ORIGINAL RESEARCH

Trends in the Burden of COPD Attributable to Ambient PM$_{2.5}$ Exposure in China 1990–2019: An Age-Period-Cohort Analysis

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Objective: Exposure to ambient particulate matter (PM$_{2.5}$) is the leading risk factor for developing chronic obstructive pulmonary disease (COPD) in China. The present study aimed to investigate the trends in COPD mortality attributable to ambient PM$_{2.5}$ exposure in China from 1990 to 2019.

Methods: Data on COPD burden attributable to ambient PM$_{2.5}$ exposure in China were extracted from the Global Burden of Disease (GBD) study 2019. The estimated annual percentage change (EAPC) was used to assess COPD mortality from 1990 to 2019. The APC model was used to analyze the temporal trends in the rate of COPD mortality attributable to ambient PM$_{2.5}$ exposure according to age, period, and cohort.

Results: Exposure to ambient PM$_{2.5}$ contributed to 192.4 thousand deaths in 1990 and 263.6 thousand deaths in 2019. The age-standardized mortality rate (ASMR) and the age-standardized disability-adjusted life year rate (ASDR) due to ambient PM$_{2.5}$ exposure showed a gradual downward trend, the ASMR and ASDR in 2019 decreased to 16.6 per 100,000 with an EAPC of −2.82 (95% CI: −8.61 to 3.34) and 278.6 per 100,000 with an EAPC of −2.02 (95% CI: −7.85 to 4.19), compared to those in 1990, respectively. The relative risk (RR) of COPD increased with age in females, while in males, mortality significantly increased from the levels among those in the 60–64 age group to that among those in the 90–94 age group. In the period group, the RR of COPD in males remained above 1.0 from the 2000 to 2004 period, but it gradually decreased in females. The cohort effect showed an overall downward trend.

Conclusion: Although the ASMR and ASDR are decreasing in Chinese patients with COPD, the number of deaths due to COPD is increasing. Ambient PM$_{2.5}$ exposure is more harmful in males and older people above 60 years of age.

Keywords: chronic obstructive pulmonary disease, PM$_{2.5}$, age-period-cohort model

Introduction

Chronic respiratory diseases are among the leading causes of incidence and mortality worldwide, and their incidence in 2017 was reported to be 544.9 million cases; chronic obstructive pulmonary disease (COPD) remained the most general disease-specific chronic respiratory disease in the world in 2017.[1,2] COPD is accompanied by persistent respiratory symptoms and airflow limitation, often with airway and alveolar abnormalities associated with high exposure to toxic particles or gases.[3] There is some evidence that dusty work environments play a role in COPD development.[4]

Air pollution from exposure to ambient particulate matter [with a diameter <2.5 μm (PM$_{2.5}$)] can have severe negative health effects, including respiratory infections, COPD, and lung cancer, leading to premature death. Particles with particle size ≤2.5 μm have the characteristics of small particle size, large surface area, and strong ability to adsorb toxic

substances.[5] Exposure to $PM_{2.5}$ has been reported to be associated not only with an increased risk of developing COPD but also with worsening of lung function and symptoms in patients with COPD.[6] Ambient air pollution mainly originates from factories, traffic, and household fuel.[7,8] Chen et al reported that smoking, male sex, low education level, family history of respiratory diseases, childhood respiratory infections, history of allergies, poor residential ventilation, exposure to occupational dust and biomass burning emissions, and living in and around polluted areas may be risk factors for developing COPD in Chinese population.[9]

Air pollution has become a serious environmental concern and has attracted increasing attention of many researchers in China.[8] Several studies have investigated the relationship between $PM_{2.5}$ exposure in China and disease burdens.[8,10] However, few studies have been conducted on the burden of COPD attributable to ambient $PM_{2.5}$ exposure in China.[11–13] In the present study, we provided an assessment of current trends in COPD mortality attributable to ambient $PM_{2.5}$ exposure in China from 1990 to 2019 by using an age-period-cohort (APC) analysis. We hope that our findings could provide a reference for developing effective public health policy to prevent COPD in China.

Methods

Data Sources

The number of deaths and mortality rate of COPD attributable to ambient $PM_{2.5}$ exposure was extracted from the Global Burden of Disease (GBD) study 2019 (http://ghdx.healthdata.org/gbd-results-tool), which is an estimate of the world's epidemiological data to offer a comparative assessment of disease burdens for 359 diseases and injuries and 84 risk factors from 1990 to 2019.[14] The APC analysis requires 5-year intervals for each age group,[15] and we excluded the group of 95-years-old and older. All methods were performed using relevant guidelines and regulations.

Descriptive Study

To assess the magnitude and direction of trends in the mortality rate and disability-adjusted life years (DALYs) of COPD over time, we used R software (version 4.1.2) to calculate the estimated annual percentage change (EAPC) and the corresponding 95% confidence interval (CI). The number of deaths, DALYs number, age-standardized mortality rate (ASMR), and the age-standardized disability-adjusted life year rate (ASDR) due to ambient $PM_{2.5}$ exposure were calculated. Because EAPC is a popular tool for calculating ASR trends from 1990 to 2019,[16] we also calculated EAPC of DALYs.

APC Model Analysis

The APC model is a common epidemiological, demographic, and sociological model that is applied to assess the age, period, and cohort effects on the disease mortality rate.[17] Age effects represent age-related developmental changes and accumulation of exposures and are related to variations linked with different age groups. Period effects are changes over time that affect all age groups simultaneously and represent changes in disease classifications, cultures, medical and diagnostic techniques, and economies specific to a given period. Cohort effects refer to changes between populations born in a region and represent early exposure to behavioral, environmental, and socioeconomic factors. Intrinsic estimator is one of the APC models that is used to analyze the three trends simultaneously and provides relatively efficient estimation results.[18]

In the APC model, the rates of COPD mortality were recoded into successive 5-year age groups (25−29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–89, 90–94), consecutive 5-year periods (1990−1994, 1995–1999, 2000–2004, 2005–2009, 2010–2014, 2015−2019), and corresponding consecutive 5-year birth cohort groups (1900−1904, 1905–1909, 1910–1914, 1915–1919, 1920–1924, 1925–1929, 1930–1934, 1935–1939, 1940–1944, 1945– 1949, 1950–1954, 1955–1959, 1960–1964, 1965–1969, 1970–1974, 1975–1979, 1980–1984, 1985–1989, 1990−1994). Population aged under 25 years is rare and not included in this study; moreover, because the APC model requires 5-year intervals for each age group, we excluded the group of 95-years-old and older. The APC model estimated coefficients for the age, period, and cohort effects, and these coefficients were used to calculate the relative risk (RR) [RR= exp (coef.)]. In the present study, Stata version 17.0 (StataCorp, College Station, TX, USA) was used. The Bayesian information criterion

(BIC) and Akaike information criterion (AIC) were used to estimate the degree of model fitting. $p < 0.05$ was considered to be statistically significant.

Results

Overall Trends in COPD Mortality Attributable to Ambient $PM_{2.5}$ Exposure in China

Figure 1 shows the trend in the ASMR of COPD attributable to $PM_{2.5}$ exposure from 1990 to 2019. The ASMR remained stable before 2000 and decreased markedly; the ASDR showed a similar downward trend in both male with an EAPC of −3.06 (95% CI: −8.85 to 3.09), and female with an EAPC of −3 (95% CI: −8.79 to 3.15) (Table 1). In Figure 2, the ASDR shows the same curve as that in Figure 1, but the decline was significantly faster in males than in females (Table 1), the ASDR in 2019 decreased to 356 per 100,000 with an EAPC of −2.49 (95% CI: −8.3 to 3.69) in males, and 224.7 per 100,000 with an EAPC of −2.23 (95% CI: −8.05 to 3.97) in females, compared to those in 1990, respectively.

Table 1 shows the DALYs and the number of deaths due to COPD attributable to ambient $PM_{2.5}$ exposure in 1990 and 2019, and its temporal trends of EAPC from 1990 to 2019. Over the past 30 years, the number of deaths increased from 192.4 thousand in 1990 to 263.6 thousand in 2019, the DALYs increased from 3969.5 thousand in 1990 to 5055.9 thousand in 2019, but the ASMR showed a downward trend with an EAPC of −2.82 (95% CI: −8.61 to 3.34) from 1990 to 2019, the ASDR also showed a decreasing trend with an EAPC of −2.02 (95% CI: −7.85 to 4.19), respectively. However, the age standardized rate (ASR) decreased from 554.8 in 1990 to 278.6 in 2019 per 100,000 in DALYs and from 33.8 in 1990 to 16.6 in 2019 per 100,000 in deaths.

APC Analysis

Age Effect

The age RR of COPD mortality attributable to ambient $PM_{2.5}$ exposure in China is shown in Figure 3A. The RR of COPD increased with age in both sexes. Females and males in the 60- to 64-year-older age group were risk groups with an RR > 1. The RR in males was higher than that in females in the 85−89 and 90−94 age groups (Tables 2 and 3).

Period Effect

Figure 3B shows the period RR of COPD mortality attributable to ambient $PM_{2.5}$ exposure in China. The period RR attributable to $PM_{2.5}$ exposure showed a slow upward trend in males. The trends among females and males were
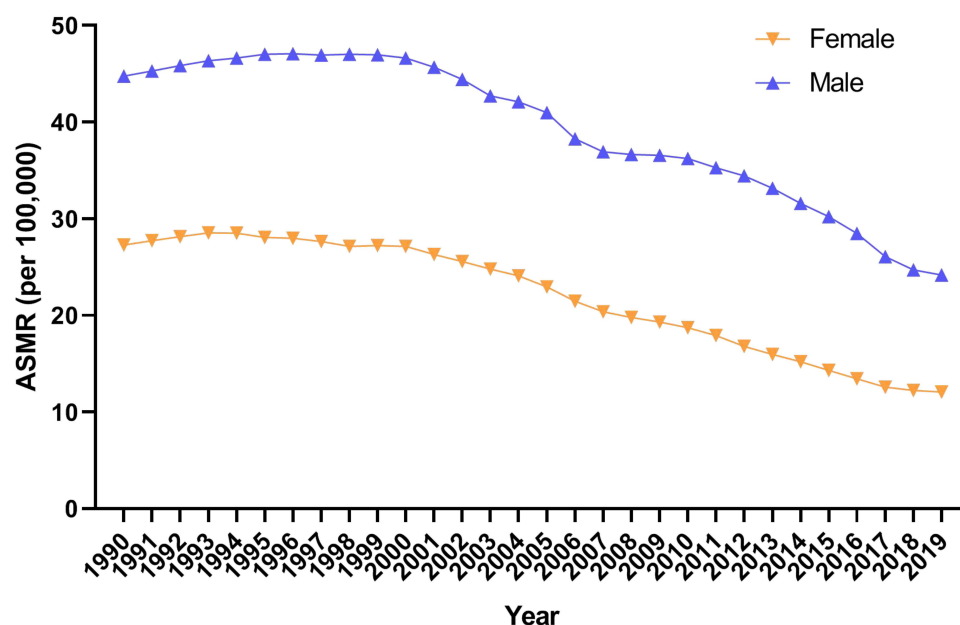

Figure 1 The trends in the age-standardized mortality rate (ASMR) of chronic obstructive pulmonary disease attributable to ambient PM2.5 exposure from 1990 to 2019 in China.

Table 1 The DALYs and Deaths of COPD in China Attributable to Ambient PM$_{2.5}$ Exposure in 1990 and 2019, and Its Estimated Annual Percentage Change from 1990 to 2019

Characteristics		1990		2019		1990–2019
	Sex	Numbers No.×103 (95% UI)	ASR per 100,000 No.(95% UI)	Numbers No.×103 (95% UI)	ASR per 100,000 No.(95% UI)	EAPC
DALYs	Both	3969.5 (1995.5–6615.1)	554.8 (280.7–926.1)	5055.9 (3969.8–6386.1)	278.6 (218.7–353.6)	−2.02 (−7.85–4.19)
	Female	1712.1 (843.5–2961.3)	450.1 (224.3–772.1)	2216.5 (1678–3047.8)	224.7 (169.9–308.4)	−2.23 (−8.05–3.97)
	Male	2257.4 (1099.6–3770.5)	698 (349–1164.1)	2839.4 (2151.5–3631.8)	356 (271.2–454.3)	−2.49 (−8.3–3.69)
Deaths	Both	192.4 (96–318.9)	33.8 (17–55.7)	263.6 (203.3–347.3)	16.6 (12.8–21.8)	−2.82 (−8.61–3.34)
	Female	86.3 (41.5–149.1)	27.3 (13.3–47.2)	110 (78.7–159.1)	12.1 (8.7–17.4)	−3 (−8.79–3.15)
	Male	106.2 (51.7–176.7)	44.8 (22.6–73.9)	153.7 (114.3–197.2)	24.2 (18.4–30.8)	−3.06 (−8.85–3.09)

Abbreviations: COPD, chronic obstructive pulmonary disease; EAPC, estimated annual percentage change; ASR, age standardized rate; UI, uncertainty interval; DALYs, disability adjusted of life years.

increased in three periods (1990−1994, 1995−1999, and 2000−2004); moreover, although the trends in females began to decrease, the trend among males did not show a significant decrease. The period groups 1990−1994, 1995−1999, 2000 −2004, and 2005−2009 were the four risk groups with an RR > 1 in females (Table 2), while the period groups 2000 −2004, 2005−2009, 2010−2014, and 2015−2019 are the four risk groups with an RR > 1 in males (Table 3).

Cohort Effect

Figure 3C shows the cohort RR of COPD mortality in both sexes. Overall, both curves show a downward trend in mortality. The 1900−1934 birth cohort showed that the cohort RR of males is slightly higher than that of females, and it tends to be stable in both sexes. The 1900−1954 birth cohort in females and the 1900−1949 birth cohort in males are the risk groups with an RR > 1 in mortality (Tables 2 and 3).

Discussion

There is growing evidence that PM$_{2.5}$ is the most harmful air pollutant to human health.[19,20] With the acceleration of industrialization and urbanization, the role of PM$_{2.5}$ in the development of COPD is becoming increasingly important.[21]
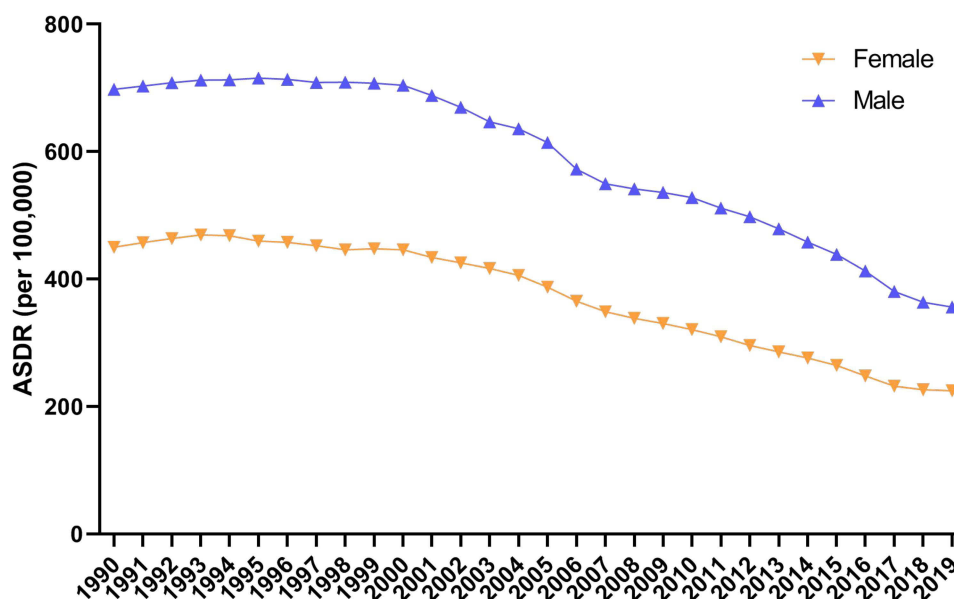
Figure 2 The trends in the age-standardized DALYs rate (ASDR) of chronic obstructive pulmonary disease attributable to ambient PM$_{2.5}$ exposure from 1990 to 2019 in China.
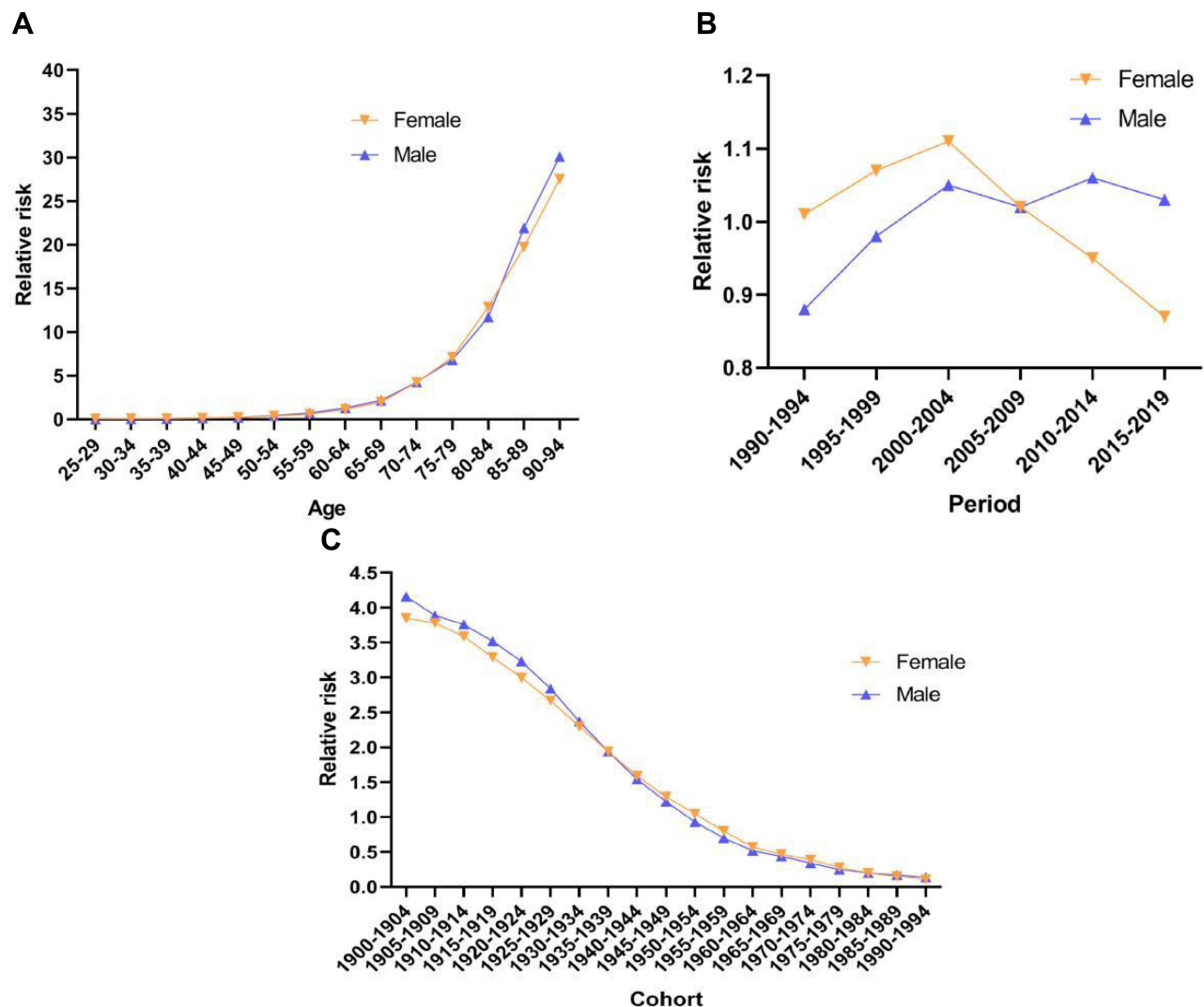
A

B

C

Figure 3 Chronic obstructive pulmonary disease mortality in China attributable to ambient PM$_{2.5}$ exposure relative risks due to (**A**) Age; (**B**) Period; and (**C**) Cohort.

Long-term exposure to PM$_{2.5}$ can result in reduced lung function and changes in airway inflammation.[22] A meta-analysis showed that exposure to PM$_{2.5}$ is a risk factor for developing COPD in Chinese population.[9] In the present study, we investigated the long-term trends in COPD mortality attributable to ambient PM$_{2.5}$ exposure in China and studied the age, period, and cohort effects on COPD mortality attributable to ambient PM$_{2.5}$ exposure by using the APC model in both sexes. The findings of the present study could help to clarify the impact of PM$_{2.5}$ on COPD in Chinese population.

Our study showed that the ASMR and ASDR values were decreased in both sexes, but the number of deaths and DALYs numbers were increased. The aging of the Chinese population could be the cause of this. If a population grows more quickly than exposures do, the overall burden of disease may rise despite decreasing exposures to air pollution. Besides, older people are more likely to be affected by air pollution-related diseases, aging populations are likely to face a higher burden of disease.[23] Chinese populations are aging rapidly. According to the findings of the seventh Chinese population census, 264 million people aged 60 and over lived in China in 2020, making up 18.7% of the country's overall population.[24] Moreover, although the EAPC of DALYs and deaths was <0 from 1990 to 2019, which represented a downward trend, it will still bring a heavy burden on society. Because the burden of COPD death is likely to become more severe in the future, we need to place greater emphasis on the prevention of COPD.

Age, period, and cohort effects affect the risks of disease mortality in specific ways. The accumulation of exposure to risk factors has been proven to be related to the development of COPD in the elderly population.[25] Age effects on COPD

Table 2 Age–Period–Cohort (APC) Model Analysis Results of COPD Mortality Attributable to Ambient $PM_{2.5}$ Exposure in China Female, $P < 0.05$

Group	Coef	95% CI	P	RR
Age				
25–29	−2.99	(−3.02,−2.96)	0.000	0.05
30–34	−2.57	(−2.6,−2.55)	0.000	0.08
35–39	−2.42	(−2.44,−2.4)	0.000	0.09
40–44	−2	(−2.01,−1.98)	0.000	0.14
45–49	−1.54	(−1.56,−1.53)	0.000	0.21
50–54	−0.99	(−1,−0.98)	0.000	0.37
55–59	−0.55	(−0.56,−0.54)	0.000	0.58
60–64	0.12	(0.11,0.13)	0.000	1.13
65–69	0.68	(0.68,0.69)	0.000	1.98
70–74	1.44	(1.44,1.45)	0.000	4.23
75–79	1.96	(1.95,1.97)	0.000	7.1
80–84	2.55	(2.55,2.56)	0.000	12.87
85–89	2.98	(2.97,2.99)	0.000	19.74
90–94	3.32	(3.31,3.33)	0.000	27.52
Period				
1990–1994	0.01	(0,0.01)	0.051	1.01
1995–1999	0.07	(0.06,0.07)	0.000	1.07
2000–2004	0.1	(0.1,0.1)	0.000	1.11
2005–2009	0.02	(0.02,0.02)	0.000	1.02
2010–2014	−0.05	(−0.05,−0.04)	0.000	0.95
2015–2019	−0.14	(−0.15,−0.14)	0.000	0.87
Cohort				
1900–1904	1.35	(1.33,1.37)	0.000	3.85
1905–1909	1.33	(1.32,1.34)	0.000	3.78
1910–1914	1.28	(1.27,1.29)	0.000	3.59
1915–1919	1.19	(1.18,1.2)	0.000	3.29
1920–1924	1.1	(1.09,1.11)	0.000	3
1925–1929	0.98	(0.97,0.99)	0.000	2.67
1930–1934	0.83	(0.82,0.84)	0.000	2.3
1935–1939	0.66	(0.65,0.67)	0.000	1.94
1940–1944	0.46	(0.45,0.47)	0.000	1.59
1945–1949	0.26	(0.24,0.27)	0.000	1.29
1950–1954	0.05	(0.03,0.06)	0.000	1.05
1955–1959	−0.23	(−0.25,−0.21)	0.000	0.8
1960–1964	−0.56	(−0.58,−0.54)	0.000	0.57
1965–1969	−0.74	(−0.77,−0.72)	0.000	0.47
1970–1974	−0.95	(−0.98,−0.93)	0.000	0.39
1975–1979	−1.27	(−1.3,−1.23)	0.000	0.28
1980–1984	−1.62	(−1.68,−1.57)	0.000	0.2
1985–1989	−1.92	(−2,−1.85)	0.000	0.15
1990–1994	−2.19	(−2.33,−2.04)	0.000	0.11
AIC	24.12			
BIC	1462.74			

Abbreviations: COPD, chronic obstructive pulmonary disease; RR, relative risk; RR, exp (coef.).

mortality attributable to ambient $PM_{2.5}$ exposure showed that the 60- to 64-year-older age group is the risk group with an RR > 1, and this group is growing exponentially, which may be related to the decline in immunity in the elderly population; hence, we should focus on the effects of $PM_{2.5}$ on the elderly population.

Period effects are often influenced by a complicated set of environmental factors and historical events. China needs to pay high attention to reducing outdoor and indoor air pollution.[8] Various measures have been implemented for reducing $PM_{2.5}$, including electrostatic precipitators and the use of fabric filters in large factories and more rigorous PM emission

Table 3 Age–Period–Cohort (APC) Model Analysis Results of COPD Mortality Attributable to Ambient PM$_{2.5}$ Exposure in China Male, P < 0.05

Group	Coef	CI	P	RR
Age				
25–29	−3.38	−3.41,−3.35	0.000	0.03
30–34	−2.89	−2.91,−2.87	0.000	0.06
35–39	−2.48	−2.5,−2.46	0.000	0.08
40–44	−1.9	−1.92,−1.89	0.000	0.15
45–49	−1.5	−1.51,−1.49	0.000	0.22
50–54	−0.86	−0.87,−0.85	0.000	0.42
55–59	−0.34	−0.35,−0.33	0.000	0.71
60–64	0.26	0.25,0.27	0.000	1.3
65–69	0.77	0.76,0.77	0.000	2.16
70–74	1.45	1.45,1.46	0.000	4.27
75–79	1.92	1.91,1.92	0.000	6.81
80–84	2.46	2.46,2.47	0.000	11.72
85–89	3.09	3.08,3.09	0.000	21.91
90–94	3.4	3.4,3.41	0.000	30.09
Period				
1990–1994	−0.13	−0.14,−0.13	0.000	0.88
1995–1999	−0.02	−0.02,−0.02	0.000	0.98
2000–2004	0.05	0.04,0.05	0.000	1.05
2005–2009	0.02	0.01,0.02	0.000	1.02
2010–2014	0.06	0.06,0.06	0.000	1.06
2015–2019	0.03	0.03,0.04	0.000	1.03
Cohort				
1900–1904	1.43	1.41,1.45	0.000	4.16
1905–1909	1.36	1.35,1.37	0.000	3.89
1910–1914	1.33	1.32,1.33	0.000	3.76
1915–1919	1.26	1.25,1.27	0.000	3.52
1920–1924	1.17	1.17,1.18	0.000	3.23
1925–1929	1.05	1.04,1.05	0.000	2.84
1930–1934	0.86	0.86,0.87	0.000	2.37
1935–1939	0.66	0.65,0.67	0.000	1.94
1940–1944	0.43	0.43,0.44	0.000	1.54
1945–1949	0.2	0.19,0.21	0.000	1.22
1950–1954	−0.07	−0.08,−0.06	0.000	0.93
1955–1959	−0.35	−0.37,−0.34	0.000	0.7
1960–1964	−0.65	−0.67,−0.64	0.000	0.52
1965–1969	−0.83	−0.85,−0.82	0.000	0.44
1970–1974	−1.07	−1.09,−1.05	0.000	0.34
1975–1979	−1.37	−1.4,−1.34	0.000	0.25
1980–1984	−1.61	−1.66,−1.57	0.000	0.2
1985–1989	−1.78	−1.84,−1.73	0.000	0.17
1990–1994	−2	−2.11,−1.89	0.000	0.14
AIC	38.55			
BIC	1983.51			

Abbreviations: COPD, chronic obstructive pulmonary disease; RR, relative risk; RR, exp (coef.).

standards for power plants.[26] Air pollution has decreased in the last two decades, which has effectively reduced COPD mortality in China.[27] Additionally, more accessible health services and improvements in medical technology have contributed to decreased period RR of COPD mortality in China.[28] In contrast, because of the industrialization process and China's rapid economic development, PM$_{2.5}$ has shown a significant upward trend due to the increase in the number of motor vehicles.[29] Our study found that the trend among females was increased in the 1990−2004 periods and began to decrease, but no significant decrease in trends was observed in males. There may be the following reasons: One, male sex

is a potential risk factor for COPD, which was also confirmed by a previous study.[9] Two, smoking is another risk factor for COPD.[30] As a result of signing the WHO the Framework Convention on Tobacco Control in 2003, China has issued a number of national and local tobacco control laws and regulations.[31] There is a 52.9% prevalence of smoking among male in China, whereas only 2.4% of adult female smoke.[32,33]

In the present study, the 1900−1954 birth cohort in females and the 1900−1949 birth cohort in males were the risk groups with an RR > 1 in mortality; the high risk was mainly caused by the Liberation War accompanied with an underdeveloped economy and poor nutrition. Better awareness of COPD-related knowledge and nutrition may play an important role in reducing COPD mortality.[34]

The present study had some limitations. First, GBD 2019 could adjusting collection and evaluation methods and its data sources, improve its data quality and collect missing data, but eliminate bias could always affect the accuracy of the results. Second, the APC model considered the effects of age, period, and cohort, without further analysis of other risk factors.

Conclusion

The number of deaths and DALYs of COPD attributable to ambient $PM_{2.5}$ exposure are heavy health burden in China, and the effect is particularly severe for those over 60 years of age. In the future, it is necessary to implement public policies and interventions to reduce the impact of $PM_{2.5}$ in order to achieve the goal of reducing the burden of COPD in China.

Data Sharing Statement

The datasets generated and/or analysed during the current study are available in the Global Health Data Exchange (GHDx) repository [http://ghdx.healthdata.org/gbd-results-tool].

Ethics Statement

This study was approved by the Ethics Committee of the Seventh Affiliated Hospital, Sun Yat-sen University in line with the Declaration of Helsinki (KY-2022-089-01), as a result of the secondary data analysis in this study, the review board waived informed consent. Additionally, this article does not contain any personal information about patients. All authors are in agreement with the manuscript.

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Disclosure

The authors report no conflicts of interest in this work.

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