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Spatial, temporal and demographic patterns in asthma mortality in China: A systematic analysis from 2014 to 2020

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ABSTRACT

Background: Asthma is an important contributor to the burden of non-communicable diseases in China. Understanding spatial, temporal, and demographic patterns in asthma mortality is relevant to the design and implementation of targeted interventions.

Methods: This study collected information on asthma deaths occurring across 605 disease surveillance points (DSPs) as recorded in the population-based national mortality surveillance system (NMSS) of China. Asthma was defined according to the International Classification of Diseases, 10th Revision code J45-J46. Estimates of age-standardized mortality rates and total national asthma deaths were calculated based on yearly population data. Statistical analysis was performed to investigate the influence of various factors on asthma mortality.

Results: Between 2014 and 2020, a total of 40 116 asthma deaths occurred in DSPs. Standardized asthma mortality per 100 000 people decreased from 1.79 (95% CI: 1.74–1.83) in 2014 to 1.07 (95% CI: 1.03–1.10) in 2020 in China. In 2020, the overall asthma mortality rate was higher for male patients than for female patients, and asthma mortality rates increased substantially with age. Age-standardized asthma mortality per 100,000 people exhibited significant geographic variation, ranging from 0.93 (95% CI: 0.89–0.98) in Eastern China to 1.04 (95% CI: 0.98–1.10) in Central China and 1.37 (95% CI: 1.29–1.45) in Western China in 2020. Asthma mortality in urban areas appeared to be higher than in rural areas. Socioeconomic factors, including gross domestic product per capita and density of hospital beds per 10,000 population, may be related to asthma mortality. Male asthma patients who lived in rural areas and were aged 65 years and above were generally at high risk of asthma-related mortality.

Conclusions: This study found a spatial and temporal trend for a reduction in asthma deaths over seven years in China; however, there remain important sociodemographic groups that have not secured the same decrease in mortality rates.

Trial registration: This was a purely observational study and thus registration was not required.

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INTRODUCTION

Asthma is a common chronic airway disease affecting individuals of all ages, which has emerged as a leading cause of mortality and a major challenge for global health systems. The most recent global estimates suggest that 339 million people have asthma worldwide,[1] and asthma ranked number 34 as a cause of global disease burden measured by disability-adjusted life years (DALYs) in 2019.[2] A recent analysis of trends in asthma mortality over the past decade based on World Health Organization (WHO) data from 46 countries revealed striking international heterogeneity.[3] An improved understanding of trends in asthma mortality could shed light on the condition's burden and the impact of changes in asthma management. However, little is known about national trends in asthma mortality in China over the past decade.

More information about the current status of asthma mortality in China is urgently needed for the following reasons: (1) the dramatically increasing prevalence of asthma–combined with a lack of awareness of the condition and available treatments among patients–may lead to poor prognoses, even death, for many individuals[4] and (2) the mortality risk from asthma may be influenced by many factors, including the presence of other medical conditions, the availability and quality of healthcare facilities and health insurance policies, and socioeconomic factors.[5-8] Most of these factors vary across provinces and regions. Therefore, having an accurate picture of asthma mortality at the national and provincial levels–based on current high-quality epidemiological evidence–may assist policymakers in allocating limited health resources efficiently and developing or adjusting tailored intervention strategies.

In this study, we used data from the national mortality surveillance system (NMSS) in China to examine secular trends in asthma mortality and assess the effects of age, region, and socioeconomic factors on asthma mortality risk. Assessing the relative contribution of period and socioeconomic effects to overall temporal trends might help determine the efficacy of early policy initiatives and identify future priorities. The findings of this study may provide new evidence of factors that influence asthma mortality and help public health managers to assess the impact of previous interventions and formulate future policies.

METHODS

Data source and procedures

We obtained asthma mortality data from the NMSS, which is managed by the Chinese Center for Disease Control and Prevention (China CDC). Detailed descriptions of the NMSS have been published elsewhere.[9] Briefly, this system is comprised of 605 counties or districts from all 31 mainland provinces, municipalities, and autonomous regions, selected by multi-stage stratified sampling and covering over 300 million residents (24% of the total population). Data from this system, which is proven to be nationally and provincially representative, have been widely used in policy formulation and disease burden assessments in China.[10-12] For deaths in hospitals, doctors certified the cause of death, and trained coders determined the underlying cause of death by applying the rules of the International Classification of Diseases. If hospital staff lacked the capacity to determine or code the underlying cause of death, these procedures were carried out by trained professionals from the county or district CDC. For deaths occurring outside the hospital, village health workers or township or community hospital staff performed a verbal autopsy from which hospital doctors determined the underlying cause of death. In this system, information on each death is systematically validated by a local CDC (i.e., at the county, prefecture, or provincial level), which also checks the completeness, coding, and internal logic of the items reported on death certificates. Causes of death are subsequently reported to the China

CDC, where data are consolidated. The Tenth Revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10: J45 and J46) was used to assess the underlying cause of death and confirm mortalities due to asthma. Data for under-reporting in this system were obtained from retrospective under-reporting field surveys for NMSS conducted in 2006, 2009, 2012, 2015, and 2018, aiming to derive the under-reporting rate for the period of 2005–2017.[9,13] All deaths from January 1, 2014, to December 31, 2020, were included in our study. For each case, we extracted the following data: age, sex, urban/rural area, province, region, educational level, highest diagnostic hospital level, date of death, the underlying cause of deaths (UCoDs), and place of death.

We also used the asthma standardized mortality data based on the Global Burden of Disease (GBD) estimation in 2014 and 2019 from 204 countries to compare the global level of asthma mortality to those observed in China.[14]

Population data were sourced from the National Bureau of Statistics.[15] Data for rate standardization were acquired from the 2010 population census.[16] Economic status at the provincial level and education status at the DSP level were also obtained from the China Statistical Yearbook,[17] whereas data on healthcare resources at the DSP level were obtained from the 2020 Year Book of Health and Family Planning in the People's Republic of China.[18] The gross domestic product (GDP) and disposable income data were converted from Renminbi (RMB) to US dollars, based on the average annual exchange rate in 2020 (1 USD = 6.8974 RMB).[19] Socio-Demographic Index (SDI) data were sourced from the 2019 GBD study.[14] The SDI ranges from 0 (worst) to 1 (best) and incorporates the total fertility rate in women under the age of 25 years, mean education for individuals aged 15 years and older, and lag-distributed income per person.

Statistical analysis

This analysis proceeded in 4 steps. First, we analyzed the number of deaths due to asthma and its age-standardized mortality rates in all 31 provinces in China, during 2014–2020. The age-standardized mortality rates (per 100 000) were calculated through direct age standardization with the standard population taken from the Chinese sixth census in 2010.[16] We calculated the under-reporting rates (URRs) annually for each age-sex stratum among all surveillance points during 2005–2017; the proportion of missed deaths among the total number of deaths identified in underreporting surveys was determined for every five-year group, with five-to-nine years as the youngest group and 80 years and older as the oldest. We used spline regression to predict the URR in each stratum from 2005 to 2020. Then, the annual UURs for each age-sex stratum among all surveillance sites during 2014–2020 were used to adjust the mortality rate. We used Joinpoint Regression Program[20] (Version 4.8.0.1-April 2020) to calculate the average annual percent change (AAPC) in age-standardized mortality during 2014–2020. We used Poisson regression and national and provincial population data to estimate 95% confidence intervals (CIs) for asthma deaths and asthma mortality rates at the national and provincial levels.

Second, a choropleth map was produced to visually examine geographic variation in asthma mortality rates across 31 Chinese provinces by using geographic information system (ArcGIS version 10.7 software). We also estimated the number of asthma deaths and age-standardized mortality rates in three regions of China to explore regional differences in asthma mortality. We divide China into 3 major divisions according to natural geographic characteristics: Eastern China (Beijing, Tianjin, Hebei, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan), Central China (Shanxi, Liaoning, Jilin, Anhui, Jiangxi, Henan, Hubei, Hunan), and Western China (Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang).

Third, to explore urban-rural differences in asthma mortality, we calculated the number of asthma deaths and age-standardized mortality rates in urban and rural areas. The division of urban and rural areas was made according to the permanent addresses of death cases.

Fourth, we used SAS9.4 software to analyze factors related to asthma death. Poisson

Characteristics	2014			2020			2014–2020 AAPC (%)
	Deaths in DSPs	Mortality rate per 100,000 in DSPs (95% CI)	Estimated deaths in China (95%CI)	Deaths in DSPs	Mortality rate per 100,000 in DSPs (95% CI)	Estimated deaths in China (95%CI)	
Overall	**6470**	**1.79 (1.74–1.83)**	**24,236 (23,614–24858)**	**4920**	**1.07 (1.03–1.10)**	**14,979 (14,491–15468)**	**−6.97 (-9.32, -4.56)***
Sex							
Male	3634	2.18 (2.11–2.25)	15,183 (14,690–15676)	2870	1.39 (1.33–1.44)	9960 (9562–10358)	−6.08 (−8.23, −3.88)*
Female	2836	1.43 (1.38–1.49)	9463 (9075–9851)	2050	0.79 (0.75–0.83)	5437 (5143–5730)	−8.03 (−10.68, −5.29)*
Age group (years)							
0∼	10	0.06 (0.02–0.09)	44 (17–71)	4	0.02 (0.00–0.04)	14 (0–30)	−6.68 (−27.68, 20.42)
5∼	20	0.04 (0.02–0.05)	87 (49–125)	14	0.03 (0.01–0.04)	58 (27–89)	−8.72 (−11.04, −6.34)*
20∼	254	0.19 (0.17–0.22)	1058 (928–1188)	130	0.11 (0.09–0.13)	538 (446–631)	−7.56 (−9.67, −5.40)*
45∼	906	1.00 (0.94–1.07)	3680 (3441–3920)	658	0.64 (0.59–0.69)	2674 (2470–2878)	−6.99 (−15.11, 1.90)
65∼	5278	16.89 (16.43–17.34)	21,280 (20,706–21854)	4114	9.51 (9.22–9.80)	16,790 (16,277–17303)	−7.84 (−10.07, −5.55)*
Region							
Eastern China	2871	1.68 (1.62–1.75)	9462 (9084–9840)	2067	0.93 (0.89–0.98)	5463 (5179–5747)	−8.37 (−10.55, −6.14)*
Central China	1792	1.70 (1.62–1.78)	7247 (6900–7595)	1405	1.04 (0.98–1.10)	4540 (4264–4816)	−6.19 (−8.44, −3.88)*
Western China	1806	2.09 (2.00–2.19)	7723 (7363–8083)	1447	1.37 (1.29–1.45)	5279 (4979–5580)	−5.24 (−10.41, 0.23)

Table 1. Asthma mortality in DSPs of China from 2014 to 2020. ***Abbreviations:*** *DSPs, disease surveillance points; AAPC, average annual percent change. *P value < 0.05*

regression was used to analyze factors influencing asthma death relative to death from other causes. In addition, we used simple linear regression to predict the SDI in China and each province in 2020 based on the SDI between 1990 and 2019. We used the SDI to determine the association between development level and asthma age-standardized mortality rates from 2014 to 2020 in China and its provinces. Examining the association of development level (SDI) with asthma mortality is important because components of the SDI affect the prevalence of asthma risk factors. A two-sided *P*-value was regarded as statistically significant if it was less than 0.05.

RESULTS

Asthma mortality and national estimation

From 2014 to 2020, a total of 40 116 asthma deaths occurred in DSPs, including 22 768 deaths in females and 17 344 in males. A total of 6470 asthma deaths occurred across the 605 DSPs in 2014, and 4920 asthma deaths occurred in 2020, marking a significant decline (see Table 1 and Supplemental Table 1). After normalization of the population distribution in the 2010 Chinese census, standardized asthma mortality per 100 000 people decreased from 1.79 (95% CI: 1.74–1.83) in 2014 to 1.07 (95% CI: 1.03–1.10) in 2020. This translates to an estimated 15 046 (95% CI: 14 491–15 468) national asthma deaths in 2020. The overall asthma mortality rate for males was higher than that for females (1.39 vs. 0.79 per 100,000 population) in 2020 (Fig. 1). In addition to this gender difference, age-standardized mortality rates increased substantially with age (Table 1). The mortality rate in 2020 was low in infants and children (0.02 per 100 000 population aged 0–4 years old; 0.03 per 100 000 population aged 5–19 years old), was moderately higher in working-age adults (0.11 per 100 000 population aged 20–44 years; 0.64 per 100 000 population aged 45–64 years), and was substantially higher in the elderly (9.51 per 100,000 population aged 65 years and above).

National geographic distribution of asthma mortality

Normalized asthma mortality rates exhibited significant geographic variation (Fig. 2A, Table 1 and Supplemental Fig. 1), ranging from 0.93 (95% CI: 0.89–0.98) death per 100 000 population in Eastern China to 1.04 (95% CI: 0.98–1.10) in Central China and 1.37 (95% CI: 1.29–1.45) in Western China. At the provincial level, Guizhou (3.48 deaths per 100,000

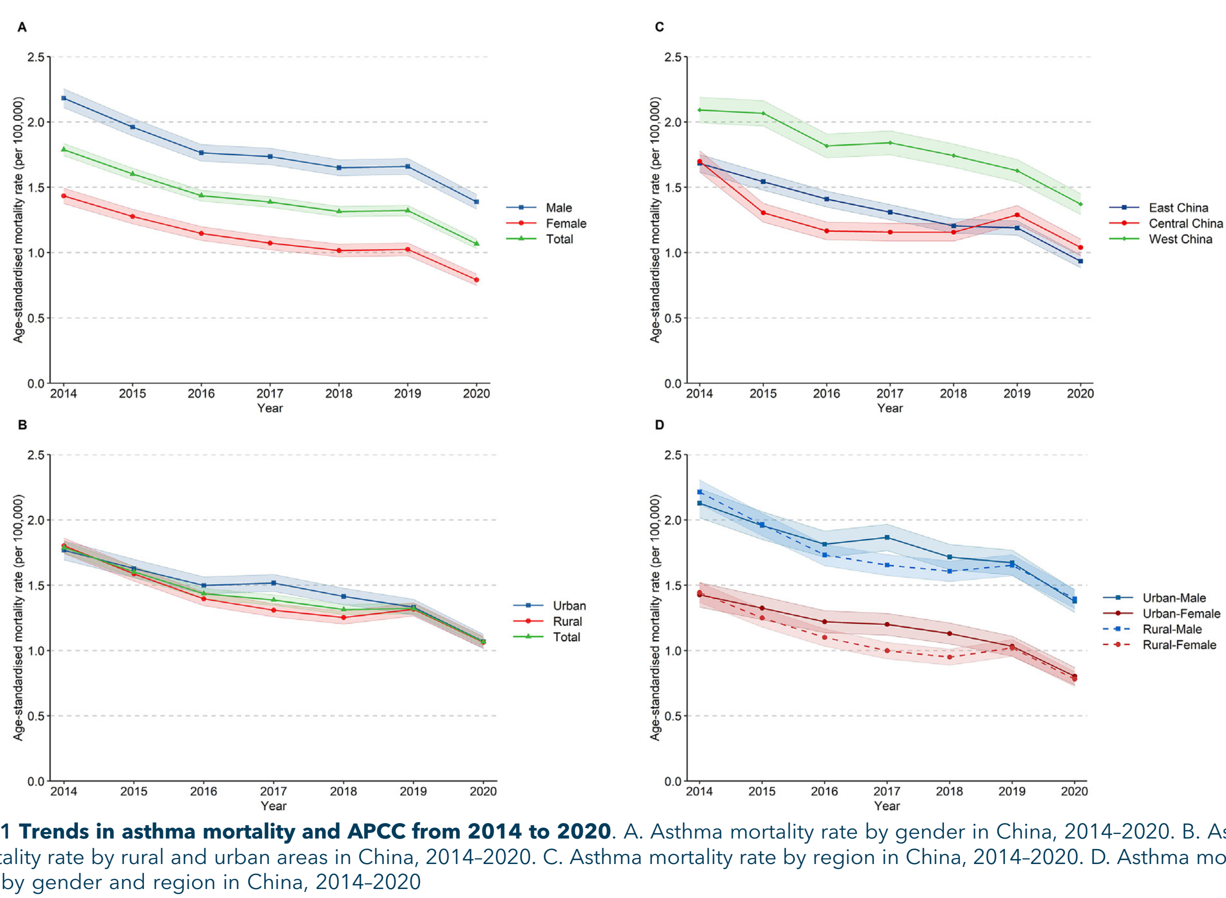

Fig. 1 Trends in asthma mortality and APCC from 2014 to 2020. A. Asthma mortality rate by gender in China, 2014–2020. B. Asthma mortality rate by rural and urban areas in China, 2014–2020. C. Asthma mortality rate by region in China, 2014–2020. D. Asthma mortality rate by gender and region in China, 2014–2020

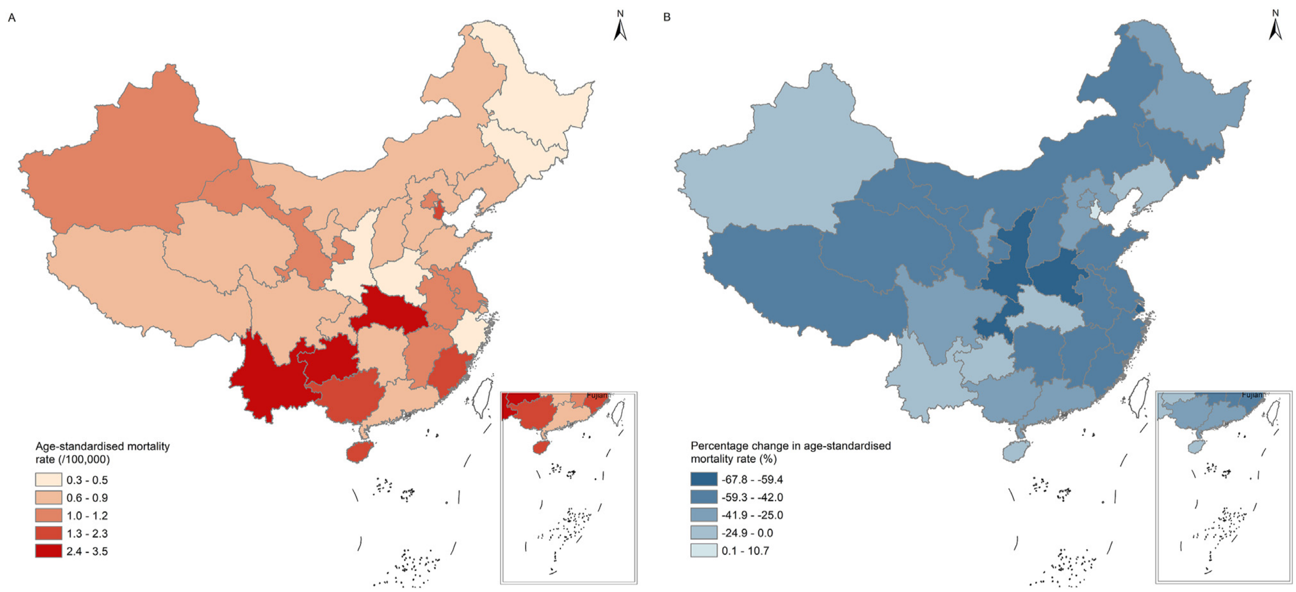

Fig. 2 Geographic distribution of age-standardized mortality rate and percentage change between 2014 to 2020. A. Age-standardized asthma deaths per 100 000 population by province, 2020. B. Percentage change in age-standardized asthma mortality rate by province between 2014 and 2020

population) and Yunnan (3.18 deaths per 100 000 population), located in Southwest China, and Hubei (3.46 deaths per 100,000 population), located in Central China, had the highest age-standardized death rates in 2020. Heilongjiang (0.29 deaths per 100 000 population), Henan (0.32 deaths per 100 000 population), and Jilin (0.36 deaths per 100 000 population) had the lowest age-standardized death rates in 2020. The geographic distribution of asthma mortality and trends in different provinces are shown in Table 2. The relative changes in asthma mortality observed over the study period also exhibited substantial geographic variations, with the largest percent decline seen in Central China (Fig. 2B).

Differences in asthma mortality trends in rural and urban areas

Overall asthma mortality declined between 2014 and 2020. Nationally, asthma mortality in urban areas remained slightly higher than that in rural areas throughout this period, but such gap was narrowed over time. Regional variation in urban-rural asthma mortality differences was also seen (Fig. 1). In the North and Northwest regions of China, asthma mortality in urban areas was higher than that in rural areas (as nationally), but Western China showed the opposite result (Fig. 3).

Benchmarking to provincial gross domestic product

GDP per capita appeared to be partly associated with asthma mortality at the provincial level (Supplemental Fig. 2). In addition to GDP per capita, urbanization appeared to be associated with the national asthma mortality rate ($R^2 < 0.05$). Socioeconomic status, urbanization ratio, and density of hospital beds per 10 000 population may also be associated with asthma mortality (Supplemental Fig. 2). In addition, an SDI of around 0.6 to 0.8 was related to low asthma mortality (Supplemental Fig. 3).

DISCUSSION

This study represents the first analysis of asthma mortality trends in China from 2014 to 2020. We found that during this period, China experienced an overall asthma mortality reduction from 1.79 to 1.07 deaths per 100 000 people, with an annual decline rate of 6.97%. Previous studies have shown global asthma mortality trending downward over time, with a rate of 0.44 deaths per 100 000 population observed in 1993 and a rate of 0.19 deaths per 100 000 population observed in 2006.[3] Although a decline in China's national asthma mortality rate was observed between 2014 and

	Age-standardized mortality (/100,000), 2020		Percentage change (%), 2014–2020	
	Males	Females	Males	Females
Overall	**1.4**	**0.8**	**−36.4**	**−44.8**
Region				
Eastern China	**1.2**	**0.7**	**−41.5**	**−48.5**
Beijing	1.3	0.8	−10.4	−56.5
Tianjin	1.8	1.6	2.1	20.5
Hebei	1.3	0.5	−19.3	−56.4
Heilongjiang	0.4	0.2	−31.2	−43.9
Shanghai	0.8	0.5	−66.7	−60.5
Jiangsu	1.6	0.8	−49.2	−61.0
Zhejiang	0.7	0.3	−34.7	−63.5
Fujian	3.1	1.1	−49.0	−49.5
Shandong	1.1	0.7	−44.1	−39.4
Guangdong	1.0	0.5	−34.2	−35.8
Hainan	2.1	1.8	−23.9	31.2
Central China	**1.4**	**0.7**	**−34.7**	**−43.5**
Shanxi	0.7	0.5	−64.5	−37.0
Liaoning	0.8	0.4	−3.5	−25.8
Jilin	0.4	0.3	−49.5	−45.6
Anhui	1.7	0.8	−44.8	−54.5
Jiangxi	1.5	0.6	−49.3	−56.6
Henan	0.4	0.2	−59.7	−58.5
Hubei	4.7	2.4	4.5	−19.4
Hunan	1.1	0.6	−44.8	−51.0
Western China	**1.7**	**1.1**	**−28.7**	**−40.1**
Inner Mongolia	1.0	0.5	−35.9	−55.4
Guangxi	3.2	1.6	−18.9	−38.3
Chongqing	1.0	0.6	−57.3	−65.4
Sichuan	0.8	0.4	−32.9	−47.5
Guizhou	4.6	2.6	−7.5	−28.8
Yunnan	3.7	2.8	−10.3	−11.9
Tibet	0.2	1.2	−87.7	−40.2
Shaanxi	0.4	0.4	−68.4	−67.3
Gansu	1.1	0.9	−41.3	−51.5
Qinghai	1.0	0.6	−39.9	−55.0
Ningxia	0.9	0.8	−22.7	−26.1
Xinjiang	1.1	1.1	59.9	−36.8

Table 2. Geographic distribution of asthma mortality and changes

2020, it remained higher than the rates in 50 other countries. According to the estimation from 2019 country-level GBD asthma mortality data, the mortality rates in those 50 countries ranged from 0.26 (95% uncertainly interval: 0.21–0.31) deaths per 100 000 population in Greece to 80.50 (95% uncertainly interval: 59.22–104.19) deaths per 100 000 population in Kiribati. Again, even though the decline was observed, it remained higher than that in the other 50 countries mentioned above. Thus, better implementation of established management strategies is therefore needed in China.

Despite the reduction in asthma mortality from 2014 to 2020, we observed some concerning patterns. First, geographic factors were related to asthma mortality, with regional mortality rates ranging from 0.93 deaths per 100,000 populations in Eastern China to 1.37 deaths per 100,000 populations in Western China. Second, in many provinces, including those that had experienced large

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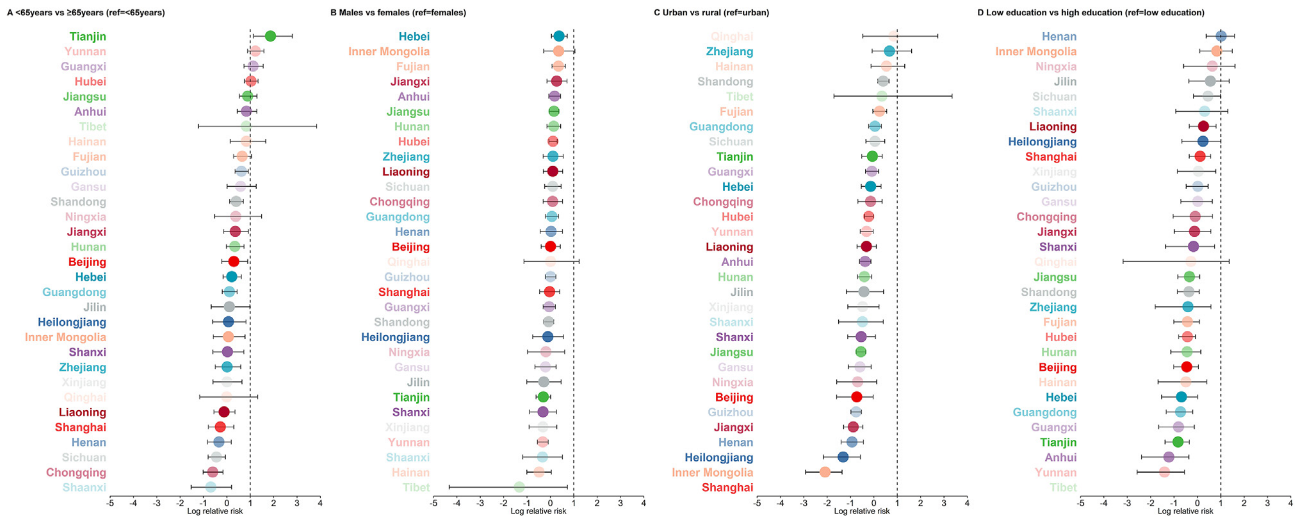

Fig. 3 Relative differences in provincial probability of asthma mortality by sociodemographic characteristics. A. Influence of age on asthma mortality in different provinces. B. Influence of gender on asthma mortality in different provinces. C. Influence of urban-rural status on asthma mortality in different provinces. D. Influence of education on asthma mortality in different provinces

decreases in mortality previously, the rate of progress has slowed. The decreases in asthma mortality seen in most provinces were insufficient to offset the demographic force of population aging, resulting in constant or increasing numbers of asthma deaths over time. Third, males in gender, living in a rural area, and low GDP per capita were observed to be partially related to trends in asthma mortality; collectively, these factors point to a vulnerable population in need of protection.

In this research, we found out that adults aged 65 and older had the highest death rate among all age groups in China. Previous research has also proven that higher morbidity and mortality are associated with elder age[21,22] and that this population suffers disproportionately from the burden of asthma and general airway diseases.[4,23] The cause of such divergent trends in asthma mortality by age is unclear, but several possible explanations exist: high mortality in this age group is likely related to misdiagnosis and poor access to health care facilities and medical consultation, especially in underdeveloped regions of China. Given the rate of population aging in China, the number of elderly patients with asthma is anticipated to grow in the future. Additionally, males face a higher risk of asthma death than females and suffer from a higher prevalence of asthma, which was consistent with previous studies.[24] Studies have suggested the association between smoking and morality in other population groups and indicated that smoking may weaken the effects of essential inhalation drugs, such as inhaled corticosteroids[25-28] and lead to poor prognoses. In China, the smoking rate among males was significantly higher than that among females,[29] which may provide some explanation for the gender differences. Future studies could further analyze and explore the reasons behind the gender difference in asthma mortality. Although our study was not able to and was not aimed to fully explain the decreasing trends of asthma mortality, we identified several key factors, including living environmental and social conditions, that have been shown to be associated with higher levels of asthma mortality. The relatively high rural mortality rates observed (in comparison with urban mortality rates) may result from low income and inadequate access to healthcare and medications, which lead to frequent emergency room visits and hospitalizations. Our study showed that asthma mortality has slightly dropped since 2014. At the same time, the density of hospital beds per 10 000 population may also be associated with decreased asthma mortality, which suggests that superior medical resources play an important role in disease prevention and treatment and that the allocation of medical resources and improvement of overall medical treatment capacity may contribute to mortality reduction.

The results of our study must be interpreted in the context of several limitations. First, data on DSPs for epidemiologic studies have certain drawbacks. These data do not come from a standardized sampling investigative design but from a national death reporting database, which is useful in terms of its availability.

Second, death certificate data are not independently authenticated, and some degree of misclassification unavoidably occurs. Some of the ICD-10 codes used might have also included patients who did not suffer from asthma. Third, for this study, we considered only crude asthma deaths rather than all asthma-related deaths. Fourth, death certificates do not include data on the severity of asthma, key risk factors such as occupational exposures, smoking status before death, and family disease history. Due to the limitations of the DSP database which can't include data at the individual level, our study was failed to quantify the impact of each factor on the decreasing trends of mortality rate, thus was not able to provide causal analysis on key factors. Future studies may further quantify the impact of each factor and their interactions on the mortality rate.

Asthma is a common disease with substantial human and economic costs globally. Given the increasing burden of chronic health conditions that plague our society and the healthcare system, recent declines in asthma deaths represent a significant and positive achievement. At the same time, it is important to bear in mind that while asthma mortality has continued to fall in China, the majority of asthma deaths are still considered preventable. Monitoring population asthma mortality trends can aid in identifying geographical areas to target for public health asthma awareness campaigns and in avoiding unnecessary asthma deaths. Our findings are an urgent call to action for the government to implement and enforce stronger disease control policies.

Abbreviations

DALY: disability-adjusted life years; WHO: World Health Organization; NMSS: national mortality surveillance system; CDC: Center for Disease Control and Prevention; AAPC: average annual percent change; DSP: disease surveillance points; SDI: Socio-Demographic Index

Abbreviations

AAPC, average annual percent change; China CDC, Chinese Center for Disease Control and Prevention; CIs, confidence intervals; DALYs, disability-adjusted life years; DSPs, disease surveillance points; GBD, Global Burden of Disease; GDP, gross domestic product; NMSS, national mortality surveillance system; RMB, renminbi; SDI, Socio-Demographic Index; UCoDs, underlying cause of deaths; URRs, under-reporting rates; WHO, World Health Organization.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

YL and MZ conceived and designed the study. XT, WL and ZL did the statistical analysis. All authors contributed to data collection, analysis, and interpretation. XT, PY, SC, PG, AC, MZ and YL drafted the report. All authors revised the report and approved the final version before submission.

Ethics approval

Ethics approval was waived because we used aggregated identified data.

Consent for publication

All authors consent the publication of the manuscript.

Declaration of competing interest

All authors have no conflicts of interest to declare that are relevant to the content of this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.waojou.2022.100735.

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