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Deaths and disability-adjusted life years burden attributed to air pollution in China, 1990–2019: Results from the global burden of disease study 2019

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Background: The impact of deaths and disability-adjusted life years (DALYs) caused by air pollution in China has not been well elucidated. We aimed to analyze the association of air pollution with deaths and DALYs in the Chinese population.

Methods: We extracted data on burden due to deaths and disability-adjusted life years attributed to air pollution in the previous 30 years in China from the Global Burden of Disease (GBD) study 2019 and performed a comprehensive analysis and summary.

Results: 1.85 (95% UI: 1.57–2.17) million Chinese people lost their lives as a result of air pollution in 2019, a slight decrease from 1990. In 2019, the disability-adjusted life years (DALYs) caused by air pollution in China was 42.51 (95% UI: 36.34–49.48) million, a 30.2% decrease from 1990. From 1990 to 2019, both age-standardized death rate (ASDR) and age-standardized DALYs due to air pollution in China showed a significant year-on-year downward trend. Air pollution–related deaths and DALYs occurred mostly in people over the age of 50 years. Stroke, ischemic heart disease, and chronic obstructive pulmonary disease were attributed the maximum death burden due to air pollution in China in 2019.

Conclusion: Over the past 30 years, air pollution has brought a heavy disease burden to China, and in the future, joint efforts are required to improve the air quality.

KEYWORDS

air pollution, China, DALYs, GBD 2019, global burden of disease study

Introduction

Air pollution is one of the most severe environmental issues that threatens public health all around the world (Landrigan et al., 2018). It is well known that air pollution is associated with premature death and diseases (Lelieveld et al., 2015). Air pollution increases the risk of mortality from respiratory diseases such as chronic obstructive pulmonary disease, pneumonia, and asthma (Garshick, 2014; Chen et al., 2017; Pirozzi et al., 2018; Liu Y et al., 2019). Air pollution is also associated with an increased number of hospital visits for allergic rhinitis, asthma, and IgE-mediated allergy (Villeneuve et al., 2007; Hu et al., 2020; Hou et al., 2021). Furthermore, air pollution exposure increases the risk of young children being hospitalized for respiratory diseases (Huang et al., 2022), which lead to increased airway obstruction in adolescence (Milanzi et al., 2018).

The World Health Organization (WHO) reported that air pollution kills an estimated 7 million people every year globally (World Health Organization, 2022). Recent data have shown that all of the global population (99%) breathe air that exceeds WHO guideline limits and contain high levels of pollutants (World Health Organization, 2022). Due to the tremendous increase in its energy consumption and to emissions of air pollutants as a result of the extraordinary economic and industrial developments, China encounters serious air pollution problems that result in health problems (Watts, 2005; Guan et al., 2009). According to a 2005 report, a third of its urban residents are exposed to harmful polluted air, and more than 400,000 people die prematurely every year because of air pollution in China (Watts, 2005). The air quality of most regions in China has improved following the release and implementation of the Air Pollution Prevention and Control Action Plan in 2013 (The State Council of the People's Republic of China, 2013; Guo et al., 2017). However, research on the disease burden and changing trends in the past decades caused by air pollution in China is lacking.

The aim of the present study is to better understand the scale of harm caused by air pollution in China. For this purpose, we analyzed air pollution–attributable disease burden in China, based on the data on deaths and disability-adjusted life years (DALYs) from GBD 2019. We also investigate the different kinds of disease burden caused by the different kinds of air pollution.

Methods

Study data

Data on deaths, DALYs, and estimated annual percentage change (EAPC) as a consequence of air pollution in China were derived from an online data source tool, the Global Health Data Exchange (GHDx) query tool (http://ghdx.healthdata.org/gbd-results-tool), which is a global collaboration that uses various kinds of available epidemiological data to provide a comparative assessment of health loss from 369 diseases and different health risks across 204 countries and territories (GBD 2019 Diseases and Injuries Collaborators, 2020). The details about the study design and methods of GBD studies have been extensively described in the existing GBD literature (Global Burden of Diseases, 2016; GBD 2019 Risk Factors Collaborators, 2020).

Data analysis

Data from the literature reviews and national surveys were used by GBD collaboration to estimate the non-death burden due to air pollution. Bayesian meta-regression with DisMod-MR 2.1, which is a tool evaluating the epidemiology of a disease, was then used to estimate the incidence and prevalence of different diseases by location, year, sex, and age in all the sources. Death burden attributed to air pollution was analyzed using vital registration and surveillance data from the cause-of-death database. The deaths were distributed to different causes according to the ICD code mappings (Global Burden of Diseases, 2016; GBD 2019 Diseases and Injuries Collaborators, 2020; GBD 2019 Risk Factors Collaborators, 2020).

A secondary descriptive analysis was conducted with regard to the burden of deaths and DALYs due to air pollution in China from 1990 to 2019, and the findings were investigated further. The disease burden for both genders and different kinds of air pollution were also compared. The uncertainty intervals (UIs) were defined as the 2.5th and 97.5th values of the posterior distributions as previously descripted (Barendregt et al., 2003; Ferrari et al., 2013).

Results

Deaths and disability-adjusted life years attributable to air pollution in China

The number of deaths due to air pollution in China was 1.90 (95% UI: 1.59–2.19) million in 1990 and 1.85 (95% UI: 1.57–2.17) million in 2019, which is a slight decrease of 2.6% as compared to 1990. There are certain differences between genders when comparing between 1990 and 2019. In 1990, air pollution killed 0.98 (95% UI: 0.80–1.16) million men as compared to 0.92 (95% UI: 0.74–1.08) million women. In 2019, air pollution killed 1.09 (95% UI: 0.87–1.34) million men, an increase since 1990, while the number of deaths was 0.76 (95% UI: 0.61–0.94) million for women, which is a moderate drop as compared to 1990 (Table 1).

DALYs represent the total health burden of a disease, which are the years of lives lost (YLLs) due to premature mortality and years of healthy lives lost due to disabilities (YLDs). In 2019, the DALYs caused by air pollution in China was 42.51 (95% UI:

TABLE 1 Deaths and DALYs attributable to air pollution in China in 1990 and 2019.

	Death cases (95% UI), million		EAPC (95% UI), %	DALYs (95% UI), million		EAPC (95% UI), %
	1990	2019		1990	2019	
Both	1.90 (1.59–2.19)	1.85 (1.57–2.17)	−0.03 (−0.21 to 0.21)	60.91 (51.58–69.88)	42.51 (36.34–49.48)	−0.30 (−0.43 to −0.13)
Male	0.98 (0.80–1.16)	1.09 (0.87–1.34)	0.11 (−0.15 to 0.43)	2.69 (27.03–38.16)	25.61 (14.09–20.06)	−0.22 (−0.39 to 0.00)
Female	0.92 (0.74–1.08)	0.76 (0.61–0.94)	−0.17 (−0.36 to 0.08)	8.21 (23.28–32.78)	42.51 (20.64–31.21)	−0.40 (−0.53 to −0.25)

DALYs, disability-adjusted life years; EAPC, estimated annual percentage change; UI, uncertainty interval. Results are rounded up to two decimal places.

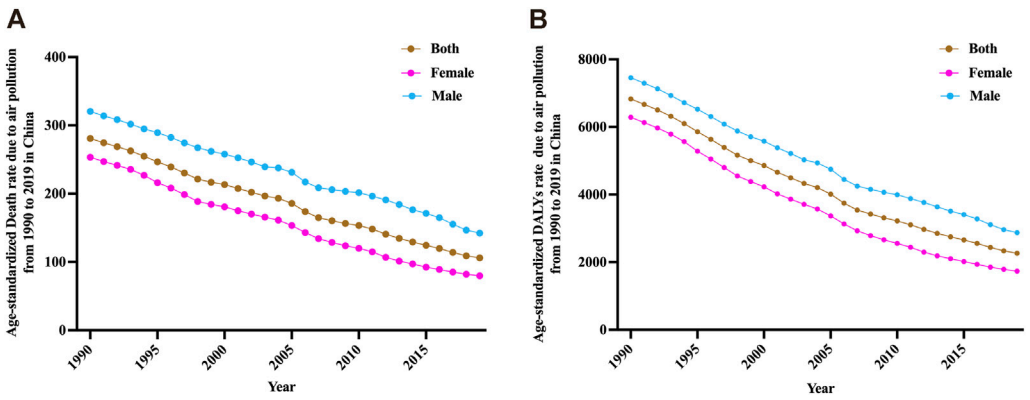

FIGURE 1
Age-standardized disease burden due to air pollution in China from 1990 to 2019. Age-standardized death **(A)** and DALYs **(B)** rate. DALYs, disability-adjusted life years.

36.34–49.48) million, a 30.2% decrease from 1990. In 2019, the DALYs of both males and females had decreased since 1990, with a larger decrease seen in females (Table 1).

From 1990 to 2019, both age-standardized death and DALYs rate caused by air pollution in China showed a significant year-on-year downward trend. The decline was almost the same across genders (Figure 1).

Disease burden of different age groups due to air pollution in China

We further analyzed the disease burden caused by air pollution in the different age groups in China. The age-standardized death rate and DALYs of four different age groups (0–14, 15–49, 50–69, and 70+ years) were analyzed.

From 1990 to 2019, air pollution has had a greater impact on the older age groups, especially those over the age of 70 years. More than 90% of the ASDR caused by air pollution occur among people over the age of 50 years (Figure 2).

In the past 30 years, the health burden of air pollution on the four different age groups has gradually declined, both the age-standardized DALYs rate and ASDR have decreased year after year (Figures 2A,B). However, from 1990 to 2019, the proportion of health burden caused by air pollution to people in the middle and older age groups (50–69 and 70+ years) has increased year after year among all the age groups (Figures 2C,D). In particular, the ASDR caused by air pollution is more prominent in the middle-aged and older age groups. These data indicate that the elderly are more vulnerable to air pollution.

Death due to different diseases caused by air pollution in China

Seven major diseases have been effected by air pollution and have led to death of patients in China. The ASDR of these diseases due to air pollution was ranked in 1990 as follows: chronic obstructive pulmonary disease, stroke, lower respiratory infections, ischemic heart disease, tracheal, bronchus and lung cancer, neonatal disorders, and diabetes mellitus. In 2019, the ranking order of these seven diseases had changed. The ASDR of the seven diseases caused by air pollution ranked from high to low was as follows: stroke, ischemic heart disease, chronic

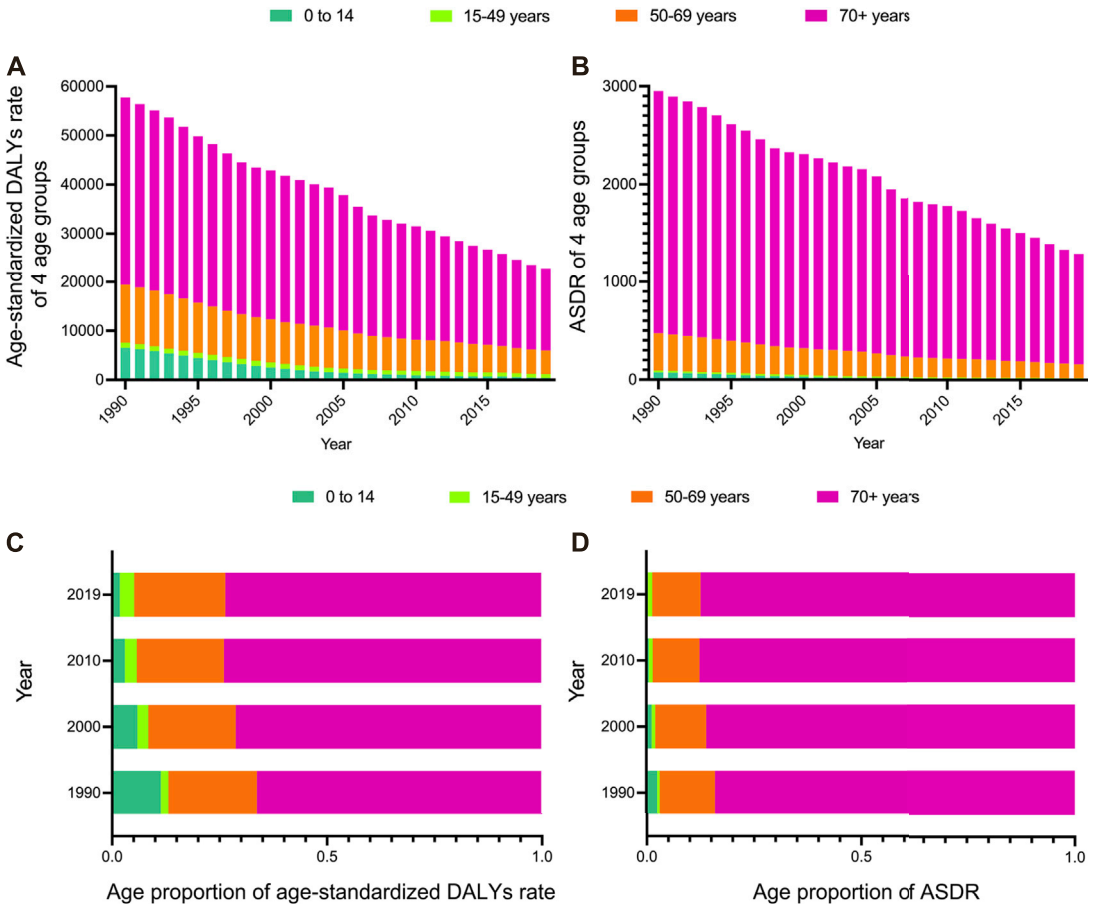

FIGURE 2
Age-standardized death and DALYs rate of different age groups due to air pollution in China from 1990 to 2019. **(A)** Age-standardized DALYs rate of four age groups from 1990 to 2019. **(B)** ASDR of four age groups from 1990 to 2019. **(C)** Four age proportions of age-standardized DALYs rate in 1990, 2000, 2010, and 2019. **(D)** Four age proportions of the ASDR in 1990, 2000, 2010, and 2019.

obstructive pulmonary disease, tracheal, bronchus, and lung cancer, lower respiratory infections, diabetes mellitus, neonatal disorders (Figure 3). In 2019, the ASDR of all the seven diseases caused by air pollution had decreased as compared to 1990. Lower respiratory infections, chronic obstructive pulmonary disease, neonatal disorders, and stroke had the most significant declines, by 87.98%, 80.62%, 77.89%, and 51.35%, respectively. However, the decline rates of diabetes mellitus; tracheal, bronchial, and lung cancer; and ischemic heart disease were slightly lower, declining by 0.46%, 3.5%, and 6.48%, respectively (Figure 3).

In the past 30 years, the ASDR of different types of diseases caused by air pollution in China had shown different trends. Before 2008, chronic obstructive pulmonary disease (COPD) was the leading cause of death due to air pollution. However, stroke rose to be the leading cause of death after 2008, while COPD declined to be the second leading cause. Lower respiratory infections were the third leading cause of air pollution–related deaths from 1990 to 1992, but their ASDR has continued to decline since then, while that of ischemic heart disease has ascended becoming the third leading cause of air pollution–related deaths. It is worth noting that the ASDR of ischemic heart disease; tracheal, bronchial, and lung cancers; and diabetes mellitus caused by air pollution has remained almost unchanged in the past 30 years, while that of the other four diseases has decreased significantly (Figure 4).

Rates and trends of age-standardized death and disability-adjusted life years caused by different kinds of air pollution in China

As a major type of air pollution, particulate matter pollution which includes ambient (outdoor) particulate

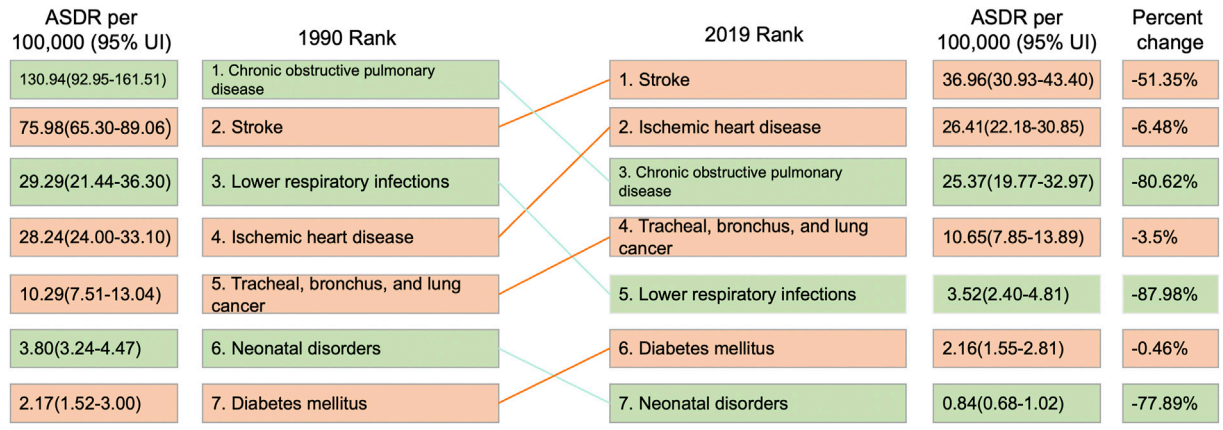

FIGURE 3
ASDR, ranking, and percent change of top seven diseases caused by air pollution in China in 1990 and 2019 (per 100,000). The ASDR of seven kinds of diseases caused by air pollution is ranked. Green block shows the diseases with decreased ranking and the orange block shows the diseases with increased ranking.

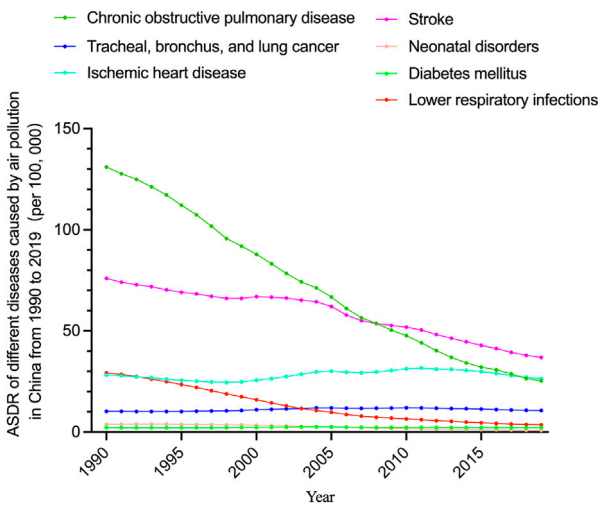

FIGURE 4
Trends of ASDR (per 100,000) of different diseases caused by air pollution from 1990 to 2019 in China.

matter pollution and household (indoor) air pollution from solid fuels led to the topmost health burden in China in both 1990 and 2019. In 1990, age-standardized DALYs rates caused by particulate matter pollution was 6707.77 (95% UI: 5652.42–7691.16)/100,000 and had decreased remarkably to 2214.48 (95% UI: 1908.94–2560.04)/100,000 in 2019, with an EAPC of −0.67% (95% UI: −0.73% to −0.59%). In 1990, the ASDR caused by particulate matter pollution was 272.71 (95% UI: 227.33–317.08)/100,000, and it declined markedly to 102.01 (95% UI: 86.97–119.37)/100,000 in 2019 (Table 2).

Three subtypes of air pollution were included in the GBD 2019 database: ambient ozone pollution, ambient particulate matter pollution, and household air pollution from solid fuels. Ambient particulate matter pollution and household air pollution from solid fuels make up particulate matter pollution, which is caused by particles with an aerodynamic diameter less than 2.5 μm. Household air pollution exposure involves fine particulate matter that comes from burning fuels inside homes with limited ventilation.

The ASDR caused by household air pollution from solid fuels had been the largest among the three kinds of air pollution in 1990. However, in 2019, ambient particulate matter pollution led to the largest ASDR, and it was the only subtype of air pollution that drove an increase in the ASDR, with an EAPC of 0.05% (95% UI: −0.37% to 1.06%) (Table 2). The age-standardized DALYs rates caused by household air pollution from solid fuels were the largest in 1990 at 4891.23 (95% UI: 3392.98–6308.02)/100,000. However, it declined dramatically to 471.13 (95% UI: 249.37–789.01)/100,000 in 2019. In 2019, ambient particulate matter pollution caused the largest age-standardized DALYs rate among the three subtypes of air pollution, and the age-standardized DALYs rate was 1743.35 (95% UI: 1438.42–2035.93)/100,000 in 2019, with the smallest decline as compare to that in 1990 (Table 2).

From the perspective of trend in the past 30 years, age-standardized death and DALYs rate related to particulate matter pollution and household air pollution from solid fuels were dramatically decreased. Age-standardized death and DALYs rate caused by ambient ozone pollution has slightly shrunk. However, ambient particulate matter pollution has led to an increase in age-standardized death and DALYs rate (Figure 5). Before 2003, household air pollution from solid fuels accounted for the largest proportion of age-standardized

TABLE 2 Age-standardized death and DALYs rate and their EAPC due to different kinds of air pollution in China from 1990 to 2019.

	Age-standardized DALYs rate (95% UI), per 100,000		EAPC (95% UI), %	ASDR (95% UI), per 100,000		EAPC (95% UI), %
	1990	2019		1990	2019	
Air pollution	6827.99 (5761.12–7795.08)	2265.40 (1949.97–2614.84)	−0.67 (−0.73 to −0.59)	280.80 (235.78–323.85)	105.92 (90.23–124.03)	−0.62 (−0.69 to −0.53)
Particulate matter pollution	6707.77 (5652.42–7691.16)	2214.48 (1908.94–2560.04)	−0.67 (−0.73 to −0.59)	272.71 (227.33–317.08)	102.01 (86.97–119.37)	−0.63 (−0.69 to −0.53)
Ambient ozone pollution	280.56 (120.49–451.97)	77.14 (35.34–124.93)	−0.73 (−0.78 to −0.54)	18.85 (8.22–30.36)	5.91 (2.73–9.65)	−0.69 (−0.74 to −0.50)
Ambient particulate matter pollution	1816.53 (884.75–2993.10)	1743.35 (1438.42–2035.93)	−0.04 (−0.43 to 0.90)	77.15 (38.47–126.56)	81.28 (67.18–96.13)	0.05 (−0.37 to 1.06)
Household air pollution from solid fuels	4891.23 (3392.98–6308.02)	471.13 (249.37–789.01)	−0.90 (−0.95 to −0.84)	195.56 (133.63–258.34)	20.73 (10.49–35.26)	−0.89 (−0.94 to −0.83)

DALYs, disability-adjusted life years; EAPC, estimated annual percentage change; UI, uncertainty interval. Results are rounded up to two decimal places.

death and DALYs rate among the three types of air pollution (ambient particulate matter pollution, ambient ozone pollution, and household air pollution from solid fuels), but after 2003, ambient particulate matter pollution ranked first. This may be caused by many factors such as changes in human lifestyles, changes in industrial production, and changes in climatic conditions and environmental protection.

Discussion

Air pollution is a global public environmental problem, which poses a major threat to public health. The negative health effects of air quality are a particular concern for sensitive populations, such as those with heart and lung disease, the elderly, and the children (Wang et al., 2022). Studies have shown that improving air quality has a positive effect on improving people's health (Broome et al., 2015; Yang and Zhang, 2018). In 2013, China passed legislation to further strengthen environmental protection and improve air quality as an important measure, and it has achieved positive results (Huang et al., 2018; Maji et al., 2020).

From the data of GBD 2019, we have concluded that air pollution creates a huge health burden in China. Around 1.85 (95% UI: 1.57–2.17) million Chinese people had lost their lives as a result of air pollution in 2019, a slight decrease from 1990. There is abundant evidence that air pollution not only brings direct harm to human health, for example, air pollution exposure directly increases the hospitalization rate (Gu et al., 2020), but also brings health damage and increases death (Carvalho, 2019; Verhoeven et al., 2021; Zhao et al., 2021). At the same time, air pollution also affects human activities. For example, air pollution limits human outdoor activities and physical exercise (Hu et al., 2017; Tainio et al., 2021). In addition, air pollution also has a direct or indirect impact on human economic activities and social development, thus further affecting human health (Husain Tahir et al., 2021). Air pollution causes significantly more deaths in men than in women and in the elderly than the youth. It is possible that men are more likely to work outdoors and are therefore more vulnerable to the health damage caused by air pollution. Furthermore, air pollution is the main risk factor of human chronic respiratory and cardiovascular diseases, and these diseases are more likely to occur in men and in the elderly population (Sierra-Vargas and Teran, 2012; Liu S et al., 2019; Rajak and Chattopadhyay, 2020).

Thanks to the improvement in air quality and advancement in medical care in China, the age-standardized death and DALYs rate caused by air pollution have decreased significantly in the past 30 years. Air pollution had led to 42.51 (95% UI: 36.34–49.48) million DALYs in 2019 in China, a 30.2% decrease from 1990. Air pollution can be prevented and ameliorated despite its enormous negative impact on human health. Reducing pollution from the source can have a rapid and

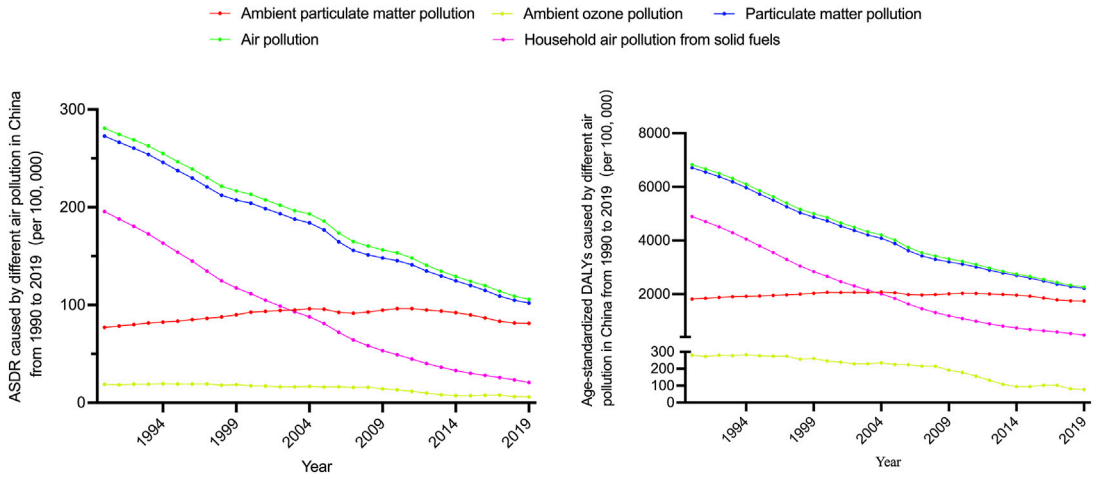

FIGURE 5
Age-standardized death and DALYs rate (per 100,000) caused by different kinds of air pollution in China from 1990 to 2019.

significant impact on health (Schraufnagel et al., 2019). In the past few decades, through government legislation, enterprises, and public participation, China's air quality has improved to a certain extent, thus improving people's health (Zeng et al., 2019; Zou et al., 2019). But China's air pollution is still at a high level, and it is also one of the most polluted countries in the world (World Health Organization, 2016). Therefore, China still urgently needs to work on cleaner air and better human health in the future.

Our research reveals that air pollution mainly provoked harm in seven kinds of diseases, that is, stroke, ischemic heart disease, chronic obstructive pulmonary disease; tracheal, bronchial, and lung cancers; lower respiratory infections; diabetes mellitus; and neonatal disorders. The ASDR caused by chronic obstructive pulmonary disease due to air pollution ranked the first in 1990, but it shifted to stroke in 2019. This indicates that in China, the damage caused by air pollution with regard to the cardiovascular system exceeds that caused to the respiratory system. This may be the reason for the aging of the population and lifestyle changes in China (Moran et al., 2008).

Particulate matter pollution is the largest source of air pollution in China and mainly includes pollutants from fossil fuel consumption, environmental particulate matter pollution, and environmental ozone pollution. These pollutants are mainly related to human lifestyle and industrial production. In the past 30 years, the sources of air pollution have also changed greatly, and its impact on human health is also changing. In recent years, people have paid more and more attention to the development of green, clean, and renewable energy. In China, the use of clean energy is already at the forefront of the world (Hannah Ritchie et al., 2020). However, due to China's large base of air pollution, huge population, and vast territory, improving air quality still requires a lot of work and investment in China.

Through a comprehensive analysis of the GBD 2019 data, this article systematically demonstrates the disease burden caused by air pollution in China over the past 30 years. But there are some limitations. First of all, we could not obtain data from different regions of China due to the limitation of the data sources. Due to China's vast territory and uneven development, and huge differences between regions, there may be large differences in air pollution in different geographical locations, but we have not been able to compare and analyze them. Secondly, the composition of air pollution is extraordinarily complex (Ghio et al., 2012), such as sulfur dioxide, nitrogen dioxide, ozone, nitric oxide etc., but we cannot obtain detailed data on the composition of air pollution in China for research. Finally, there are various sources of air pollution, such as factories, automobiles, home life, animal husbandry, etc., and these are also affected by climate, vegetation coverage, geographical environment, and other aspects, which our study fails to cover. Therefore, more detailed and comprehensive research is needed in the future to assess the health impact of air pollution in China and to analyze the sources and causes of specific air pollution in China to provide better evidence for air pollution prevention and control. Despite these limitations, our research extracts the latest GBD data to comprehensively and systematically analyze the disease and health burden caused by air pollution in China over the past 30 years. This may provide inspiration for the formulation of environmental policies and the health protection strategies for the vulnerable population in China.

Conclusion

Over the past 30 years, air pollution has brought an enormous disease burden to China, resulting in a large number of deaths and health losses. Air pollution mainly damages the respiratory and cardiovascular systems, and people over the age of 50 years are more vulnerable. Particulate matter pollution is the main culprit of health damage caused by air pollution. Although China has made great efforts to improve air quality in the past few decades, more efforts are needed to further control air pollution in the future. Especially for particulate pollution, a long-term mechanism should be established to effectively curb it. In addition, for the elderly, additional attention should be given to reduce health damage caused by air pollution.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

HG, BS, LC, YZ, and ZZ designed the study and wrote the manuscript. HG, LC, and HH collected and analyzed the data. YW, ZZ, YZ, and HH provided suggestions for study design and data analysis. BS and ZZ supervised the study. All authors have read and approved the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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