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Original Article

Decomposition analysis of lung cancer and COPD mortality attributable to ambient $PM_{2.5}$ in China (1990–2021)

Xiaoxue Liu [a], Haoyun Zhou [a], Xun Yi [a], Xinyu Zhang [a], Yanan Lu [a], Wei Zhou [b,*], Yunzhao Ren [c,*], Chuanhua Yu [d,e]

[a] Global Health Research Division, Public Health Research Center and Department of Public Health and Preventive Medicine, Wuxi School of Medicine, Jiangnan University, Wuxi, Jiangsu, China

[b] The Second Xiangya Hospital of Central South University, Changsha, Hunan, China

[c] School of Public Health, Zhejiang University School of Medicine, Hangzhou, Zhejiang, China

[d] Department of Epidemiology and Biostatistics, School of Public Health, Wuhan University, Wuhan, Hubei, China

[e] Global Health Institute, Wuhan University, Wuhan, Hubei, China

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ABSTRACT

Objective: This study aimed to evaluate the long-term trends in lung cancer (LC) and chronic obstructive pulmonary disease (COPD) mortality attributable to particulate matter ($PM_{2.5}$) in China and to identify the contributions of population aging and other risk factors to changes in mortality rates.

Methods: Using data from 1991 to 2021, we assessed trends in LC and COPD deaths attributable to $PM_{2.5}$ through linear regression. Decomposition analysis was conducted to determine the extent to which changes in mortality rates were driven by demographic and non-demographic factors.

Results: The crude mortality rates attributable to $PM_{2.5}$ increased significantly for LC (500.40%) and COPD (85.26%). From 1990 to 2021, LC mortality attributable to $PM_{2.5}$ increased annually by 4.11% (95% CI: 3.64%, 4.59%), while COPD mortality decreased annually by 1.23% (95% CI: −0.82%, −1.65%). Decomposition analysis revealed that 43.0% of the increase in LC mortality was due to population aging, and 57.0% was attributed to changes in other risk factors. For COPD, population aging contributed to an 18.547/100,000 increase, whereas other risk factors reduced mortality by 10.628/100,000.

Conclusions: The findings highlight the critical roles of population aging and risk factor modification in LC and COPD mortality trends. Interventions to address aging-related vulnerabilities and air pollution control are essential to mitigate future health burdens.

Introduction

Air pollution is a significant public health issue in China, where the population is exposed to high levels of both ambient and household air pollution.[1,2] Despite recent improvements, $PM_{2.5}$ concentrations in many areas continue to exceed the World Health Organization (WHO) Air Quality Guidelines, with 81% of the population living in regions surpassing the WHO Interim Target 1.[2] Among all cancers, lung cancer (LC) poses the greatest threat to the health and lives of Chinese people, while chronic obstructive pulmonary disease (COPD) is associated with a notably high disability rate. Both conditions are among the top five chronic diseases in China. Long-term exposure to ambient fine particulate matter has been strongly linked to increased risks of LC and COPD.[1,3–5] According to the latest Global Burden of Disease (GBD) estimates from 2021, the crude mortality rates for LC and COPD attributable to $PM_{2.5}$ in 2021 were 12.55/100,000 and 27.28/100,000, respectively.[6] This burden is further reflected in the disability-adjusted life years (DALYs) for LC and COPD attributable to $PM_{2.5}$, estimated at 4,125,752 and 7,144,155 person-years, respectively.[6] Notably, COPD-related deaths began to decline in 2014 following a turning point in air quality

* Corresponding author.
E-mail addresses: yunzhren@163.com (Y. Ren), sandyzhou1992@163.com (W. Zhou).

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improvements in China.[7] However, evidence on the association between $PM_{2.5}$ and LC mortality in the Chinese population remains limited and warrants further investigation.[8,9]

In recent years, ambient $PM_{2.5}$ pollution in China has significantly decreased, yet it remains a critical risk factor for public health. Understanding the long-term trends and changes in LC and COPD mortality attributable to $PM_{2.5}$ is essential. This study investigates the factors driving LC and COPD mortality rates linked to $PM_{2.5}$ exposure. As chronic diseases such as LC and COPD are among the leading causes of death in older populations, the burden of LC is likely to intensify with China's rapidly aging population. This research aims to analyze the long-term trends in LC and COPD mortality attributable to $PM_{2.5}$ and provide insights necessary for mitigating the long-term health impacts of air pollution.

Methods

Data sources

Mortality data for LC and COPD from the Global Burden of Disease (GBD) dataset spanning 1990 to 2021 were analyzed. The original data were sourced from the Chinese Center for Disease Control and Prevention Cause of Death Reporting System, the Disease Surveillance Points, and the Maternal and Child Surveillance System, ensuring national representativeness. Detailed information on data sources, processing methods, and completeness assessments can be found in Appendix 1, Section 3.5 of the GBD study.[10]

The population attributable fraction was defined as the proportion of diseases or deaths that could be prevented by reducing exposure to a specific risk factor to its theoretical minimum level within a given population. Attributable deaths for LC and COPD were calculated by multiplying the population attributable fraction by the corresponding outcome quantity for each demographic group, including age, sex, location, and year. LC and COPD were classified based on the clinical criteria established by the WHO. Ambient particulate matter pollution was assessed using a theoretical minimum risk exposure range of 2.4–5.9 μg/m^3.

Data analysis

The average annual percentage changes (AAPC) in age-standardized mortality rates (ASMR) were calculated to evaluate trends over the study period. Linear regression was employed to determine the annual percentage changes in ASMR for LC and COPD attributable to $PM_{2.5}$ exposure during the study years. Decomposition analysis was conducted to identify the key drivers of changes in disease-related mortality, focusing on the impacts of population aging and age-specific mortality rates in China.[11,12]

Linear regression was utilized to examine the relationship between a continuous dependent variable and an independent variable. In this analysis, the natural logarithm of the mortality rate for LC or COPD attributable to $PM_{2.5}$ served as the dependent variable, while the calendar year (1990, 1991, 1992, …, 2021) was used as the independent variable. AAPC > 0 indicated an increase in mortality rates, whereas an AAPC < 0 signified a decrease. Statistical significance was determined at $P < 0.05$. The AAPC was computed using the general formula: $y = \alpha + \beta x + \varepsilon$, $y = \ln(\text{rate})$, $x =$ calendar year, AAPC $= 100 \times (e^{\beta} - 1)$.

The mortality differential decomposition method, widely used in demographic studies, was applied to quantify how much of the difference in mortality between two populations (A and B) could be attributed to differences in age structure. This method is particularly effective for analyzing mortality data across regions or generations. For two generations within the same region, it can identify the extent to which changes in mortality are driven by population aging versus other risk factors.

This decomposition approach integrates interactions among various component effects, including population growth, aging, and transitions in mortality patterns, into additive main effects. In this study, decomposition analysis was used to determine how much of the observed change in mortality between generations was attributable to population aging compared to other risk factors.

To calculate the difference between the crude mortality rates of populations A and B, we defined CDR^B as the crude mortality rate of population B, CDR^A as the crude mortality rate of population A, and *diff* as the mortality difference between the two populations. *C* represents the age composition of the populations, and *M* denotes the age-specific mortality rate. The formula is as follows:

$$diff = \mathrm{CDR}^{B} - \mathrm{CDR}^{A} = \sum C_X^B M_X^B - \sum C_X^A M_X^A$$

We further summarized the differences in mortality rates between the two populations and their age composition as follows:

$$diff = \sum \left(C_X^B - C_X^A\right)\left(\frac{M_X^B + M_X^A}{2}\right) + \sum \left(M_X^B - M_X^A\right)\left(\frac{C_X^B + C_X^A}{2}\right)$$

=Difference in age structure (weighted by mean of age-specific mortality rates of population A and population B) + difference in mortality rates (weighted by age structure of population A and population B)

=Effects of age structure difference + contribution percentage of mortality difference effects

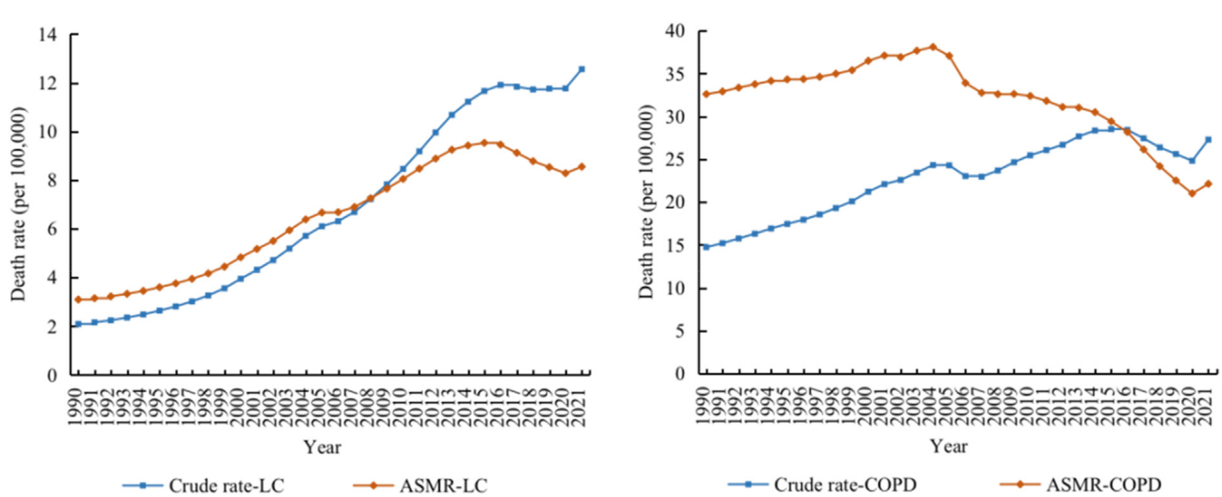

Fig. 1. The change in crude and age-standardized mortality rates (ASMR) of LC and COPD attributable to PM(2.5) across China. LC, lung cancer; COPD, chronic obstructive pulmonary disease.

All analyses were conducted using Stata 15.1 software (StataCorp, College Station, TX, USA).

Results

LC and COPD deaths attributable to $PM_{2.5}$ across China

The long-term trends in LC and COPD deaths across China were analyzed by examining the percentage change in ASMR attributed to $PM_{2.5}$ from 1990 to 2021 (Fig. 1). The ASMR for LC rose to a peak in 2015 before slightly declining, resulting in a total percentage change of 176.37%. In contrast, the ASMR for COPD decreased by 32.13%. Meanwhile, the crude death rate increased substantially for both LC and COPD (500.40% and 85.26%, respectively). Linear regression analysis revealed that LC deaths attributable to $PM_{2.5}$ increased by 4.11% annually (95% confidence interval [CI]: 3.64%, 4.59%), while COPD deaths attributable to $PM_{2.5}$ declined by 1.23% annually (95% CI: −0.82%, −1.65%).

LC and COPD deaths attributable to $PM_{2.5}$ by sex

The trends in crude rates and ASMR for LC attributable to $PM_{2.5}$ increased in both males and females, with a slight decline observed in males after 2016 (Fig. 2). For COPD, both the crude rate and ASMR

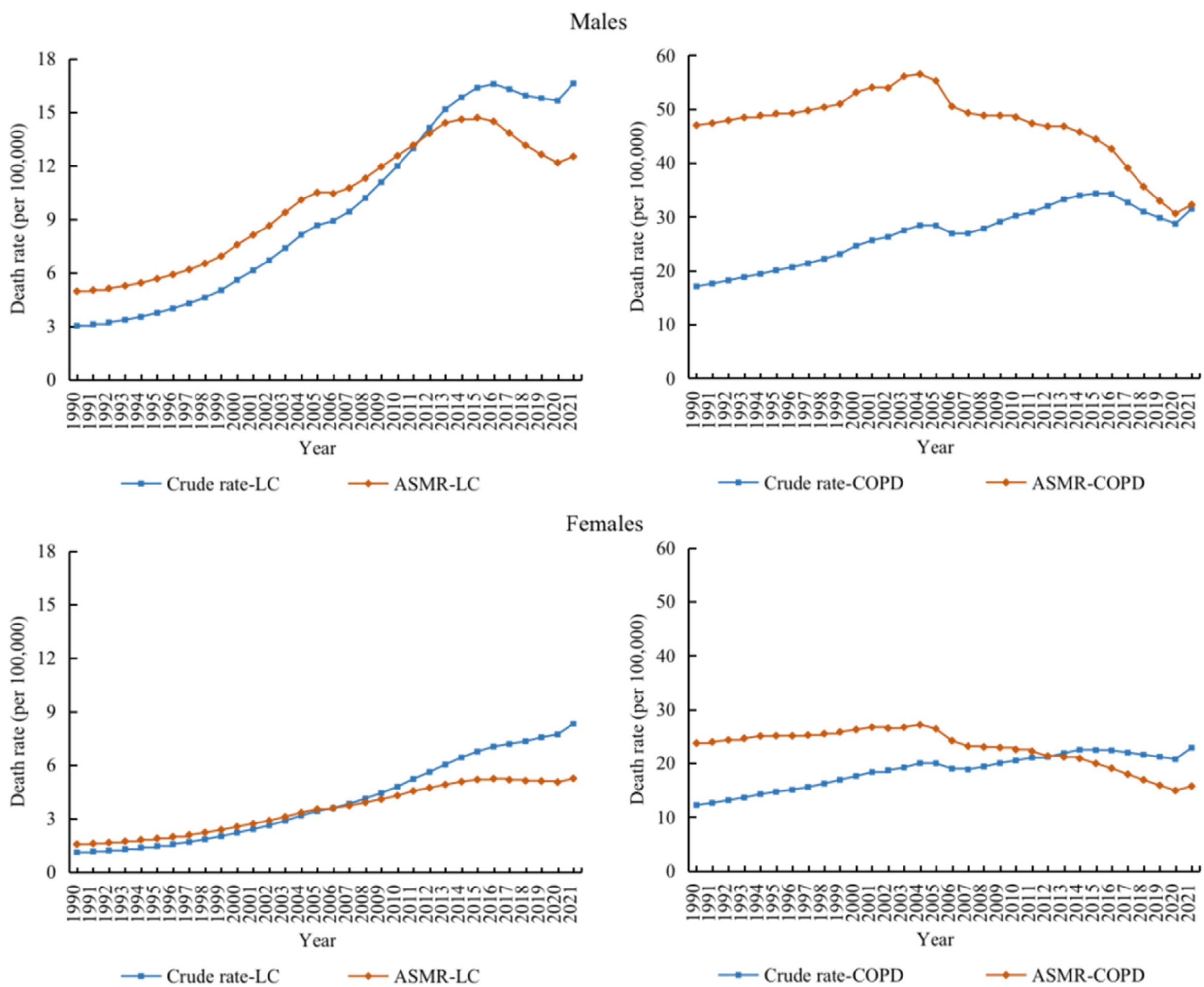

Fig. 2. The long-term change in crude mortality rates and age-standardized mortality rates (ASMR) of LC and COPD attributable to PM(2.5) by sex. LC, lung cancer; COPD, chronic obstructive pulmonary disease.

Table 1
The ASMR and average annual percentage change in LC and COPD mortality attributable to PM(2.5) from 1990 to 2021.

	1990		2021		Average annual percentage change (%)	95% confidence interval (CI)
	Crude rate	ASMR (per 100,000)	Crude rate	ASMR (per 100,000)		
Lung cancer						
Male	3.01	4.95	16.6	12.50	3.91*	3.39, 4.44
Female	1.11	1.56	8.31	5.25	4.56*	4.19, 4.92
Both	2.09	3.09	12.55	8.54	4.11*	3.64, 4.59
COPD						
Male	17.08	47.01	31.48	32.23	−1.09*	−0.63, −1.55
Female	12.22	23.72	22.89	15.73	−1.44*	−1.05, −1.83
Both	14.73	32.60	27.28	22.12	−1.23*	−0.82, −1.65

LC, lung cancer; COPD, chronic obstructive pulmonary disease; ASMR, age-standardized mortality rates. *$P < 0.001$.

attributable to $PM_{2.5}$ increased until 2004, followed by a decline in both sexes. Mortality levels for both LC and COPD attributable to $PM_{2.5}$ were significantly higher in males than females. The AAPC in ASMR for LC attributable to $PM_{2.5}$ was significantly greater in females (AAPC = 4.56%, 95% CI: 4.19%, 4.92%) compared to males (AAPC = 3.91%, 95% CI: 3.39%, 4.44%) (Table 1). The AAPC for COPD showed a slightly higher decline in females (AAPC = −1.44%, 95% CI: −1.05%, −1.83%) than in males (AAPC = −1.09%, 95% CI: −0.63%, −1.55%).

Decomposition analysis of LC and COPD mortality attributable to $PM_{2.5}$

The increase in LC mortality attributable to $PM_{2.5}$ resulted from the combined effects of demographic and non-demographic factors (Tables 2 and 3). The difference in crude LC mortality attributable to $PM_{2.5}$ between the 1991 population and the 2021 population was 10.21/100,000, of which 4.39/100,000 was due to differences in the age structure of the two populations, and 5.81/100,000 was attributed to differences in true mortality. Thus, demographic factors played a more significant role than non-demographic factors. Population aging accounted for 43.0% of the increase in LC mortality attributable to $PM_{2.5}$ over the past decades, while 57.0% of the increase was explained by other risk factors.

Regarding the difference in COPD mortality attributable to $PM_{2.5}$ in China between the 1991 and 2021 populations, 18.547/100,000 was due to the age structure of the two populations, while −10.628/100,000 was attributed to the influence of other risk factors (Table 3). The increase in crude COPD mortality was driven entirely by demographic factors, whereas the decrease was attributed to other risk factors. Since demographic factors played a larger role than non-demographic factors, they ultimately contributed to the overall increase in mortality rate.

Discussion

Main findings

Long-term exposure to ambient air pollution has been closely associated with the risk of LC and COPD mortality.[1,13–15] This study indicated that the crude mortality and ASMR for LC attributable to $PM_{2.5}$ increased over the past decades. The crude COPD mortality attributable to $PM_{2.5}$ also clearly increased, whereas the ASMR declined during the same period. This result was consistent with a previous report suggesting that the standardized COPD mortality would decrease significantly by 2030.[16] However, the associations between exposure to major air pollutants and the risk of COPD exacerbation require further evaluation.[17] The mortality levels for both LC and COPD attributable to $PM_{2.5}$ were much higher for males than females. The LC mortality attributable to $PM_{2.5}$ has also been reported to be higher among males than females in China.[15] In a cohort study on the association between long-term exposure to outdoor air pollution and mortality, deceased individuals tended to be older and to be male.[18]

This study was aimed at conducting a decomposition analysis to determine the extent to which changes in mortality between the 1991 and 2021 populations were due to population aging and to changes in other risk factors. The analysis indicated that, under the interaction of demographic and non-demographic factors, the LC mortality rates attributable to $PM_{2.5}$ in the Chinese population substantially increased from the 1990s to the 2020s. The increased LC mortality attributable to $PM_{2.5}$ was decomposed into population aging (43.0%) and other risk factors (57.0%). As previously reported, adult population growth was the main driver of the transition in the age-related LC burden.[10] Aging further increased the burden of LC deaths, given that biological aging is an important risk factor in cancer morbidity and mortality.[11] The burden of LC mortality remains heavy; therefore, control of major risk factors such as $PM_{2.5}$ and smoking, and improvements in the Chinese aging problem are necessary. $PM_{2.5}$ is associated with COPD prevalence, morbidity, and acute exacerbation.[13] Since the 1990s, the crude COPD mortality attributable to $PM_{2.5}$ clearly increased, whereas the ASMR declined. Hu et al. have also predicted that the age-standardized

Table 2
Decomposition of changes in LC mortality attributable to PM(2.5) in China between the 1991 and 2021 populations.

Age group	Age structure of the population in 1991 C_X^A (1)	Age-specific mortality rate in 1991 M_X^A (2)	Age structure of the population in 2021 C_X^B (3)	Age-specific mortality rate in 2021 M_X^B (4)	Difference in population weight by age $C_X^B - C_X^A$ (5)	Weight $(M_X^B + M_X^A)/2$ (6)	Difference in age structure of the population (7) = (6) × (5)	Difference in age-specific mortality rate between two populations $M_X^B - M_X^A$ (8)	Weight $(C_X^B + C_X^A)/2$ (9)	Difference in mortality rate (10) = (8) × (9)
25~	0.096	0.197	0.0614	0.102	−0.0346	0.150	−0.005	−0.094	0.0787	−0.007
30~	0.08	0.408	0.0857	0.204	0.0057	0.306	0.002	−0.204	0.08285	−0.017
35~	0.075	0.812	0.0731	0.359	−0.0019	0.585	−0.001	−0.452	0.07405	−0.033
40~	0.059	1.862	0.0656	0.785	0.0066	1.323	0.009	−1.077	0.0623	−0.067
45~	0.047	3.441	0.0767	1.407	0.0297	2.424	0.072	−2.034	0.06185	−0.126
50~	0.043	9.076	0.0866	3.419	0.0436	6.247	0.272	−5.657	0.0648	−0.367
55~	0.04	17.976	0.0816	7.093	0.0416	12.535	0.521	−10.883	0.0608	−0.662
60~	0.032	38.775	0.0474	16.367	0.0154	27.571	0.425	−22.407	0.0397	−0.890
65~	0.025	75.818	0.0544	36.258	0.0294	56.038	1.648	−39.561	0.0397	−1.571
70~	0.017	176.373	0.0376	96.138	0.0206	136.256	2.807	−80.236	0.0273	−2.190
75~	0.011	312.890	0.0233	200.883	0.0123	256.887	3.160	−112.007	0.01715	−1.921
80~	0.006	570.816	0.0151	425.577	0.0091	498.197	4.534	−145.239	0.01055	−1.532
85~	0.003	1092.781	0.0082	870.469	0.0052	981.625	5.104	−222.311	0.0056	−1.245
$\sum C_X^A M_X^A = 17.773$ $\sum C_X^B M_X^B = 25.692$							18.547			−10.628

LC, lung cancer.

Table 3
Decomposition of changes in LC and COPD mortality attributable to PM(2.5) in China.

	1991	2021	Difference in mortality rate	Impact of demographic composition	Impact of other risk factors
	Crude mortality	Crude mortality		The increase value	The increase value
LC	2.350	12.560	10.210	4.395 (43.05%)	5.815 (56.95%)
COPD	17.773	25.692	7.919	18.547 (234.21%)	−10.628 (−134.21%)

LC, lung cancer; COPD, chronic obstructive pulmonary disease.

mortality rate for COPD would decrease by 38.88% by 2030, and if the control target $PM_{2.5}$ concentration were achieved, 0.27 million COPD deaths could be avoided.[16] As reported herein, the ASMR for COPD attributable to $PM_{2.5}$ declined over the study period. Further decomposition analysis of the mortality difference indicated that the increase in COPD mortality attributable to $PM_{2.5}$ was caused entirely by population aging, whereas the other risk factors contributed to a decrease in mortality. The underlying reason for the decline might be associated with smoking control.[19] However, COPD mortality is expected to increase by 2030 if exposures to tobacco use and air pollution continue.[16] Thus, air pollution control efforts should continue to be enhanced to maintain a stable decrease in COPD. By comparison, a simulated decrease in the annual mean values of $PM_{2.5}$ to 10 $\mu g/m^3$ in Korea has suggested that approximately 8539 premature deaths due to IHD, COPD, LC, and stroke would be prevele.[20] In that study, decreasing trends in the mortality burden attributable to $PM_{2.5}$ were noted since 2006. Improvements in health effects attributable to ambient $PM_{2.5}$ concentrations have also been observed across the United States.[21] These findings might provide insights into potential strategies that could be adopted in China.

Implications for nursing practice and research

Higher concentrations of $PM_{2.5}$ are associated with poorer LC survival rates[15,22] and have been correlated with COPD exacerbation.[23] In general, the prognosis of cancer and the nurse care are related. Nurses were increasingly working in global health arenas but were typically ill-prepared to address this complex environmental health problem. Nurses can play a key role in education, practice, and research to develop and support interventions, which may reduce this substantial burden of disease.[24] In nursing practice, epidemiology risk factors could be utilized to target the fraction of population, which may benefit most from the introduced screening modality.[25]

As reported, linking risk information with knowledge of strategies for reducing these risks provided a basis for planning and implementing interventions to prevent lung cancer.[26] This study can provide epidemiology information to effectively reduce death burden of LC and COPD, and also provide evidence-based recommendations for policy makers, the general public, and clinicians and nurses. More advanced medical equipment, a wider variety of effective drugs, and humanized nursing measures are crucial for increasing the survival rates of LC and COPD. As reported, a core challenge to health systems is the chronic illnesses requiring ongoing and long-term health care.[27] Further studies will be necessary to enable evaluation of interventions and policies.[28–30]

Limitations

This study has several limitations. This study lacks epidemiological survey data on air pollutants which were not provided and discussed in the Chinese population. The exploration of predictive statistical methods for LC and COPD trends could be estimated in the next study. There might be uncertainty of the exposure estimates as there was no measurement in some areas, or the data was not available in GBD 2021 study.

Conclusions

The lung cancer deaths attributable to ambient $PM_{2.5}$ exposure in China is increasing. The COPD deaths attributable to ambient $PM_{2.5}$ seems to have been improved somewhat. Air pollution remains an important leading risk factor in China. Thus, the continued measures of air pollution control should be enhanced to prevent and control LC and COPD deaths. Besides, the situation of aging problem should be improved in Chinese population to reduce the impact of population aging on population health and economic development.

CRediT authorship contribution statement

Xiaoxue Liu: Conceptualization, Methodology, Data curation, Formal analysis, Writing. **Haoyun Zhou**: Methodology, Writing – Original draft preparation. **Xun Yi**: Methodology, Writing – Original draft preparation. **Xinyu Zhang**: Writing – Original draft preparation. **Yanan Lu**: Writing – Original draft preparation. **Wei Zhou**: Writing – Revised draft preparation. **Yunzhao Ren**: Writing – Revised draft preparation. **Chuanhua Yu**: Writing – Revised draft preparation. All authors had full access to all the data in the study, and the corresponding author had final responsibility for the decision to submit for publication. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Ethics statement

Not required.

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Declaration of competing interest

The authors declare no conflict of interest.

Data availability statement

The datasets analyzed in the current study are available in the GBD repository, http://ghdx.healthdata.org/gbd-results-tool.

Declaration of generative AI and AI-assisted technologies in the writing process

No AI tools/services were used during the preparation of this work.

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