Preplanned Studies

A Modelling Study on $PM_{2.5}$-Related Health Impacts from Climate Change and Air Pollution Emission Control — China, 2010s and 2040s

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Summary

What is already known about this topic?

Climate change and air pollution are two important environmental issues in China. It is important to investigate particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$)-related health impacts from climate change and air pollution emission control.

What is added by this report?

Deaths and years of life lost related to $PM_{2.5}$ would increase in climate change scenario, although emission control would outweigh the influence of climate change.

What are the implications for public health practice?

More targeted actions should be taken to meet challenges of exacerbated $PM_{2.5}$ pollutions and its health impacts related to climate change in the future.

Climate change and air pollution are two important environmental issues in China. The study aimed to model different scenarios to assess the health impacts related to ambient particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) from climate change and air pollution emission control in China. A regional meteorology-climate model was used to simulate the ambient $PM_{2.5}$ concentrations in China in the 2010s and the 2040s under different scenarios (climate change scenario, air pollution emission control scenario, and climate change and emission control scenario). Furthermore, changes in mortality and years of life lost (YLLs), an indicator which considers life expectancy at death, were adopted to estimate $PM_{2.5}$-related health impacts. The concentrations of $PM_{2.5}$ were estimated to slightly increase in climate change scenario but decrease in emission control scenario in 2040s. $PM_{2.5}$-related health impacts would increase in climate change scenario in the 2040s, although emission control would outweigh the influence of climate change. The findings suggest that more targets actions should be taken to confront challenges of exacerbated $PM_{2.5}$ pollutions and its health impacts attributable to climate change in the future.

As the biggest global health threat of the 21st century, tacking climate change could be the greatest global health opportunity (*1*–*2*). There are multiple linkages connecting climate change and air quality, and climate change is expected to degrade air quality (*3*). Considering $PM_{2.5}$ is one of the leading contributors to global disease burden (*4*), it is of great importance to predict future ambient $PM_{2.5}$ concentrations and its related health impacts by considering both the near-term changes in climate conditions and the changes in anthropogenic pollutant emissions in China on interdecadal timescales. Nevertheless, evidence investigating the health impacts attributable to ambient $PM_{2.5}$ from both climate change and air pollution emission control under different scenarios in China is still lacking.

In order to assess the combined effects of interdecadal climate change and anthropogenic emission reductions on ambient $PM_{2.5}$, the Flexible Global Ocean-Atmosphere-Land System Model, Grid-point Version 2 (FGOALS-g2) decadal climate prediction and a Multi-Resolution Emission Inventory for China (MEIC) were used to drive a Weather Research Forecast Model Coupled with Chemistry (WRF-Chem) model to simulate the ambient $PM_{2.5}$ concentrations in China during the 2010s and the 2040s in the national level and different districts under the Representative Concentration Pathway 4.5 (RCP4.5) scenario. The WRF-Chem model is a flexible and efficient atmospheric simulation model, the chemical module of this model mainly includes the emission, transport, photolysis, gaseous chemical reaction, deposition, aerosol dynamics, and chemical processes of air pollutants. It was used to simulate $PM_{2.5}$ concentrations in the 2010s, which were set as baseline; and $PM_{2.5}$ concentrations with only climate change and emission control, respectively, and under both scenarios in the 2040s in this study (*5*).

The burden attributable to $PM_{2.5}$ under the scenarios above for ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), and lung cancer was estimated using the integrated exposure–response functions (IER) for each cause of death, which have been used in a Global Burden of Disease study (*6*) and are based on studies of ambient air pollution, household air pollution, and second-hand smoke exposure and active smoking (*7*). Data of the annual average population size were collected from the China Statistical Yearbook, and the city-level proportions of different age groups were obtained from the 2010 census. Yearly mortality data in the mainland of China were obtained from the national death surveillance data, which originated from China CDC. The age-specific and cause-specific mortality rates were estimated based on the death surveillance points, and the proportions of cause-specific mortality in different districts and age groups were collected from the China Death Surveillance Data set. The deaths and YLLs attributable to ambient $PM_{2.5}$ were then calculated by applying the year-specific, location-specific, and age-specific population-attributable fractions to the number of deaths and YLLs (*8*). Monte Carlo simulations were used to calculate the 95% confidence interval of death burden of $PM_{2.5}$. Because the data used in the study were collected without any individual identifiers, the study was exempted from the Institutional Review Board of Peking University Health Science Center in Beijing.

The national $PM_{2.5}$ concentrations in the 2010s and the changes of its predicted concentrations under different scenarios in the 2040s in China are presented in Figure 1. Climate change scenarios increased the $PM_{2.5}$ concentrations in most regions, while emission control scenarios would decrease the $PM_{2.5}$ concentrations at the national level. With the impact of both climate change and emission control, the

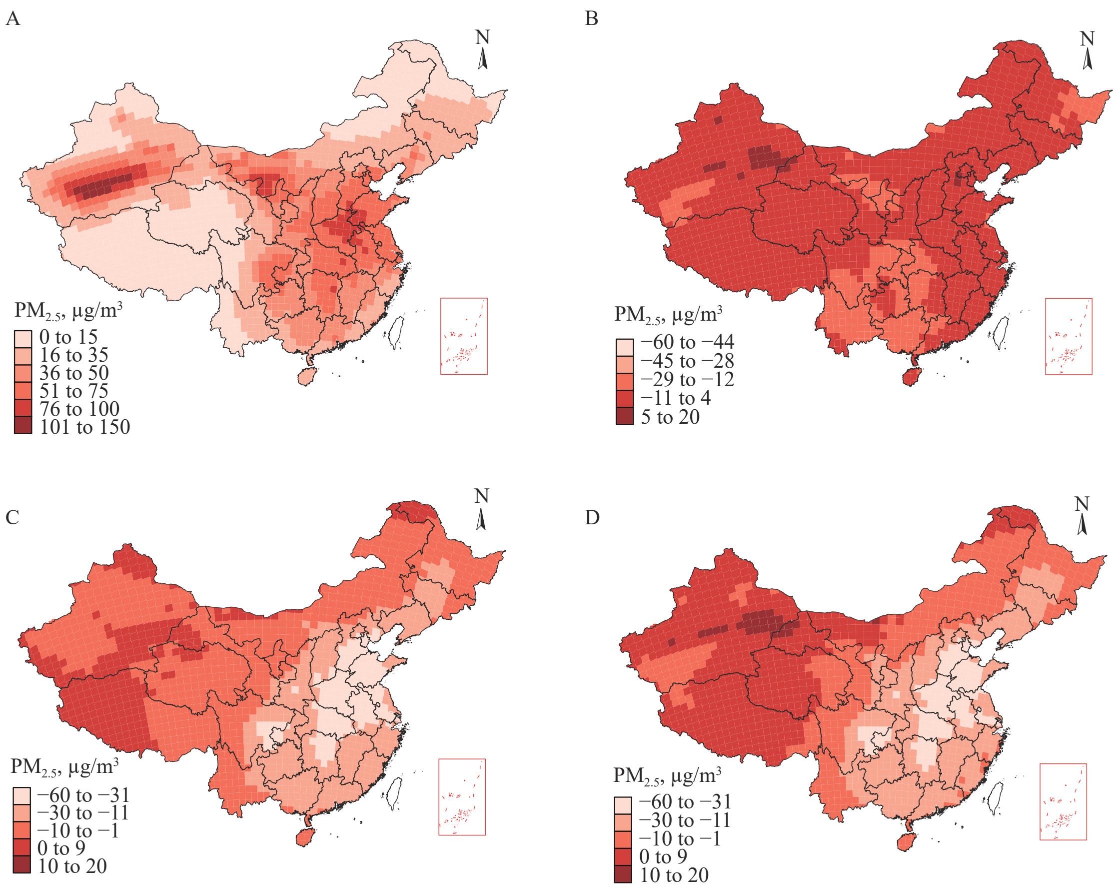

FIGURE 1. Baseline $PM_{2.5}$ concentration in the 2010s and the changes of its predicted concentrations under different scenarios in the 2040s in China. (A) Baseline $PM_{2.5}$ concentrations in the 2010s; (B) Changes of $PM_{2.5}$ concentrations under climate change scenario in the 2040s; (C) Changes of $PM_{2.5}$ concentrations under emission control scenario in the 2040s; (D) Changes of $PM_{2.5}$ concentrations under both climate change and emission control scenarios in the 2040s.

$PM_{2.5}$ concentrations at the national level would decrease from 28.05 μg/m^3 in the 2010s to 18.75 μg/m^3 in the 2040s, with a reduction percentage of 33.16%.

Climate change scenario under RCP4.5 would aggravate the health impacts of $PM_{2.5}$ pollutions on death and YLLs, while the emission control scenario would alleviate the health influence of $PM_{2.5}$ from the 2010s to the 2040s in the national level. The attributable number of deaths related to ambient $PM_{2.5}$ pollutions was estimated to be 1,278,734 in the national level in the 2010s, which comprised of 371,939, 610,694, 177,455, and 118,646 cases from IHD, stroke, COPD, and lung cancer, respectively. In the 2040s, the estimate would increase by 0.96% under the climate change scenario, while it would decrease by 32.20% under the emission control scenario. Considering both the impact of both climate change and emission control, there were an estimated 385,004 fewer deaths, with a reduction percentage of 30.11%. The corresponding YLL would increase by 0.85% under the climate change scenario, while it would decrease by 31.06% under the emission control scenario. The attributable YLLs would decrease from 16,328,977 in the 2010s to 11,577,480 in the 2040s considering both scenarios. There would be 4,751,497 fewer YLL at the national level, with a reduction percentage of 29.10%. The largest reduction number is stroke among the four major diseases (Figure 2).

Table 1 showed the prediction of deaths and YLLs from main types of diseases associated with ambient $PM_{2.5}$ pollutions in different districts of China in the 2040s. Generally, the attributable deaths and YLLs from major diseases would increase in most of the districts in the climate change scenario, with the largest increasing percentage in the east region. While considering both climate change and emission control scenarios, the attributable deaths and YLLs would decrease in the 2040s compared with the 2010s, with the largest percentage change in the Northeast.

DISCUSSION

In this study, the ambient $PM_{2.5}$ in the 2010s and the 2040s in China was simulated. The changes of $PM_{2.5}$ under the scenarios of climate change, emission control, and both climate change and emission control in the 2040s were evaluated. Furthermore, the deaths and YLLs attributable to $PM_{2.5}$ were also assessed. Climate change would aggravate $PM_{2.5}$ pollution and cause adverse health effects, while emission control would reduce $PM_{2.5}$ concentration and alleviate adverse health effects of $PM_{2.5}$ to some degree. The health benefits would be noticeable under the scenario of climate change with emission control. The results were similar to a modelling study conducted in Great Britain which assessed the public health impacts of the air quality changes arising from climate change interventions and indicated that mitigation policies have the potential to generate dramatic improvements in public health through the improvement in air quality (*9*). The findings suggest that emission control may mitigate $PM_{2.5}$-related impacts attributable to climate change and may inform policymaking

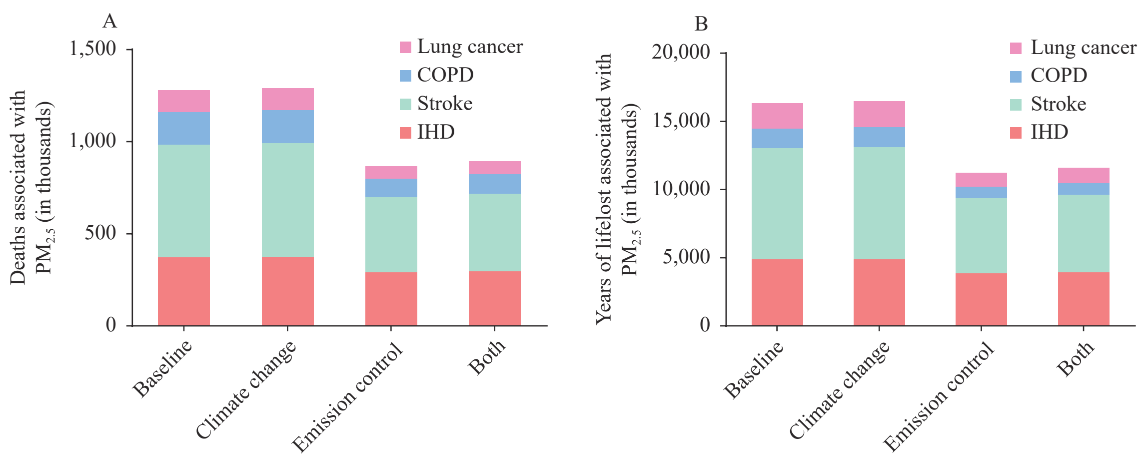

FIGURE 2. Deaths and years of life lost from main types of diseases associated with ambient $PM_{2.5}$ pollution in the national level in the 2010s (baseline) and different scenarios in the 2040s. (A) Deaths associated with $PM_{2.5}$ (in thousands). (B) Years of life lost associated with $PM_{2.5}$ (in thousands).
Abbreviations: COPD=chronic obstructive pulmonary disease; IHD=ischemic heart disease.

TABLE 1. Deaths and years of life lost from main types of diseases associated with ambient $PM_{2.5}$ pollution in different districts in the 2010s and in different scenarios in the 2040s in China.

	Disease	Region	Baseline (2010s)	Emission control (2040s)	Climate change (2040s)	Both scenarios (2040s)
Deaths	Lung cancer	Central	38,961(37,072−40,985)	21,519(20,212−22,825)	39,130(37,309−40,992)	22,109(20,752−23,487)
		East	27,963(25,783−30,140)	16,408(14,688−18,013)	29,371(27,182−31,550)	17,854(16,009−19,647)
		North	26,498(24,619−28,218)	14,537(13,202−15,761)	27,741(25,959−29,476)	16,217(14,873−17,596)
		Northeast	7,446(6,727−8,254)	3,410(2,917−3,866)	7,570(6,724−8,372)	3,325(2,819−3,817)
		Northwest	5,211(4,757−5,652)	3,886(3,509−4,274)	5,283(4,863−5,744)	3,976(3,616−4,353)
		South	12,568(11,544−13,715)	7,352(6,629−8,055)	12,349(11,302−13,432)	7,017(6,294−7,750)
		Subtotal	118,646 (114,756−122,448)	67,112(64,362−69,925)	121,444 (117,581−125,190)	70,498 (67,662−73,192)
	COPD	Central	64,204(61,198−67,190)	35,962(33,880−38,073)	63,973(60,818−67,072)	36,224(34,063−38,449)
		East	36,447(33,740−39,034)	21,779(19,727−23,965)	38,210(35,595−41,120)	23,597(21,496−25,654)
		North	31,488(29,716−33,292)	17,800(16,458−19,084)	32,920(31,243−34,905)	19,710(18,206−21,074)
		Northeast	8,258(7,454−9,026)	3,964(3,460−4,499)	8,393(7,586−9,228)	3,869(3,354−4,396)
		Northwest	11,841(10,900−12,783)	8,919(8,180−9,672)	12,004(11,063−12,987)	9,117(8,342−9,864)
		South	25,217(23,769−26,741)	14,720(13,658−15,827)	24,395(22,823−25,911)	13,894(12,733−14,934)
		Subtotal	177,455(172,588−182,322)	103,144(99,239−106,638)	179,895(175,040−185,082)	106,411(102,670−110,041)
	Stroke	Central	211,289(207,855−214,510)	143,301(140,430−145,945)	211,024(207,658−214,034)	145,453(142,741−148,320)
		East	134,204(130,650−137,631)	94,621(91,183−97,837)	137,556(133,848−141,212)	101,686(98,280−105,428)
		North	114,137(111,590−116,745)	77,724(75,660−80,055)	116,413(113,937−118,848)	85,351(83,266−87,702)
		Northeast	40,158(38,860−41,346)	17,860(17,105−18,580)	40,436(39,159−41,638)	17,379(16,647−18,099)
		Northwest	33,097(32,288−33,905)	26,975(26,238−27,812)	33,454(32,670−34,341)	27,579(26,891−28,303)
		South	77,808(75,814−79,792)	46,743(45,324−48,253)	75,754(73,877−77,502)	44,132(42,768−45,573)
		Subtotal	610,694 (604,864−616,772)	407,224(401,877−412,712)	614,637(608,880−620,705)	421,580(416,769−426,887)
	IHD	Central	122,087(120,667−123,605)	94,903(93,821−95,959)	122,239(120,806−123,808)	96,030(94,922−97,213)
		East	86,372(84,339−88,472)	68,678(67,149−70,229)	88,168(86,186−90,257)	71,379(69,693−73,016)
		North	73,129(71,754−74,462)	56,570(55,614−57,606)	74,447(73,095−75,727)	59,453(58,444−60,418)
		Northeast	28,545(27,984−29,102)	19,549(19,127−19,945)	28,684(28,096−29,275)	19,166(18,780−19,593)
		Northwest	15,877(15,599−16,138)	13,954(13,732−14,182)	16,029(15,778−16,306)	14,209(13,986−14,415)
		South	45,929(44,978−46,852)	35,896(35,282−36,514)	45,404(44,460−46,285)	35,005(34,323−35,639)
		Subtotal	371,939(368,700−375,355)	289,550(287,271−291,731)	374,971(371,754−378,145)	295,242(292,987−297,421)

TABLE 1. (Continued)

	Disease	Region	Baseline (2010s)	Emission control (2040s)	Climate change (2040s)	Both scenarios (2040s)
Years of life lost	Lung cancer	Central	618,254(586,213−649,797)	341,506(319,484−362,722)	621,022(591,164−650,132)	351,005(330,626−373,382)
		East	418,525(382,735−449,965)	245,493(220,072−271,775)	439,634(403,395−473,071)	267,137(241,539−292,445)
		North	420,444(392,967−449,296)	231,199(213,427−249,338)	440,286(411,122−469,785)	257,814(238,033−278,906)
		Northeast	122,896(109,279−136,079)	55,989(48,557−63,878)	124,838(112,378−138,037)	54,451(46,232−62,246)
		Northwest	92,129(83,979−100,523)	68,858(62,224−75,353)	93,412(85,682−102,071)	70,491(64,039−76,854)
		South	195,933(180,046−211,995)	113,982(101,729−125,447)	192,213(176,544−209,435)	108,683(97,777−121,219)
		Subtotal	1,868,180(1,812,549−1,923,629)	1,057,027(1,016,384−1,099,968)	1,911,405(1,853,155−1,968,896)	1,109,581(1,066,029−1,153,705)
	COPD	Central	533,842(508,080−559,411)	298,877(280,884−317,152)	531,693(506,880−555,737)	300,812(283,007−319,205)
		East	264,192(245,779−282,745)	157,595(143,103−171,801)	276,908(258,560−294,864)	170,783(156,431−185,607)
		North	249,773(235,613−264,032)	142,174(132,390−151,925)	261,227(247,682−275,951)	157,236(146,015−168,021)
		Northeast	68,880(62,685−75,530)	32,767(28,474−36,638)	69,885(63,360−76,504)	31,828(27,951−35,856)
		Northwest	115,897(10,6659−125,847)	87,489(80,382−94,952)	117,461(109,153−126,100)	89,434(82,145−96,694)
		South	201,664(190,662−214,335)	116,153(107,836−124,542)	194,344(182,096−205,559)	109,339(101,195−117,871)
		Subtotal	1,434,247(1,396,645−1,473,934)	835,055 (807,109− 862,422)	1,451,518(1,415,206−1,490,994)	859,433 (831,918−888,195)
	Stroke	Central	2,897,759(2,862,356−2,933,572)	1,989,408(1,957,755−2,023,614)	2,894,476(2,857,322−2,928,761)	2,019,695(1,985,656−2,052,569)
		East	1,635,016(1,604,390−1,666,452)	1,166,149(1,135,143−1,192,614)	1,674,562(1,642,650−1,705,592)	1,249,500(1,219,969−1,277,281)
		North	1,512,628(1,488,675−1,536,426)	1,044,102(1,022,670−1,066,083)	1,542,562(1,520,764−1,565,874)	1,141,362(1,118,516−1,164,129)
		Northeast	576,933(562,761−591,702)	264,880(255,562−273,217)	580,051(566,909−594,491)	256,258(247,343−264,957)
		Northwest	524,131(512,919−534,952)	430,440(419,469−440,682)	529,729(517,994−540,703)	440,257(430,930−450,217)
		South	1,024,580(1,006,117−1,041,922)	626,070(613,184−638,980)	995,327(977,612−1,013,550)	591,710(579,543−604,362)
		Subtotal	8,171,047(8,112,361−8,227,274)	5,521,049(5,469,542− 5,570,697)	8,216,707(8,153,930−8,275,064)	5,698,783(5,647,037− 5,751,956)
	IHD	Central	1,615,329(1,601,388−1,629,674)	1,278,244(1,268,105−1,289,128)	1,616,886(1,602,627−1,630,338)	1,291,823(1,280,616−1,303,193)
		East	1,014,773(1,000,467−1,028,710)	820,795(810,026−831,461)	1,034,273(1,020,591−1,048,177)	850,757(839,236−862,970)
		North	951,341(940,914−961,546)	750,993(743,038−759,030)	967,379(955,759−978,445)	786,134(778,072−794,507)
		Northeast	402,678(397,267−408,094)	280,576(276,317−285,381)	404,150(398,385−409,863)	274,587(269,975−278,978)
		Northwest	264,156(260,580−267,665)	234,337(231,380−237,418)	266,697(263,514−269,950)	238,737(235,792−241,603)
		South	607,226(600,696−614,201)	479,783(474,860−485,079)	599,035(592,333−605,730)	467,646(462,523−472,811)
		Subtotal	4,855,503(4,830,782−4,879,767)	3,844,728(3,825,368−3,862,978)	4,888,419(4,862,291−4,914,803)	3,909,683(3,889,792− 3,930,251)

Note: The number in parentheses indicates the 95% confidence interval of the mean death number or years of life lost. Both scenarios indicate considering both climate change and emission control scenarios.

Abbreviations: COPD=chronic obstructive pulmonary disease; IHD=ischemic heart disease.

decisions of emission control to confront climate change.

$PM_{2.5}$ concentrations show an increasing trend with climate change in this study. Climate change is expected to degrade air quality by changing air pollution meteorology, precipitation, and other removal processes and by triggering some amplifying responses in atmospheric chemistry and in anthropogenic and natural sources, which would shape distributions and extreme episodes of particulate matter (*3*). Following higher $PM_{2.5}$ concentrations triggered by climate change, the attributable deaths and YLLs related to $PM_{2.5}$ would increase in most districts. The largest increasing percentage would be in the east region considering high increment in $PM_{2.5}$ concentrations in this region under climate change scenario. Making policies to rival climate change considering the severe health effects and the burden of diseases caused by it is of vital importance. In this modelling study, the measure of emission control could counteract the health impacts attributable to $PM_{2.5}$ generated by climate change due to reduction of $PM_{2.5}$ concentrations. Among the main types of diseases, stroke had the most noticeable health benefits. The evidence emphasizes the necessity of evaluating the effects of mitigation policies such as emission control on health impacts triggered by climate change, which could verify the effectiveness and evaluate the benefits of the policies and, in turn, inform policymaking decisions.

For different districts, the health benefits of avoiding attributable deaths and YLLs from main types of diseases associated with ambient $PM_{2.5}$ pollution varied. The deaths and YLLs from main types of diseases experienced the largest decreasing percentage in the Northeast region under both the climate change and emission control scenarios, which may result from the large reduction percentage of $PM_{2.5}$ concentration in this region.

This study was the first to estimate the health impacts related to ambient $PM_{2.5}$ from both climate change and air pollution emission control under different scenarios in China, and it provided evidence for policymaking related to climate change and emission control. However, the study was subject to some limitations. First, the emission control scenario was designed based on RCP4.5, which only stands for a moderate level of greenhouse gas emissions. Second, accounting for some factors, such as population structure, would affect the climate-related health burden in the future (*10*), and assuming that the $PM_{2.5}$-mortality association, mortality rate, and population structure were constant at the 2010s levels might lead to some deviations. Further exploration should be performed if data are available.

In summary, the findings suggest the ambient $PM_{2.5}$-related health benefits from air pollution emission control outweighed the influence of climate change. The health impacts of $PM_{2.5}$ related to climate change should be prioritized in the future.

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