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Burden of Ischemic Heart Disease Attributable to Particulate Matter Pollution in China From 1990 to 2021 Based on the Global Burden of Disease Study 2021

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Abstract

Background:

The long-term temporal trends in the Ischemic Heart Disease (IHD) burden attributable to particulate matter (PM) pollution in China have not yet been systematically quantified.

Methods:

We assessed the age-standardized mortality rate (ASMR) and age-standardized disability-adjusted life-year rate (ASDR) of IHD attributable to PM pollution in China from 1990 to 2021 using data from the Global Burden of Disease Study 2021 and updated forecast data.

Results:

The ASMR of IHD attributable to PM pollution in China decreased slightly (Average Annual Percent Change [AAPC] = –0.38, 95% Uncertainty Interval [UI]: –0.89 to 0.12), while the ASDR declined significantly (AAPC = –0.77, 95% UI: –1.20 to –0.34, P = 0.001) from 1990-2021. Females experienced statistically significant declines in both ASMR and ASDR ($P < 0.01$), whereas reductions in males were not significant. Age-specific analyses revealed that among the elderly, males aged ≥75 years suffered a higher disease burden. The decomposition analysis indicated that population growth and aging were the primary drivers of the increase in absolute disease burden, whereas improvements in epidemiological factors partially offset this increase, with a pronounced offsetting effect in females. The forecasts for 2022–2036 suggest that ASMR and ASDR will increase in males, while these indicators are

expected to stabilize in females.

Conclusions:

Although the age-standardized rates of IHD attributable to PM pollution in China have improved, the absolute burden of the disease remains, with the burden on males projected to increase.

Keywords: Ischemic Heart Disease; Particulate matter pollution; Disability-adjusted life years (DALYs); Mortality

Contributions to the literature

This study provides updated national estimates of ischemic heart disease (IHD) burden attributable to particulate matter (PM) pollution in China, offering insights from 1990 to 2021.

It highlights significant gender and age disparities in the health impact of PM pollution, emphasizing the disproportionate burden on elderly males.

The study offers critical data on the demographic drivers—such as aging and population growth—that shape the long-term burden of IHD in China.

Projections for 2022–2036 underscore the ongoing public health challenges posed by PM pollution, stressing the need for continued policy interventions.

Introduction

Cardiovascular diseases (CVDs), particularly ischemic heart disease (IHD), remain the leading cause of mortality and disease burden worldwide [1, 2]. The disease burden of IHD has increased significantly over the past three decades, with accelerated urbanization, industrialization, and population aging in China [3]. Among the numerous modifiable risk factors for IHD, ambient particulate matter (PM) pollution—especially fine particles with aerodynamic diameters less than 2.5 μm ($PM_{2.5}$)—has been recognized as a critical environmental hazard contributing to the global and national burden of CVDs [4, 5]. $PM_{2.5}$ can penetrate deep into the alveoli, enter the circulatory system, and provoke systemic inflammation, oxidative stress, endothelial dysfunction, and atherogenesis, ultimately triggering acute cardiovascular events [6]. The estimates from the Global Burden of Disease (GBD) study indicated that ambient PM pollution was responsible for over 8.9 million deaths globally in 2019, with more than half of these deaths occurring in low- and middle-income countries, particularly in Asia [1, 7].

Several GBD-based studies have provided valuable insights into the burden of CVDs attributable to PM pollution across regions, populations, and age groups in the recent past [8-10]. However, most of these studies have focused on either global patterns or specific CVD subtypes (such as stroke), and relatively few have examined the long-term trends in IHD attributable to PM pollution, specifically within the Chinese population. Even fewer studies have analyzed temporal patterns across gender and age or disentangled the relative contributions of demographic shifts (e.g., aging and

population growth) and changes in exposure or risk [11, 12]. Previous studies have revealed widening disparities in PM-related cardiovascular burden by gender and age, particularly among older adults aged ≥70 years. [12] This suggests that traditional metrics, such as the age-standardized mortality rate (ASMR) and disability-adjusted life year rate (ASDR), must be interpreted in light of dynamic demographic and environmental transitions. The Eastern Mediterranean, the former Soviet republics, and North Africa have all reported persistent or worsening trends in PM-related IHD burden. This underscores the global nature of this problem and its policy implications [13-15].

To address these gaps, this study systematically assessed the temporal trends in the IHD burden attributable to PM pollution in China from 1990 to 2021 using GBD 2021 data. This study aims to provide a more comprehensive understanding of the long-term impact of PM pollution on IHD and project the future disease burden, highlighting the need for targeted policy interventions.

Methods

Data Sources

All data were obtained from the GBD 2021 via the Global Health Data Exchange (GHDx) platform (https://ghdx.healthdat.cgbd-results-tool) developed by the Institute for Health Metrics and Evaluation (IHME). The GBD provides standardized estimates for 204 countries and territories using a consistent analytical framework and incorporates multiple data sources, including national censuses, health surveys,

disease surveillance systems, hospital discharge records, and satellite-based environmental monitoring [2, 3].

Disease Burdens: Measures and Metrics

The primary health outcomes assessed in this study were the IHD-related deaths and Disability-adjusted life years（DALYs） attributable to the PM pollution. DALYs were computed as the sum of the years of life lost (YLLs) due to premature mortality and years lived with disability (YLDs) due to non-fatal health outcomes. Deaths and DALYs were presented as counts and age-standardized rates per 100,000 people, using the GBD world standard population.

Distribution and Trends of Disease Burden

The annual estimates of IHD-related deaths and DALYs attributable to PM pollution in China from 1990 to 2021 were extracted. Data were stratified by gender and five-year age groups. Age- and gender-specific trends were visualized to assess the patterns of burden distribution over time. Population-weighted exposure to ambient PM2.5 was calculated at the national level based on satellite-derived estimates, chemical transport models, and ground-level monitoring data [9, 10].

Joinpoint Regression Analysis

The temporal trends in age-standardized mortality rate (ASMR) and age-standardized DALY rate (ASDR) were analyzed using joinpoint regression models developed by

the U.S. National Cancer Institute's Joinpoint Regression Program (version 5.1.0.0). This method identifies inflection points (joinpoints) where a significant change in trend occurs and estimates the annual percent change (APC) and average annual percent change (AAPC) with the corresponding 95% confidence intervals [11]. The statistical significance was determined using the Monte Carlo permutation method ($P < 0.05$).

Decomposition Analysis

We applied a decomposition framework to separate the drivers of change in the absolute number of deaths and DALYs into three components: population growth, population aging, and epidemiological changes [12]. Following the method proposed by Gupta, the overall difference between two time points (1990 and 2021) was partitioned by computing counterfactuals: one assuming no population growth, another assuming no aging, and the other assuming no epidemiological change. This allowed the quantification of each factor's contribution to the total change in disease burden.

Prediction Analysis

To forecast trends in the IHD burden attributable to PM pollution from 2022 to 2036, ARIMA models were constructed separately for ASMR and ASDR by gender. The model selection was based on the autocorrelation function (ACF), partial autocorrelation function (PACF), and Akaike Information Criterion (AIC). Time series

were tested for stationarity using the augmented Dickey-Fuller (ADF) test. The forecast accuracy was assessed via residual diagnostics and comparisons with historical data. Forecast intervals were generated at a 95% confidence level were generated [2].

Statistical Software and Statistical Significance

All statistical analyses and visualizations were performed using the R software (version 4.5.0). Joinpoint regression was performed using the Joinpoint Regression Program described above. Time series forecasting was conducted using the "forecast" package in R. The statistical significance was defined as a two-tailed p-value of < 0.05.

Results

Temporal Trends of the IHD Burden Attributable to PM Pollution in China (1990–2021)

The temporal trends in the ASMR and ASDR of IHD attributable to PM pollution in China from 1990 to 2021 are presented in Table 1. Overall, the ASMR decreased slightly from 41.70 per 100,000 in 1990 to 38.55 per 100,000 in 2021, with an average annual percent change (AAPC) of -0.38 (95% UI: 0.89–0.12), although the difference was not statistically significant (P=0.135).

The ASDR showed a significant decline, decreasing from 778.10 per 100,000 to 640.36 per 100,000, with an AAPC of -0.77 (95% UI: -1.20– -0.34, P=0.001).

Notably, a clear gender disparity was observed : females experienced significant decreases in both ASMR (AAPC=-0.74; 95% UI: -1.27– -0.21, P=0.006) and ASDR (AAPC=-1.30; 95% UI: -1.73– -0.87, P<0.001), whereas changes among males were not statistically significant (P>0.05). These results demonstrated a gender-specific improvement in the burden of IHD related to PM pollution in China, with females benefiting more significantly from the overall reduction trend (Table 1).

Table 1 Trends in ASMR and ASDR for ischemic heart disease attributable to particulate matter pollution in China, from 1990 to 2021,along with the AAPC of these rates ,stratified by sex.

	1990	2021	AAPC(95% UI)	t	P
Male					
ASMR (per 100,000)	48.60	51.26	0.01 (-0.38 - 0.41)	0.0619	0.951
ASDR (per 100,000)	896.48	849.21	-0.31 (-0.76 - 0.14)	-1.3628	0.173
Female					
ASMR (per 100,000)	37.43	30.15	-0.74 (-1.27 - -0.21)	-2.7553	0.006
ASDR (per 100,000)	682.24	471.05	-1.30 (-1.73 - -0.87)	-5.8647	＜0.001
Both					
ASMR (per 100,000)	41.70	38.55	-0.38 (-0.89 - 0.12)	-1.4931	0.135
ASDR (per 100,000)	778.10	640.36	-0.77 (-1.20 - -0.34)	-3.482	＜0.001

ASMR age-standardized mortality rate,**ASDR** age-standardized DALY rate,**DALY** disability-adjusted life year,**UI** uncertainty interval

Age and Gender Distribution of the IHD Burden Attributable to PM Pollution in China (1990–2021)

The age- and gender-specific distributions of IHD deaths and DALYs attributable to PM pollution in China in 1990 and 2021, as shown in Figure 1. In 1990, the number of deaths (Figure 1A) was mainly concentrated in the population aged ⩾70 years, with a modest male predominance. By 2021 (Figure 1B), the number of deaths had increased substantially across nearly all older age groups, especially among males

aged 75–94 years, reflecting an aging population and an elevated disease burden in elderly males. The DALY patterns in 1990 (Figure 1C) indicated the highest burden among adults aged 60–79 years, with male predominance. In 2021 (Figure 1D), DALYs increased sharply in both genderes, particularly among males aged 70–89 years, exceeding 900,000 in several age groups. Across all time points and metrics, males consistently bore a heavier burden than females. Additionally, in both years, the absolute number of deaths and DALYs in the younger age groups (<55 years) were relatively low, and the proportional increase over time was small, indicating that the disease burden in the younger populations was relatively stable (Figure 1).

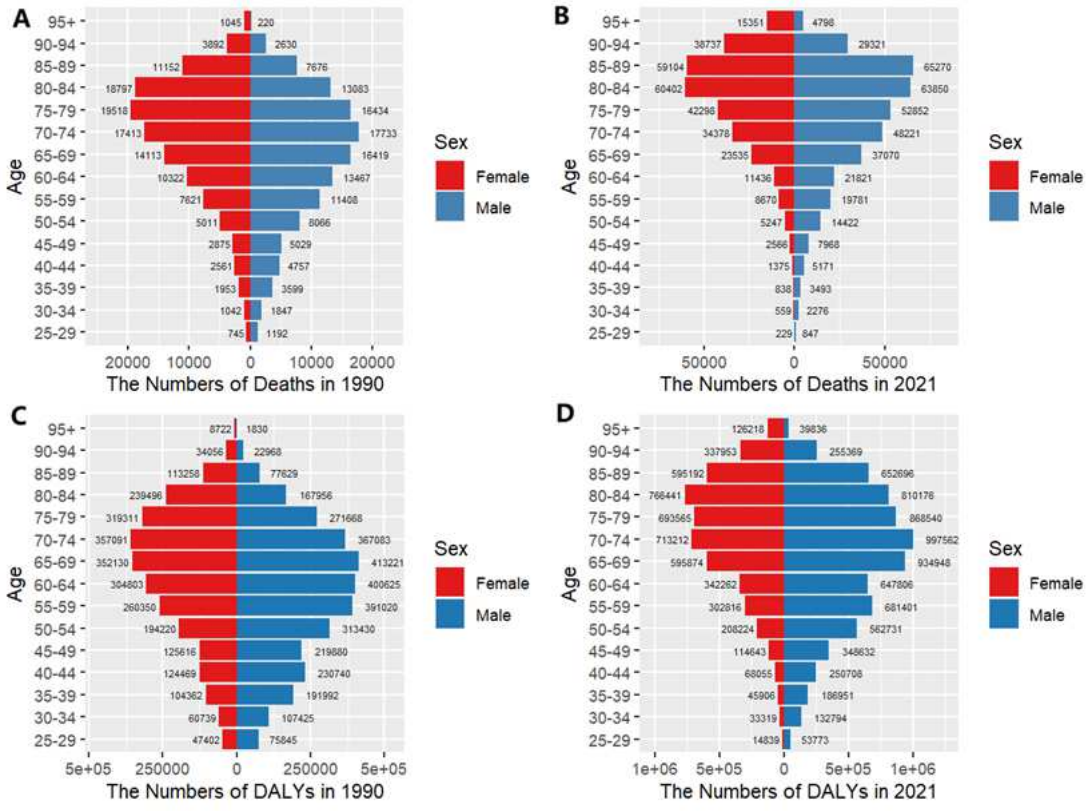


Figure 1. Age- and sex-specific distributions of ischemic heart disease deaths and DALYs attributable to particulate matter pollution in China in 1990 and 2021

Age-specific patterns of IHD burden attributable to PM pollution in China, 1990 and 2021

Figure 2 depicts the age-specific rates of IHD-related deaths (A–B) and DALYs (C–D) attributable to PM pollution by gender in China in 1990 and 2021. In both years, the mortality and DALY rates increased exponentially with age, with a minimal burden observed before 55 years of age. In 1990, male and female death rates rose steadily after age 65, peaking in those ≥90 years, with comparable trends between genderes (Figure 2A). By 2021, male death rates surpassed those of females across nearly all older age groups, with the largest gap observed in the ≥95 age group (Figure 2B). Similarly, DALY rates in 1990 (Figure 2C) rose progressively from age 60 and were highest in those ≥85, with overlapping patterns between genderes. In 2021 (Figure 2D), DALY rates in males significantly exceeded those of females among those aged ≥75 years, with a pronounced divergence in the ≥90 group. The rates increased between 1990 and 2021 substantially among males than females, particularly in the oldest cohorts. These findings indicate age- and gender-specific intensification of disease burden over time, particularly in elderly males (Figure 2).

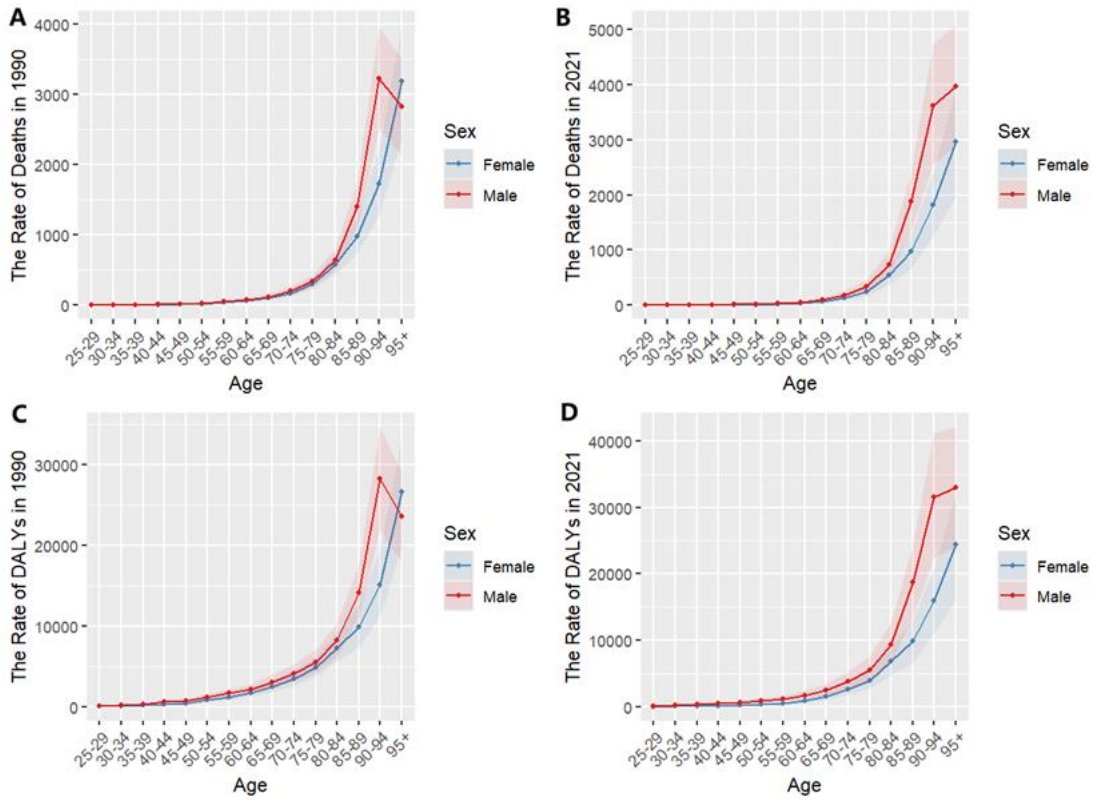


Figure 2. Age-specific rates of ischemic heart disease deaths and DALYs attributable to particulate matter pollution in China, by sex, in 1990 and 2021.

Joinpoint Analysis of Long-Term Trends of ASMR and ASDR of IHD Attributable to PM Pollution in China (1990–2021)

Joinpoint regression analysis revealed dynamic trends in ASMR and ASDR due to IHD attributable to PM pollution from 1990 to 2021 (Figure 3). For ASMR (Figure 3A), the total population experienced a stable period during 1990–1998 (APC = –0.26), followed by a significant increase from 1998 to 2004 (APC = 5.00, $P < 0.05$). From 2004 to 2007, the ASMR declined slightly (APC = –2.20), followed by a flat trend between 2007 and 2013 (APC = 0.39) and a significant downward trend from 2013 to 2021 (APC = –4.25, $P < 0.05$). The gender-stratified analyses showed that

males experienced a significant increase between 1999 and 2004 (APC = 5.58, $P < 0.05$), followed by a significant decrease from 2014 onward (APC = –4.41, $P < 0.05$). For females, the ASMR significantly increased from 1998 to 2004 (APC = 4.94, $P < 0.05$) and declined sharply after 2011 (APC = –3.83, $P < 0.05$).

Similarly, the ASDR (Figure 3B) of the total population decreased significantly from 1990 to 1998 (APC = –0.59, $P < 0.05$), increased significantly between 1998 and 2004 (APC = 3.76, $P < 0.05$), and declined sharply after 2013 (APC = –4.27, $P < 0.05$). Among males, the ASDR significantly increased from 1999 to 2004 (APC = 4.64, $P < 0.05$) and dropped markedly post-2013 (APC = –4.09, $P < 0.05$). Among females, ASDR rose significantly from 1998 to 2004 (APC = 3.60, $P < 0.05$), followed by a significant decline from 2013 to 2021 (APC = –4.53, $P < 0.05$).

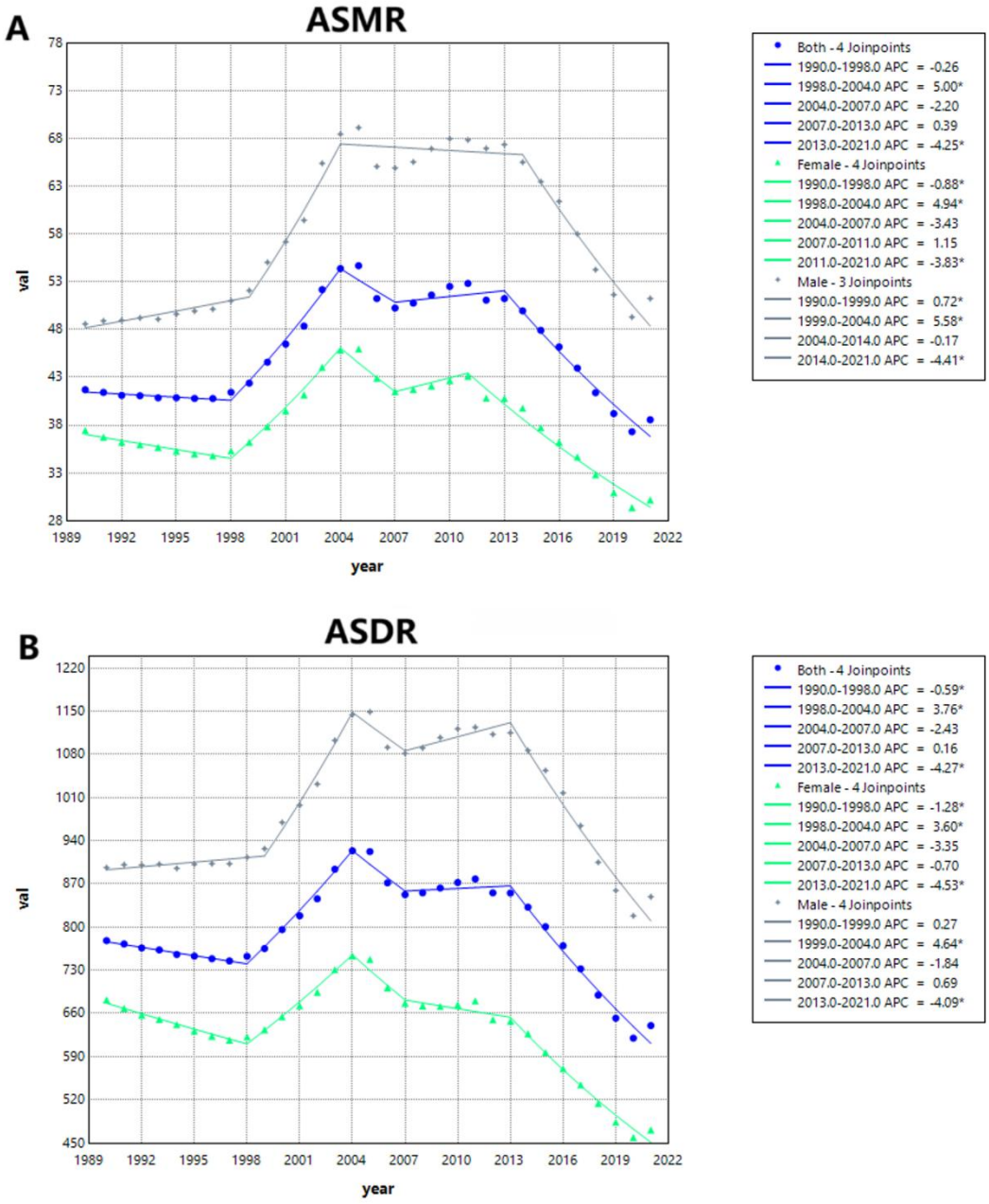


Figure 3. Temporal trends in ASMR and ASDR of ischemic heart disease attributable to particulate matter pollution in China, 1990–2021.

Decomposition of factors driving changes in deaths and DALYs of IHD attributable to PM pollution in China, 1990–2021

Figure 4 represents the decomposition analysis of the change in IHD burden attributable to PM pollution in China from 1990 to 2021. The analysis separates the contributions of population growth, population aging, and epidemiological changes to deaths (Figure 4A) and DALYs (Figure 4B). Among both genderes, population growth was the predominant contributor to the overall increase in IHD deaths and DALYs, followed by aging. However the, epidemiological changes had a negative contribution, indicating a partial reduction in the disease burden due to improved healthcare, prevention, or exposure reduction. When stratified by gender, population growth remained the largest contributor to the increased burden in both males and females, the relative contribution of aging was higher in females. In contrast, the offsetting effect of epidemiological changes was more pronounced in females than males, especially for DALYs. This suggests greater health improvements among women over the study period. Despite these counteracting effects, the total deaths and DALYs continued to increase, as demonstrated by the black dots representing the net change (Figure 4). These results provide a structured view of the demographic and epidemiological factors influencing the IHD burden related to PM pollution in China.

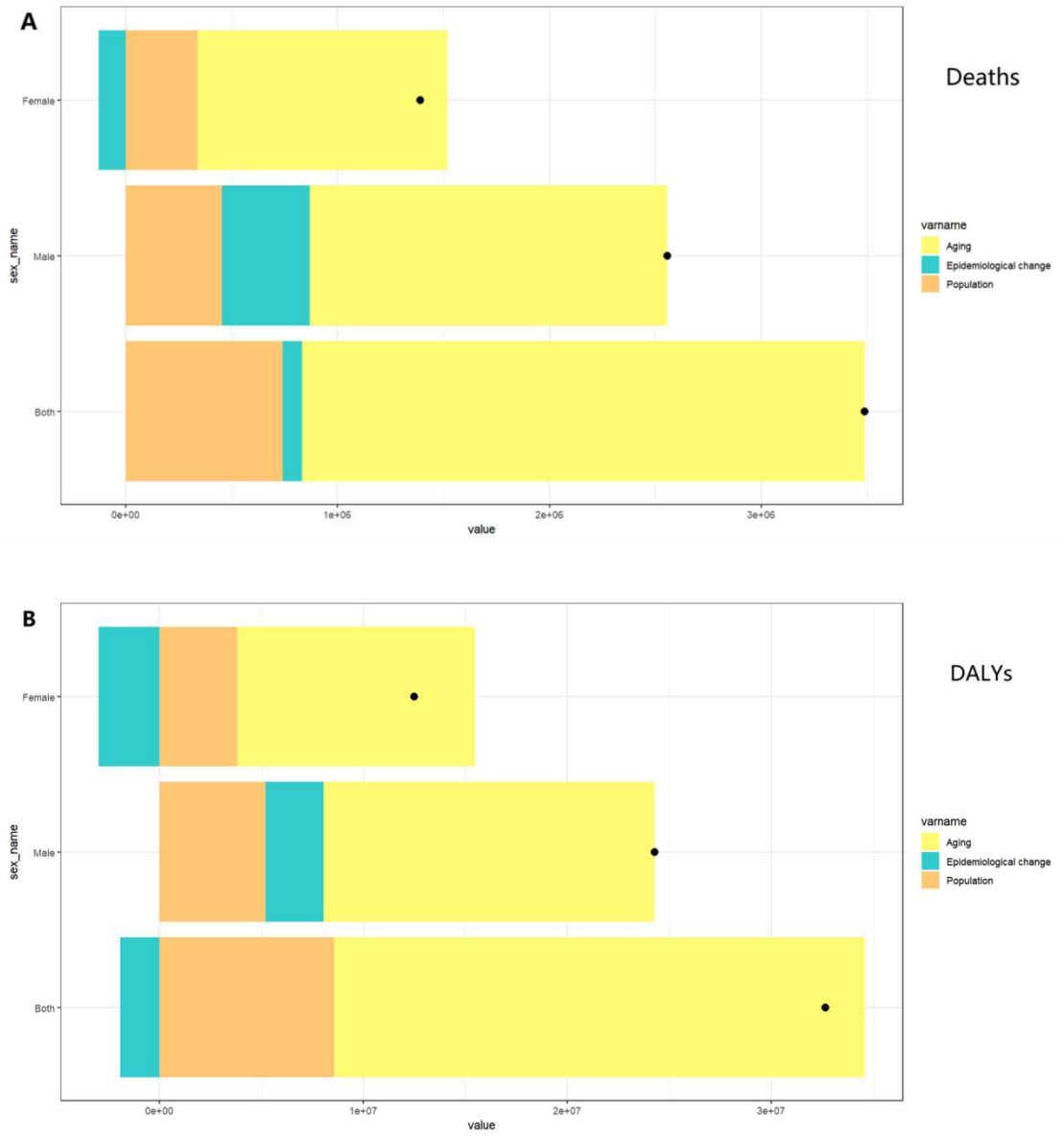


Figure 4. Decomposition of changes in deaths and DALYs of ischemic heart disease attributable to particulate matter pollution in China by aging, population growth, and epidemiological change.

Projected trends in the burden of IHD attributable to PM pollution in China, 2022–2036

Figure 5 presents the ARIMA-based forecasts for the ASDR and ASMR from IHD attributable to PM pollution in China between 2022 and 2036 stratified by gender. For

males, both ASDR and ASMR were projected to increase gradually over the forecast period (Figure 5A and 5C), suggesting a growing disease burden despite past stabilization. In contrast, among females, both ASDR and ASMR were predicted to remain stable or decline slightly, with the ASDR plateauing around 450 per 100,000 and the ASMR fluctuating around 30–35 per 100,000 (Figure 5B and 5D). The forecast intervals indicate greater uncertainty in male estimates, particularly after 2030. These projections suggest a diverging trend in disease burden between genderes, with males likely to face increased health impacts from PM-related IHD in the coming years, whereas the burden among females may remain relatively high. The results in Figure 5 highlight the potential evolution of the IHD burden under the current demographic and environmental conditions by 2036.

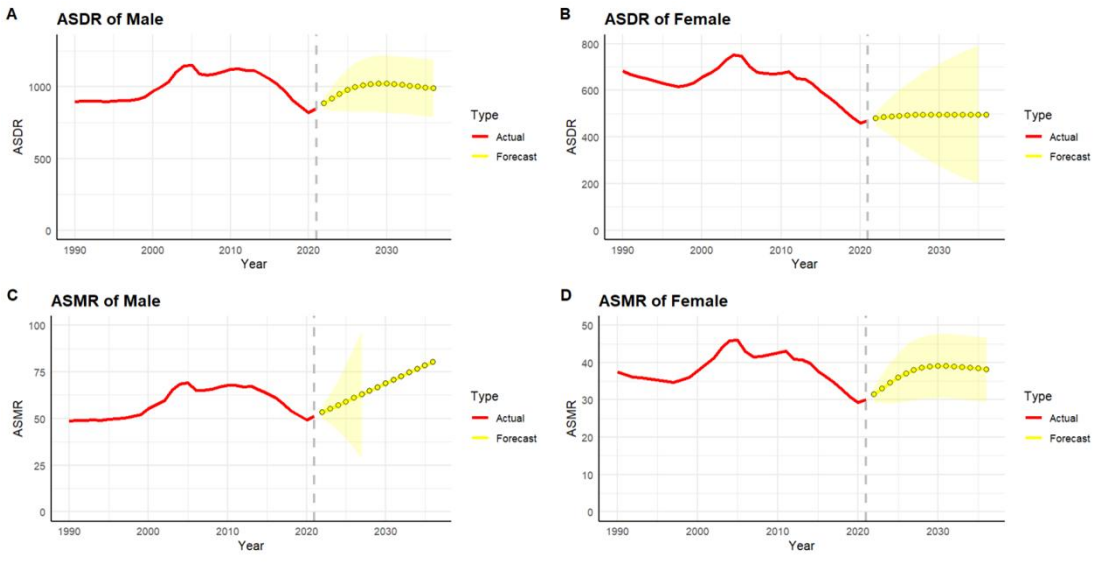


Figure 5. Forecast trends in ASDR and ASMR of ischemic heart disease attributable to particulate matter pollution in China by sex, 2022–2036.

Discussion

Principal findings

This study systematically assessed the burden of IHD attributable to PM pollution in China from 1990 to 2021 based the GBD Study 2021 data. Our findings indicate a modest overall decline in age-standardized mortality and DALY rates from IHD attributable to PM pollution over the past three decades, with significant reductions, particularly among females. However, decomposition analysis revealed that the gains from epidemiological improvements were largely offset by population growth and aging. Moreover, future projections suggest a continuous but gradual increase in the absolute IHD burden by 2036, underscoring persistent challenges. This study provides updated and comprehensive evidence on the historical, current, and projected burdens of PM-related IHD in China. It highlights the critical need for sustained air quality and cardiovascular health interventions.

Interpretations of mechanisms underlying these findings

$PM_{2.5}$ can penetrate deep into the alveoli and translocate into the bloodstream, triggering systemic inflammation, oxidative stress, endothelial dysfunction, autonomic imbalance, and prothrombotic states due to their small aerodynamic diameter and large surface area. These factors contribute to the progression of atherosclerosis and increase the risk of myocardial infarction [6, 16]. Long-term exposure has been associated with both incident and recurrent ischemic events, especially among susceptible populations, such as the elderly, those with pre-existing

316 cardiometabolic conditions, and individuals in low-resource environments [17, 18].

317 The significant gender differences observed, particularly the more pronounced
318 reductions in ASMR and ASDR among females, may reflect differential biological
319 susceptibilities and health behavior patterns. Estrogen has been shown to modulate
320 inflammatory and vascular responses to air pollution, potentially offering
321 cardiovascular protection in premenopausal women [19]. In contrast, higher baseline
322 risk factors among males, including increased smoking rates and occupational
323 exposure, may exacerbate vulnerability and dampen the effects of pollution control
324 policies. Additionally, the disproportionately higher burden among the elderly can be
325 attributed to age-related declines in immune and cardiovascular resilience,
326 compounded by prolonged cumulative exposure and comorbidities [12, 20].

327 The limited impact of recent epidemiological improvements on the total burden,
328 despite declining age-standardized rates, underscores the dominant role of
329 demographic transitions, particularly aging and urbanization. These factors not only
330 increase the size of the high-risk population but may also intensify exposure through
331 greater proximity to pollution sources in urban areas. Furthermore, policy actions
332 targeting ambient $PM_{2.5}$ and household air pollution have achieved measurable
333 reductions in exposure. Although the uneven implementation across provinces and
334 persistent indoor air pollution from solid fuel use continue to impede equitable health
335 gains [3, 8]. The integration of the biological, behavioral, and environmental
336 mechanisms helps explain both the observed trends and persistent disparities in the
337 IHD burden related to PM pollution.

Comparison with prior studies

This study presents updated and expanded insights into the temporal trends and demographic drivers of IHD attributable to PM pollution in China compared to prior research. Notably, our finding of a modest decline in ASMR and ASDR from 1990 to 2021 is broadly consistent with earlier national and global studies that reported similar downward trends in the standardized burden despite rising absolute numbers [2, 8]. For example, Zhao et al. projected a global decrease in ASMR from PM-related cardiovascular diseases, including IHD, particularly in high-income and East Asian countries. This aligns with our findings of statistically significant AAPC decline among the Chinese females. However, our study highlights that the reduction in males was not statistically significant, diverging from earlier projections that predicted uniform gains across genderes [1, 9]. This disparity may reflect persistent occupational exposure disparities, behavioral differences (e.g., smoking and alcohol consumption), and healthcare utilization gaps, which were not fully captured in earlier aggregate models.

In addition, our results diverge from those of regional or disease-specific analyses in certain aspects. For instance, Ma et al. [11] reported substantial declines in coronary heart disease mortality attributable to outdoor PM2.5, especially in urban areas, whereas our analysis of both ambient and household PM sources revealed modest improvements at the national level. This discrepancy may be attributed to methodological differences such as the inclusion of household air pollution and the broader IHD category, which encompasses both acute and chronic disease entities.

Similarly, while He et al. [12] focused on the burden among individuals aged 70 years and older and found rising rates in this subgroup, our findings confirm that demographic aging significantly offsets gains in younger cohorts, as demonstrated by the decomposition analysis.

The analysis also provided a more granular breakdown of demographic contributions to burden changes, thus extending the findings of previous studies. While earlier investigations, such as those by Yin et al. [21] and Burnett et al. [18] emphasized the dominant role of PM exposure itself, the decomposition analysis results suggest that population growth and aging together account for the majority of burden increases despite declining exposure-adjusted risk. This contrast underscores a shifting epidemiological landscape in which ambient exposure may be declining due to policy interventions but demographic pressures continue to amplify the absolute burden. The limited impact of household air pollution mitigation in rural or low-income regions may also explain why reductions in the overall PM-attributable burden have been slower than anticipated in recent decades.

Furthermore, our future burden projections using ARIMA modeling indicate continued increases in the absolute number of deaths and DALYs until 2036. This contrasts with some prior forecasts suggesting stabilization or decline beyond 2030 [10, 13]. This divergence may be due to differences in assumptions regarding policy implementation, pollution control trajectories, and demographic transition rates. Earlier GBD iterations may have underestimated the speed and scale of aging in the Chinese population. Additionally, our model is based on observed historical trends

without assuming future interventions, making it a conservative but realistic estimate of current trajectories.

Strengths and limitations

This study leveraged the most recent and comprehensive data from GBD 2021, enabling an accurate and updated evaluation of long-term trends in ischemic heart disease attributable to particulate matter pollution.

This study had some limitations. First, GBD 2021 estimates rely on limited data and model assumptions, especially in areas with sparse surveillance. Second, The ARIMA model assumes historical trends and cannot account for future policy or environmental changes. Third, Only PM was assessed, excluding other pollutants that may interact with it Finally, causal inferences are limited due to the observational nature of the GBD data, and findings should be interpreted with consideration of these methodological constraints.

Future directions

Future research should focus on enhancing the spatial and temporal resolutions of exposure assessments by integrating satellite data, local monitoring networks, and individual-level exposure modeling. To obtain a more thorough risk profile, additional air contaminants and their interactions with PM must be considered. Dynamic forecasting models that integrate policy, climate, and technological scenarios may increase the accuracy of long-term burden estimates. Furthermore, longitudinal cohort

studies with biomarker validation could assist in refining exposure-response functions and identifying vulnerable populations. Strengthening local disease surveillance and data transparency are critical for fine-tuning GBD estimates and driving public health policy precision.

Conclusion

While the age-standardized rates of mortality and DALYs declined modestly from 1990 to 2021, the absolute burden increased, primarily driven by population aging and growth. These findings underscore the need for continued enforcement of environmental policies and targeted cardiovascular prevention. This study adds new knowledge on how demographic transitions shape disease burden and provides timely estimates to aid health planning. Despite the limitations of data granularity and modeling assumptions, future research should prioritize higher-resolution exposure measures, multi-pollutant assessments, and prediction models that incorporate policy and demographic shifts. In the face of rapid societal and environmental changes, it is vital to strengthen data infrastructure and conduct individual-level exposure studies to guide effective and equitable public health interventions.

List of abbreviations

IHD: Ischemic Heart Disease

PM: Particulate Matter

$PM_{2.5}$: Fine Particulate Matter (aerodynamic diameter < 2.5 μm)

ASMR: Age-Standardized Mortality Rate

ASDR: Age-Standardized Disability-Adjusted Life Year Rate

DALY: Disability-Adjusted Life Year

YLL: Years of Life Lost

YLD: Years Lived with Disability

AAPC: Average Annual Percent Change

GBD: Global Burden of Disease

ARIMA: Auto-Regressive Integrated Moving Average

GHDx: Global Health Data Exchange

IHME: Institute for Health Metrics and Evaluation

Declarations

1 Ethics approval and consent to participate

Not applicable.

2 Clinical trial number

Not applicable.

3 Consent to Publish

All authors have read and approved the final manuscript. Written informed consent for publication was obtained from all participants included in the study. The consent covers the publication of the data and associated findings in a scientific journal.

4 Data Availability Statement

The datasets analysed during the current study are available in the Global Health Data Exchange (GHDx)[https://vizhub.healthdata.org/gbd-results/].

5 Conflict of interest:

Not applicable.

6 Funding

No funding.

7 Author Contributions

J.W. conceived the study, analyzed the data, and contributed to writing the manuscript.

Y.L. performed the statistical analysis and contributed to interpreting the results.

J.-B.L. contributed to data interpretation and reviewed the manuscript.

Y.Y. contributed to the writing and critical revision of the manuscript.

Y.Z. assisted with the data analysis and contributed to the manuscript review.

K.H. supervised the methodology and contributed to manuscript revisions.

X.-Y.Z. provided expertise in environmental factors and contributed to data interpretation.

W.G. provided overall supervision and contributed to the manuscript's final revision.

T.-H.T. contributed to the study design and manuscript revision.

All authors read and approved the final manuscript.

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Figure Legends

Figure 1. Age- and gender-specific distributions of IHD deaths and DALYs attributable to PM pollution in China in 1990 and 2021.

Figure 1 illustrates the numbers of IHD deaths (A-B) and DALYs (C-D) attributable to PM pollution in China by age and gender in 1990 and 2021. Panels A and B show an age shift in mortality toward older age groups over time, with higher counts in males. Panels C and D show a pronounced increase in DALYs among the elderly, particularly males aged 70–89, in 2021.

Figure 2. Age-specific rates of IHD deaths and DALYs attributable to PM pollution in China, by gender, in 1990 and 2021.

Figure 2 shows the age-specific rates of deaths (A-B) and DALYs (C-D) from IHD attributable to PM pollution by gender in China in 1990 and 2021. Mortality and DALY rates increased exponentially with age in both years. In 2021, males consistently exhibited higher rates than females, particularly in the ⩾85 age groups. Compared with 1990, both death and DALY rates rose more steeply in older males in 2021. Shaded areas represent 95% uncertainty intervals.

Figure 3. Temporal trends in ASMR and ASDR of IHD attributable to PM pollution in China, 1990–2021.

(A) ASMR and (B) ASDR for IHD attributable to PM pollution from 1990 to 2021, stratified by gender, based on Joinpoint regression analysis. Solid lines represent

observed trends for males, females, and both genderes, with inflection points identified. Annual percent change (APC) is reported, with statistically significant trends ($P < 0.05$) indicated by asterisks. The results reveal nonlinear, gender-specific trend patterns with multiple turning points.

Figure 4. Decomposition of changes in deaths and DALYs of IHD attributable to PM pollution in China by aging, population growth, and epidemiological change. Figure 4 presents the decomposition of total changes in deaths (A) and DALYs (B) from IHD attributable to PM pollution in China, by gender, from 1990 to 2021. The total change (black dots) is separated into contributions from population growth (yellow), population aging (orange), and epidemiological change (blue). Population growth was the largest driver of the increase in both deaths and DALYs across all groups. Epidemiological changes offset the increases, especially in females.

Figure 5. Forecast trends in ASDR and ASMR of IHD attributable to PM pollution in China by gender, 2022–2036.
Figure 5 presents the actual (1990-2021) and forecast (2022-2036) trends of ASDR (A-B) and ASMR (C-D) for IHD attributable to PM pollution in China, stratified by gender, based on ARIMA models. A steady upward trend in both ASMR and ASDR is projected for males, whereas rates in females are expected to plateau or decline slightly. The yellow shaded area indicates the 95% prediction interval for the forecast period.

Tables

Table 1. Trends in ASMR and ASDR for IHD attributable to PM pollution in China, from 1990 to 2021, along with the AAPC of these rates, stratified by gender.

	1990	2021	AAPC(95% UI)	t	P
Male					
ASMR (per 100,000)	48.60	51.26	0.01 (-0.38 - 0.41)	0.0619	0.951
ASDR (per 100,000)	896.48	849.21	-0.31 (-0.76 - 0.14)	-1.3628	0.173
Female					
ASMR (per 100,000)	37.43	30.15	-0.74 (-1.27 - -0.21)	-2.7553	0.006
ASDR (per 100,000)	682.24	471.05	-1.30 (-1.73 - -0.87)	-5.8647	＜0.001
Both					
ASMR (per 100,000)	41.70	38.55	-0.38 (-0.89 - 0.12)	-1.4931	0.135
ASDR (per 100,000)	778.10	640.36	-0.77 (-1.20 - -0.34)	-3.482	＜0.001

ASMR, age-standardized mortality rate; ASDR age-standardized DALY rate; DALY disability-adjusted life year; UI, uncertainty interval