while ASMR is projected to increase.

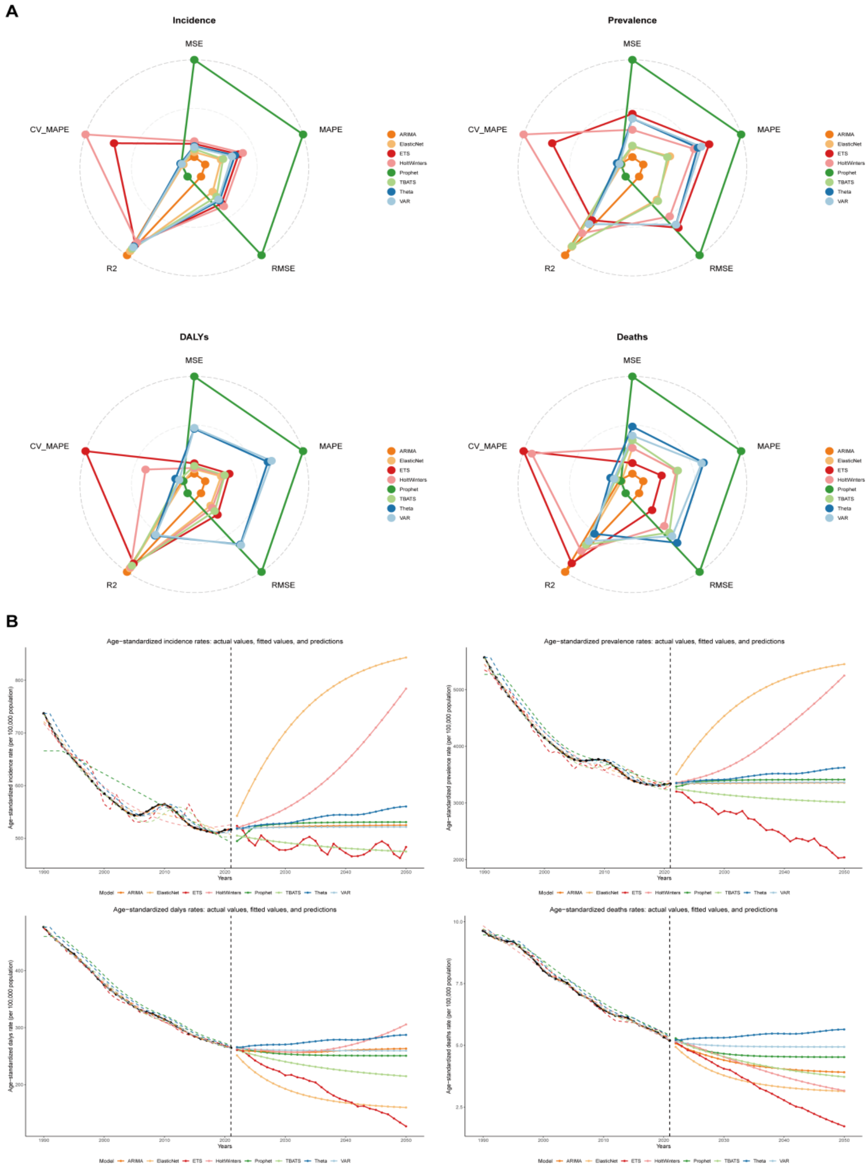

Figure 5. Prediction of Global Asthma Burden Using Eight Machine Learning Algorithms

A: Comparison of evaluation metrics for different prediction models of global asthma age-standardized rates.

B: Predicted values of global asthma age-standardized rates from 2022 to 2050 using different models.

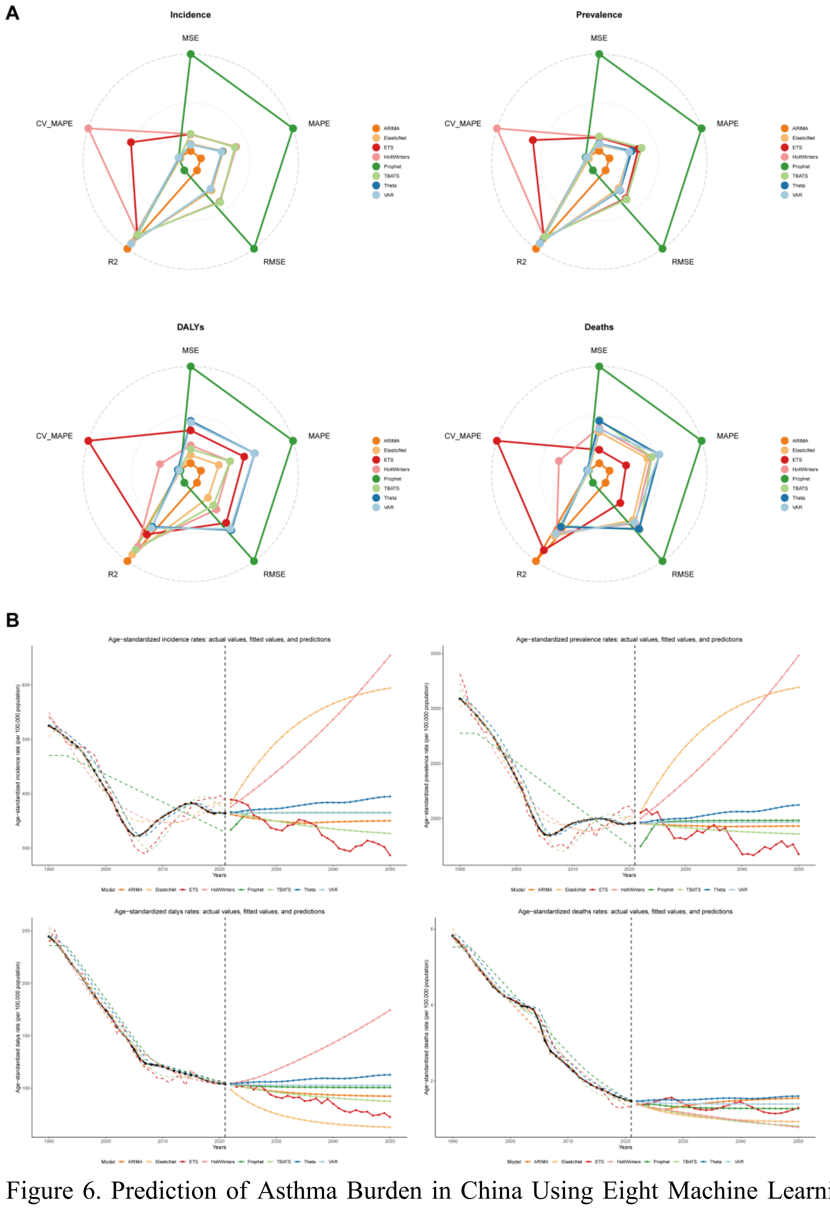

Figure 6. Prediction of Asthma Burden in China Using Eight Machine Learning Algorithms

A: Comparison of evaluation metrics for different prediction models of age-standardized rates of asthma in China.

B: Predicted values of age-standardized rates of asthma in China from 2022 to 2050 using different models.

4 Discussion

Asthma is a common chronic inflammatory airway disease. This study evaluated the disease burden of asthma in China and globally from 1990 to 2021. In terms of the ASRs, the ASIR, ASPR, ASDR, and ASMR of asthma in both China and globally have decreased. This phenomenon reflects the effectiveness of global prevention, control, and treatment efforts for asthma globally over the past 32 years. Since the 1990s, due to the high incidence and prevalence of asthma, various countries have successively issued guidelines on the diagnosis and management of asthma [16]. In this century, asthma has also been included in the World Health Organization's Global Action Plan for the Prevention and Control of Noncommunicable Diseases and the United Nations' 2030 Agenda for Sustainable Development [17]. At the same time, the medical community has been continuously developing new scoring systems and diagnostic criteria suitable for the current situation. For example, Fitzpatrick et al. [18] developed a multidimensional asthma severity scoring system for adolescents and adults, which has favorable measurement characteristics and responsiveness to changes in patients' quality of life.

However, it is concerning that, despite the decrease in the numbers of incidence, prevalence, and DALYs globally, the number of deaths has increased by 16.51% during this period. On the one hand, with the continuous growth of the global population and the deepening of population aging, the size of the high-risk population for asthma has expanded, leading to a corresponding increase in the number of deaths. On the other hand, there are huge gaps in economic development levels, the allocation of medical and health resources, and disease prevention and control capabilities among different regions. In some economically underdeveloped regions, due to the lack of sufficient medical resources, advanced diagnosis and treatment technologies, and effective disease management systems, the mortality rate of asthma patients remains high, thereby contributing to the global increase in deaths [8]. In addition, the intensification of climate change and environmental pollution may also be a potential factor [][10]. Studies have shown that in areas with high environmental particulate matter pollution, the incidence and severity of asthma are higher [19]. China's reduction in asthma burden—particularly in contrast to the global increase in deaths—reflects the complex interactions among socioeconomic factors, environmental factors (e.g., air quality), and healthcare services. Notably, the overall asthma burden in both China and globally has decreased compared with 1990, but in recent years, the incidence and prevalence of asthma have shown an upward trend. In the face of the heavy burden of asthma, we still cannot be negligent.

From the perspective of age stratification, the numbers of incidence and prevalence among children and adolescents, as well as their ASRs, are at a high level compared with all age groups. From a genetic point of view, the susceptibility to asthma has a strong genetic component [20]. Meanwhile, due to the high heterogeneity of asthma, there is currently a lack of universally effective preventive measures, which may be one of the reasons for the high incidence and prevalence of asthma among children [21]. Premature infants and low-birth-weight infants are also at very high risk of asthma due to poor lung development [22]. Exposure to air pollution during pregnancy and early childhood can also damage lung function, thereby increasing the risk of asthma in children [23]. Over the past few decades, as society globally has entered the stage of nutritional transition, the rates of overweight and obesity have increased rapidly [24]. Compared with children with normal weight, obese children are at a higher risk of developing asthma [25]. A study has pointed out that a high body mass index trajectory in fathers significantly increases the risk of their offspring developing asthma in childhood [26]. In addition, the elderly (⩾60 years) also face a heavy asthma burden, especially in terms of ASRs, which are all extremely high level. With the increase of age, the asthma phenotype in the elderly is more severe, airway obstruction is more obvious, comorbidities are more common, and severe complications are more likely to occur during asthma attacks [27],[28]. The aging of the population in the modern world has become a major trend [29], which means that countries around the world are facing greater challenges. This is not limited to asthma; the complex health conditions of the elderly pose a heavy burden on the entire public health system.

From a sex-stratified perspective, the asthma burden in China is generally higher in males across most age groups, whereas globally, females bear a greater burden in most age groups. The global pattern aligns with previous studies, which indicate that asthma burden is higher in males during childhood but shifts towards a female predominance after puberty [30],[31]. This may be related to lung development: there is a developmental mismatch between airway development and airflow velocity in boys and obese women [30]. Additionally, hormonal influences play a significant role: androgens can suppress immune responses and mitigate asthma symptoms, while estrogens enhance immune responses and are associated with asthma exacerbation, particularly during pregnancy and menopause, making asthma management more challenging for women [30],[31]. The underlying sex differences are also shaped by genetic variations between males and females, including differences in gene expression and epigenetic modifications [20],[32]. However, in China, males bear a greater asthma burden across most age groups, which may be linked to gender-specific lifestyles and behavioral factors. For example, smoking is a well-established asthma trigger [33], and in China, the prevalence of smoking is significantly higher in males (60.7%) than in females (2.8%) [34]. Given the sex differences and heterogeneity in asthma, many researchers have advocated for personalized treatment strategies to improve asthma management and control [35],[36]. Considering the higher global asthma burden among females, greater attention should be given to asthma management during critical life stages in women, with more effective treatments tailored to their specific needs.

Future trend predictions using the ARIMA algorithm reveal contrasting patterns between China and the global trajectory of asthma. From 2022 to 2050, the global ASIR, ASPR, and ASDR are projected to increase gradually, whereas the ASMR is expected to decline. This suggests that while asthma incidence and disease burden may worsen due to ongoing environmental changes and limited healthcare improvements in certain regions, advancements in medical technology and increased disease awareness could help reduce asthma-related mortality risks. In contrast, China's ASIR, ASPR, and ASDR are projected to decline by 2050, while ASMR is expected to rise. The decline in asthma incidence-related metrics may reflect the positive impact of sustained environmental policies, improvements in the public health system, and the promotion of healthy lifestyles, which have collectively reduced asthma risk factors and enhanced overall population health [37]. However, the increase in ASMR may be attributed to the accelerating aging population. Elderly asthma patients often experience more severe disease progression and complications, and despite improvements in overall asthma control, their declining physiological functions still lead to a relatively higher mortality risk [28],[38].

Given the projected upward trend, the asthma burden remains a significant public health challenge. Globally, strengthening international collaboration, facilitating knowledge and technological exchange, and increasing healthcare investments in developing countries are crucial for enhancing early asthma diagnosis capacity and improving healthcare infrastructure. For China, resource allocation should prioritize geriatric medicine, including expanding specialized asthma clinics for the elderly and training more healthcare professionals to provide precision care for older asthma patients. Furthermore, global efforts in environmental protection should be intensified to reduce asthma-inducing factors, alongside public awareness campaigns to improve asthma education. Enhancing public understanding of asthma prevention and management is essential to mitigate its burden and promote long-term respiratory health.

5. Conclusion

Based on the GBD database, this study conducts an in-depth analysis of the evolutionary characteristics of asthma disease burden in China and globally from 1990 to 2021 across age, gender, and time dimensions, and predicts the trends from 2022 to 2050. The results show that over the past three decades, the overall burden of asthma in China and globally has shown a downward trend, but the global number of deaths has increased by 16.51%. From the age perspective, newborns and children aged 0-9, as well as the elderly over 60, are facing an extremely high burden of asthma. In terms of gender distribution, the burden in males in most age groups in China is higher than that in females, while globally, the burden among females in most age groups is higher than that among males. The prediction results indicate that the situation of asthma burden remains severe. Based on this, this study puts forward targeted suggestions. China should focus on strengthening the standardized management of children and elderly asthma patients, especially improving the capabilities of early screening and long-term care in primary medical institutions, and optimizing the allocation of medical resources to meet the differentiated needs of patients in different age groups. Globally, it is necessary to strengthen international cooperation, with a focus on improving drug access, diagnostic and treatment technologies, and public health education in developing countries in asthma prevention and treatment, while emphasizing asthma management during women's special life stages. Future research should continuously monitor trends in asthma burden and dynamically adjust prevention and control strategies in light of environmental changes, socioeconomic development, and other factors, to effectively reduce the persistent burden of asthma on global public health.

Declarations:

Ethics approval and consent to participate: not applicable.

Consent for publication: agree to publish.

Availability of data and materials declarations: All data generated or analysed during this study are included in this published article [and its supplementary information files].

Conflicts of Interest: The authors declare no conflict of interest.

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