Projections of mortality risk attributable to short-term exposure to landscape fire smoke in China, 2021–2100: a health impact assessment study

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Summary

Background **Landscape fire smoke, including smoke from all vegetation burning in natural and cultural landscapes, remains a threat to the health of the population. However, the future health impacts of landscape fire smoke in China have not been sufficiently investigated. We aimed to estimate the mortality risk attributable to landscape fire-related $PM_{2·5}$ under different scenarios.**

Methods **In this health impact assessment study, we used the projected population and landscape fire-related $PM_{2·5}$ concentration to calculate deaths attributable to short-term exposure to landscape fire smoke $PM_{2·5}$ during 2021–2100. We did the analysis in three defined future periods: 2021–40 (near term), 2051–70 (medium term), and 2081–2100 (long term), with 1986–2005 as the historical period. We used fire-specific short-term epidemiological functions with the regional parameters specific to China. We assessed the mortality risks of landscape fire-related smoke and further identified their spatiotemporal distribution under two shared socioeconomic pathway (SSP) scenarios: SSP1–2·6, an optimistic scenario with strict control of carbon emissions, and SSP2–4·5, an intermediate scenario with weaker control of carbon emissions.**

Findings **The national mortality rate attributable to short-term exposure (ie, a few days) to landscape fire-related $PM_{2·5}$ is projected to increase compared with historical values. The national deaths attributable to landscape fire smoke $PM_{2·5}$ could peak in 2021–40, with increases of 28·10% (95% CI 14·08–53·11) under the SSP1–2·6 scenario and 37·38% 22·85–62·61 under the SSP2–4·5 scenario. Deaths would then decrease slightly during 2051–70 and 2081–2100. The provinces with the highest projected number of deaths attributable to landscape fire-related $PM_{2·5}$ are located in east and south-central China, and those with the largest percentage increase in projected deaths are located in northwest and southwest China.**

Interpretation **Our results suggest that global warming could increase the contribution of landscape fire smoke to the total $PM_{2·5}$ concentration, leading to an increase in the mortality rate in China. Our findings could help policy makers implement effective interventions in hotspot areas during different periods to reduce the impact of landscape fire smoke on human health.**

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Introduction

The size and frequency of landscape fires, including any prescribed or non-prescribed combustion or burning of plants,[1] have been increasing as the length of the fire weather season has increased.[2] Fire weather, which is characterised by high temperatures and low humidity, has become more severe because of climate change.[3] China faces a large landscape fire risk because of its large population and large subtropical forests. Forest fires occur primarily in northeast and southeast China, whereas grassland fires occur in Inner Mongolia in northeast China. Crop fires dominate in northeast, south-central, and east China, peaking after the harvest season.[4] Although all administrative levels of the Chinese Government strictly control and intensively monitor landscape fires as a serious hazard, landscape fire disasters still threaten the nation. The 2020 Liangshan forest fire killed 19 people, and the 2019 forest fire in the same region killed 31 people. One study reported that fire probability could increase by up to 99·9% relative to 2003–15 in the northern forest zone during 2061–80.[5] Therefore, the ability to track future landscape fire health impacts is of vital importance.

Landscape fire smoke has a wide-ranging impact and is responsible for many premature deaths around the world each year.[6] Of all the air pollutants from the landscape fire smoke, particulate matter (PM), especially $PM_{2·5}$, poses a significant public health risk.[7] China recorded the

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Research in context

Evidence before this study

The health effects of landscape fires, including forest fires, grass fires, bush fires, and agricultural-waste burning, have received attention in recent years as an important aspect of climate change affecting health. We searched PubMed, Web of Science, Google Scholar, and China National Knowledge Infrastructure using the keywords "landscape fire," "$PM_{2·5}$," "health," and "China". Previous studies have investigated the historical health effects of landscape fire-related $PM_{2·5}$ on a national or global scale and indicated that China had the highest annual average deaths related to landscape fire-related $PM_{2·5}$ (89 369) in Asia during 2016–19. However, few studies were done at the provincial level or used epidemiological methods specific to landscape fire smoke in China. Furthermore, although some future projections of fire-related mortality risk have been done on a global scale or within the USA, these projections have not yet been adapted to the Chinese context.

Added value of this study

To the best of our knowledge, this is the first detailed assessment of China's future disease burden associated with short-term exposure to landscape fire smoke. The deaths attributable to landscape fire-related $PM_{2·5}$ are considerable and expected to increase by the middle of this century. Moreover, we identified the spatiotemporal pattern of the change and characterised the relative contributions of the various driving factors to this change from 1985 to 2100. The effect of increasing landscape fire smoke due to climate change could strongly compound the number of smoke-related deaths, which might be offset mainly by a decreased population size in the future. Due to the large proportion of national population, east and south-central China would experience the largest absolute increase in the number of landscape fire-related deaths.

Implications of all of the available evidence

The identification of vulnerable regions and key factors affecting distribution patterns can inform policy makers in developing targeted policies to tackle landscape fire-related health impacts. The predicted national increase in fire-related mortality risk indicates the need for the continual implementation of strict policies to prevent and mitigate landscape fire smoke in the future, especially during the period 2020–40. Additionally, more stringent actions for landscape fire smoke should be implemented in potential hotspot areas, including east and south-central China. Moreover, this study provides evidence that keeping global warming below 2°C could reduce the landscape fire-related health burden in China, highlighting the importance of mitigating and reducing the effects of climate change.

highest mean number of annual deaths (89 369) attributed to landscape fire-related $PM_{2·5}$ in Asia over the period 2016–19.[8] Another study showed that 4741 premature deaths were associated with open-crop straw burning-related $PM_{2·5}$ exposure in China in 2018.[9]

Although fire-related $PM_{2·5}$ poses a significant health hazard, few attempts have projected the future health impact of fire-related $PM_{2·5}$. Existing studies on the health effects of $PM_{2·5}$ often neglect fire-related sources in future $PM_{2·5}$ estimates[10] and do not adequately address the specific health effects of fire-related $PM_{2·5}$.[11,12] However, landscape fire smoke $PM_{2·5}$ can be more detrimental than $PM_{2·5}$ from other sources.[13,14] Previous studies on the health effects of landscape fire smoke did not use the epidemiological method developed for fire-related $PM_{2·5}$ but instead used those for ambient $PM_{2·5}$,[8,9] resulting in an underestimation of the projected risk. Therefore, the future health effects of $PM_{2·5}$ concentrations from landscape fire smoke in China have not been comprehensively estimated to date.

In this study, we investigated the temporal and spatial dynamics of the health effects of landscape fires through the projection of annual deaths associated with short-term exposure to landscape fire smoke $PM_{2·5}$ by 2100 at the national and provincial scales. We estimated the relative importance of the population size and distribution and landscape fire-related $PM_{2·5}$ to the deaths resulting from all causes and to cardiovascular and respiratory problems caused by landscape fire smoke $PM_{2·5}$. This study was part of the initiative of the Lancet Countdown Asia Centre, which aims to provide a multi-dimensional projection of future health risks of climate change in China.

Methods

Study design and scenario models

In this health impact assessment study, we used projected fire emissions, landscape fire smoke $PM_{2·5}$ concentration, and population density data for several decades to project the future mortality attributable to landscape fire smoke $PM_{2·5}$ in China.

This study was done in two stages. First, we estimated the population-attributable fraction (PAF) of daily deaths attributable to future landscape fire smoke $PM_{2·5}$ under two shared socioeconomic pathway (SSP) scenarios according to a concentration-response function.[13] We calculated the landscape fire smoke $PM_{2·5}$-attributable deaths by multiplying the projected baseline mortality and PAF attributable to future landscape fire smoke $PM_{2·5}$. Second, we analysed the spatiotemporal trend and relative importance of different factors in mortality change, aiming to provide evidence to support the mitigation of landscape fire smoke and the promotion of health adaptation strategies.

The timeframe was 1985–2100. In accordance with China's carbon-neutrality target, we did the analysis in three defined future periods: 2021–40 (near term), 2051–70 (medium term), and 2081–2100 (long term), with 1986–2005 as the historical period. We used two SSP scenarios: an optimistic scenario (SSP1–2·6) and an intermediate scenario (SSP2–4·5) in the Scenario Model Intercomparison Project for the Coupled Model Intercomparison Project 6 (CMIP6).[15] The optimistic scenario represents global warming below 2°C and the intermediate scenario represent warming below approximately 3°C by 2100.

Projection of landscape fire smoke $PM_{2·5}$ concentration

We estimated the global atmospheric $PM_{2·5}$ concentration near the surface at the grid level (0·9°×1·25°, latitude×longitude) using the Community Atmosphere Model version 5.3 (CAM5.3)[16] with fire emissions as the input. We calculated black carbon, organic carbon, and SO_2 emissions caused by surface fires, derived using the method of Li and colleagues[17] based on the simulated fire carbon emissions from 11 CMIP6 Earth system models (appendix pp 3–4).

To quantify the $PM_{2·5}$ concentrations from landscape fire smoke emissions and other sources separately, we did two sets of experiments (appendix pp 6–7). The first set was run with only fire emissions changing with time, and the second set was done with only anthropogenic emissions changing with time and without fire emissions (appendix pp 6–7). Here, we considered only the fire $PM_{2·5}$ formed from fire black carbon, organic carbon, and SO_2 emissions. We did not include secondary organic aerosol formation because significant uncertainties are associated with secondary organic aerosol formation from fire emissions.[18]

Surface fire carbon emissions were calculated from 11 CMIP6 Earth system models (appendix pp 3–4). All the CMIP6 Earth system models were driven by the same standardised input data (atmospheric CO_2 concentration and anthropogenic emissions),[19] the Land Use Harmonization 2,[20] emission factors, and simulated the climate rather than having it prescribed. We corrected the CMIP6 surface fire emissions for the 1997–2014 period using the 1997–2014 mean monthly carbon emissions from fire from the Global Fire Emissions Database version 4 with small fires[21] and then applied the same scaling factors to the 1986–2100 periods, similar to the method of van Marle and colleagues (appendix p 3).[22]

Finally, to map the changes at a finer resolution, we used the nearest neighbour method to re-grid the daily $PM_{2·5}$ concentration to a spatial resolution of 0·25°×0·25° to prevent over-smoothing.

Projection of the future population

We derived 1850–2016 historical and 2017–2100 SSP population density data (per km²) from the History Database of the Global Environment[23] with a spatial resolution of 0·5°×0·5°. The data were the default input data for the Community Land Model and the CMIP6 Community Earth System Model version 2 simulations. We calculated population counts by multiplying the population density by the surface area of each grid cell. To preserve the total numbers, the population dataset was re-gridded to 0·25°×0·25° using a conservative method.

Projections of short-term mortality attributable to landscape fire-related $PM_{2·5}$

We used Chen and colleagues'[13] concentration-response functions to calculate the short-term mortality attributable to landscape fire-related $PM_{2·5}$. These functions were developed to quantify the association between short-term exposure to landscape fire-related $PM_{2·5}$ and mortality risks by analysing data from 43 countries and regions, including China. In this study, we used the relative risks (RRs) pooled for China, which is the ratio of the risks between the landscape fire-related $PM_{2·5}$-exposure group and the non-exposure group. The RRs were associated with each 10 μg/m³ increase in the moving average of the projected landscape fire-related $PM_{2·5}$ with a lag of 0–2 days. Therefore, the short-term exposure presented in this study refers to impacts during the first 3 days.

See Online for appendix

We obtained the baseline mortality rate from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019[24] for all-cause and cardiovascular-related and respiratory-related mortality rates. We calculated the mean annual PAF and annual deaths attributable to landscape fire-related $PM_{2·5}$ concentrations under all SSP scenarios by averaging the daily PAF and aggregating the daily total mortalities at both the national and provincial levels. To consider the uncertainties in the landscape fire smoke $PM_{2·5}$ concentration and the concentration-response function, we used the Monte Carlo approach to report the 95% CI of the mortality rate and the number of deaths attributable to the landscape fire-related $PM_{2·5}$, as well as to their changes during the three periods.

To identify the driving factors of changes in projected death, we assessed the relative importance of three driving factors (ie, population, landscape fire-related $PM_{2·5}$ concentration, and their interaction) on the basis of Jones's factor separation method (appendix pp 12–13).[25] This interaction factor indicated whether the population would increase in the regions with increasing landscape fire-related $PM_{2·5}$ concentrations. At the national level, we further decomposed the effect of the population into the effects of population growth and spatial population distribution (appendix p 13). Additionally, we did a hotspot analysis on the gridded population, fire-related $PM_{2·5}$ concentration, and projected number of deaths attributable to landscape fire smoke (appendix pp 13–18).

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

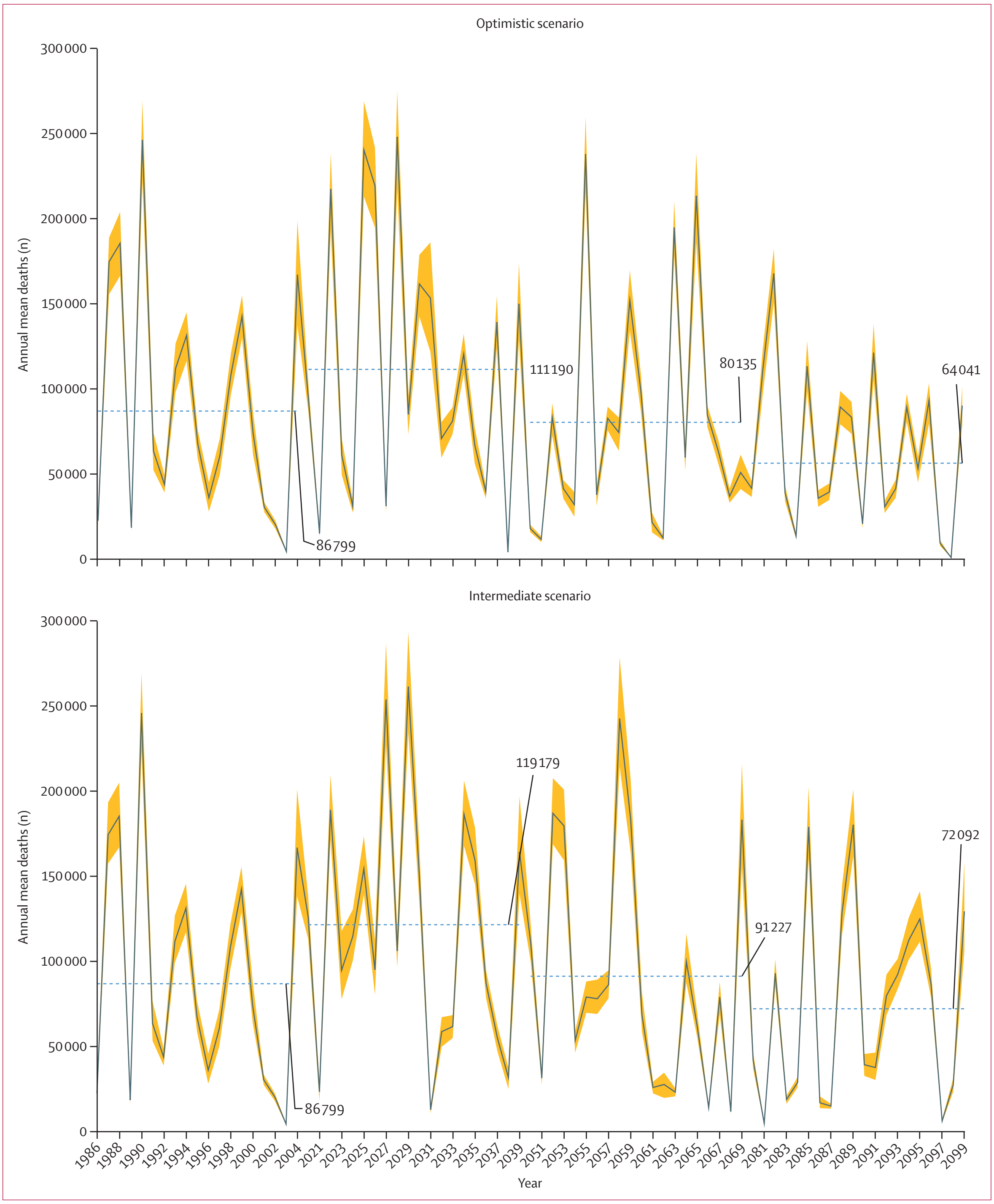

Figure 1: **Projected annual average number of all-cause deaths attributable to changes in the landscape fire-related $PM_{2·5}$ concentration**
The dashed lines represent the annual mean number of deaths attributable to the landscape fire-related $PM_{2·5}$ concentration across the two SSP scenarios. The shaded areas represent 95% CIs. PM=particulate matter. SSP=shared socioeconomic pathway.

Results

Despite some fluctuations, the landscape fire-related $PM_{2·5}$ concentration exhibited an upwards trend under both scenarios. During the historical period (1986–2005), the annual mean landscape fire-related $PM_{2·5}$ concentration at the national level was 1·86 μg/m³ per year (appendix p 19). In the near term (2021–40), landscape fire-related $PM_{2·5}$ concentrations are projected to peak, followed by a slight decrease in the medium term (2051–70), but remaining higher than historical levels (appendix p 19). In the long term (2081–2100), the annual mean landscape fire-related $PM_{2·5}$ concentration is expected to increase under both scenarios (appendix p 19). The relative contribution from landscape fire smoke to total $PM_{2·5}$ becomes greater in the future in both scenarios (appendix p 19). In the historical term, the mean relative contribution of landscape fire-related $PM_{2·5}$ to the total $PM_{2·5}$ concentration was 3·54% (appendix p 19). The relative contributions of landscape fire emissions are also expected to peak in the near term (appendix p 19). By contrast, the contribution of anthropogenic sources to the annual mean surface $PM_{2·5}$ concentration is projected to decline under the SSP1–2·6 scenario but increase under the SSP2–4·5 scenario by 2081–84, in comparison with 1991–94 (appendix p 20).

Our projections show an increase in the national projected mortality rate attributable to the landscape fire-related $PM_{2·5}$ concentration, (appendix p 22). Historically (1986–2005), the national annual mortality rate attributable to landscape fire-related $PM_{2·5}$ was 0·54% (95% CI 0·51–0·64) for all causes (appendix p 22). Under the SSP2–4·5 scenario, the national mortality rate is expected to be higher than that under the SSP1–2·6 scenario in all periods (appendix p 22). In the near term, the national annual mean all-cause mortality rate attributable to the landscape fire-related $PM_{2·5}$ concentration is projected to increase by 11·85% (7·40–16·62) under the SSP2–4·5 scenario compared to that during historical period (appendix p 22).

We also showed the rate of change in the projected mortality rate attributable to landscape fire-related $PM_{2·5}$ by province (appendix pp 44–45). Chongqing and Guizhou, both located in southwest China, are projected to be the most affected, with a mortality rate attributable to landscape fire-related $PM_{2·5}$ of more than 1% in all periods (appendix pp 44–45). By comparison, Tibet, Qinghai, and Xinjiang, located in northwest and southwest China, might have the least effects, with a mortality rate attributable to landscape fire-related $PM_{2·5}$ of less than 0·2% in all periods. In nine provinces, which are located primarily in northwest and southwest China, the mortality rate attributable to landscape fire-related $PM_{2·5}$ could continue to increase in all periods compared with the historical period under both scenarios. Notable decreases are expected in the projected mortality in northeast China, in which the mortality rate attributable to landscape fire-related $PM_{2·5}$ could continue to decrease in three of four provinces (Jilin, Heilongjiang, and Liaoning) in all periods. In the long term, 14 (41%) of 34 provinces were projected to have a larger mortality rate attributable to the landscape fire-related $PM_{2·5}$ concentration under the SSP1–2·6 scenario compared with the SSP2–4·5 scenario.

There could be an increase and then a decrease in the national number of deaths due to landscape fire-related $PM_{2·5}$ during 1985–2100 under both the SSP1–2·6 and SSP2–4·5 scenarios (figure 1). The all-cause, cardiovascular disease, and respiratory disease mortality rates attributable to landscape fire-related $PM_{2·5}$ exhibited similar trends with time, but the mortality rate of cardiovascular disease was larger than that of respiratory disease (appendix p 22). During the historical period (1986–2005), the annual mean number of all-cause deaths attributed to the landscape fire smoke $PM_{2·5}$ concentration at the national level was 86 799 (95% CI 81 505–95 597; figure 1). In the near term, the projected number of mean annual all-cause national deaths attributed to landscape fire-related $PM_{2·5}$ is projected to increase by 28·10% (14·08–53·11) under the SSP1–2·6 scenario and by 37·38% (14·08–53·11) under the SSP2–4·5 scenario (figure 1). The increase in the landscape fire-related $PM_{2·5}$ concentration is expected to contribute to more than half of the increase in the deaths attributed to landscape fire-related $PM_{2·5}$ under both SSP scenarios (appendix p 29). In the medium term, the annual mean number of deaths attributed to landscape fire-related $PM_{2·5}$ is expected to slightly decrease to 80 135 (72 366–93 276) under the SSP1–2·6 scenario and to slightly increase to 91 227 (84 766–97 776) under the SSP2–4·5 scenario (figure 1). This change probably results from a decrease in the population in regions with high landscape fire smoke (appendix pp 21, 29). Compared with SSP1–2·6, the concentration contributes almost twice as many projected deaths under the SSP2–4·5 scenario (appendix p 29). Finally, in the long term, the annual average number of deaths attributed to landscape fire-related $PM_{2·5}$ is expected to decrease under both scenarios (figure 1). During this period, the decline in the national population size and its spatial distribution could counteract the attributable mortality of all disease types resulting from landscape fire-related $PM_{2·5}$ under both scenarios (appendix p 29).

The provinces with the highest projected deaths are mainly located in east and south-central China (figure 2). Those provinces with the largest projected populations (appendix pp 36–39) are expected to have the largest number of all-cause deaths attributable to landscape fire-related $PM_{2·5}$ (appendix pp 31–34). By contrast, the provinces with the smallest annual mean number of deaths attributable to landscape fire-related $PM_{2·5}$ are mainly located in northwest China (Qinghai, Ningxia, and Xinjiang provinces), which have the smallest projected populations (appendix pp 36–39). In the near term, most provinces are projected to experience an increase in the number of deaths attributable to landscape fire-related $PM_{2·5}$ (figure 2), including 31 provinces under the SSP2–4·5 scenario (appendix pp 42–43) and 30 provinces under the SSP1–2·6 scenario (appendix pp 40–41). Under both scenarios and throughout all periods, the merging of hot spots, which refer to localised areas with high levels of mortality attributable to landscape fire-related $PM_{2·5}$, is projected to occur on the North China Plain, which constitutes an important agricultural region in China (appendix p 24).

In the near term, these three provinces in the North China Plain (Hebei, Henan, and Shandong) are expected to have 7301 more annual deaths attributable to landscape fire-related $PM_{2·5}$ under the SSP2–4·5 scenario than in the historical period (appendix pp 33–34).

The provinces with the highest average annual percentage increases in landscape fire-related mortality would be present in south-central China and East China (appendix pp 40–43). Taiwan, Hong Kong, Hainan, and Guangdong are projected to experience an increase of more than 90% in landscape fire-related mortality under the SSP2–4·5 scenario compared with the historical period, which can be attributed to the increases in landscape fire-related $PM_{2·5}$ concentration (figure 3). For all the provinces in northeast China (Heilongjiang, Jilin, Liaoning, and Inner Mongolia), mortality attributable to landscape fire-related $PM_{2·5}$ is expected to decrease in the medium term and long term under the SSP1–2·6 scenario as a result of decreases in both the population and the landscape fire-related $PM_{2·5}$ concentration (figure 3).

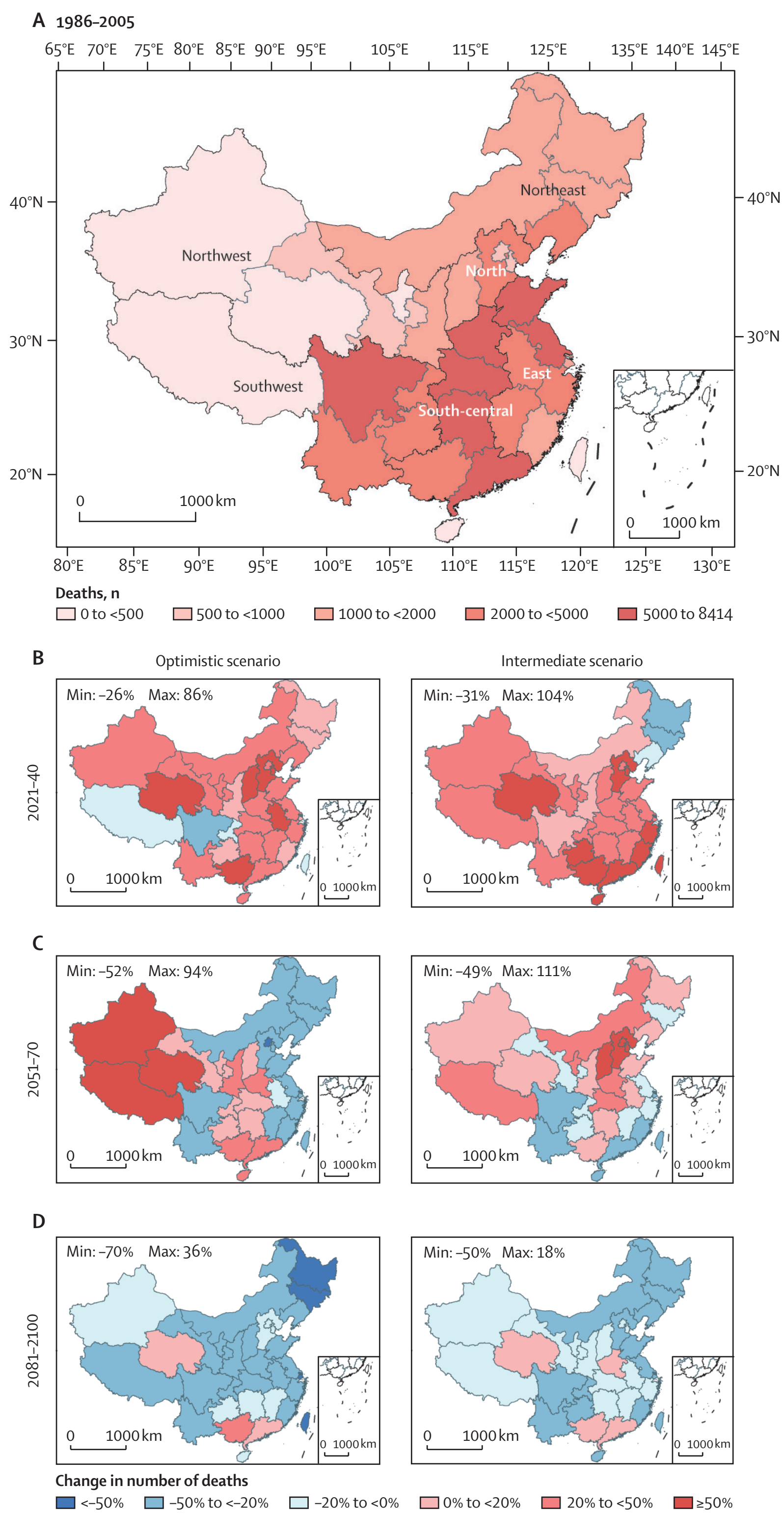

Figure 2: **Spatial and temporal patterns of the projected changes in the annual all-cause deaths attributable to landscape fire-related $PM_{2·5}$ at the provincial level**

(A) Number of deaths attributable to landscape fire-related $PM_{2·5}$ per year aggregated at the provincial level during the historical period (1986–2005). Corresponding simulated changes in the number of deaths for the near term (2021–40; B), medium term (2051–70; C), and long term (2081–2100; D) under the SSP1–2·6 and SSP2–4·5 scenarios. The projected coordinate system used for this map is the China Albers Equal Area Conic. PM=particulate matter. SSP=shared socioeconomic pathway.

Discussion

To the best of our knowledge, this study is the first to estimate the potential future mortality risk associated with landscape fire-related $PM_{2·5}$ in China. We estimated the mortality attributable to landscape fire-related $PM_{2·5}$ at the national and provincial levels from 1985 to 2100. To better prioritise and inform risk management strategies, we also identified the spatiotemporal pattern and investigated the relative importance of the different driving factors of the changes in the number of deaths.

Compared with previous global-scale studies on the health impact of landscape fire-related $PM_{2·5}$,[8,26,27] the projected historical number of deaths and its future trend by 2100 derived in this study was similar, although the estimated number of future deaths was higher. The possible reason for the higher projected number could be the use of the multi-model ensemble method and the use of epidemiological equations dedicated for fire-related $PM_{2·5}$. Notably, previous studies on the health impact of landscape fire smoke under future scenarios have only used a single global fire model for the projection of future surface-fire emissions and used the epidemiological model for ambient $PM_{2·5}$ to calculate the mortality resulting from landscape fire smoke.[27–29]

Future climate change would exert a notable effect on increasing the projected annual number of deaths by increasing landscape fire-related $PM_{2·5}$. In particular, the

Figure 3: **Driving factors of all-cause deaths attributable to landscape fire-related $PM_{2.5}$ by province during the three key periods**

Each panel presents the mortality associated with landscape fire-related $PM_{2.5}$ during the three key periods under the respective scenarios. PM=particulate matter. SSP=shared socioeconomic pathway.

SSP2–4·5 scenario is expected to result in a much greater increase in the proportion of projected deaths due to the landscape fire-related $PM_{2·5}$ concentration than the SSP1–2·6 scenario in the medium term. This finding supports the urgency and necessity of taking mitigation measures now and in the future. Therefore, it is essential to limit the global temperature increase to within 2°C to reduce the health risk of landscape fire-related $PM_{2·5}$.

The number of deaths attributed to landscape fire-related $PM_{2·5}$ is projected to increase compared with the historical period and should peak in the near term because of the increase in landscape fire-related $PM_{2·5}$ concentration. Thus, in China's plans to reach its greenhouse-gas emissions peak in 2030, close attention should be given to the increase in landscape fire-related emissions to reduce the potential fire-related mortality risks. However, no relevant policies in China exist for mitigation after 2025. The existing plan and policy for mitigating landscape fires in China include the National Forest Fire Prevention Plan (2016–25) and the National Grassland Fire Prevention Plan (2021–25), which correspond to the 14th Five-Year Plan for the National Disaster Emergency Response System, slated to end in 2025. The policy for natural disaster prevention and response in the 15th Five-Year Plan and 16th Five-Year Plan should pay attention to the increased risk of landscape fire smoke in vulnerable areas. For local mitigation efforts, the focus should be shifted from fire extinguishing to fire management, including fuel-reduction treatments that are effective for reducing wildfire size and intensity.[30]

The estimates in our study could also draw the attention of policy makers and the scientific community to the most vulnerable areas. South-central China and east China, the most developed regions, are expected to experience the highest increase in deaths attributable to landscape fire-related $PM_{2·5}$. Additionally, the North China Plain, characterised by high population density and intensive agricultural activities, might face the largest absolute increase in deaths attributable to landscape fire-related $PM_{2·5}$. The most populated and affected regions have agricultural land cover, supporting the urgency of establishing a stricter policy for fire prevention and control. Notably, the existing policies for crop burning, such as Measures for the Management of Prohibition of Burning and Comprehensive Utilization of Crop Straw, would reduce the mortality risk of agricultural waste fires to some extent.[9]

This study had several major limitations. First, the prediction of future landscape fire-related $PM_{2·5}$ concentrations used in this study might have large uncertainty because of challenges in accurately predicting $PM_{2·5}$ and quantifying air-pollutant emissions from both anthropogenic and natural sources. These challenges are still present even in the state-of-the-art chemical transport model and the simplified CAM5.3 model used in this study. Second, we considered only the all-age population, which might have underestimated the projected results because the baseline mortality rate of older individuals (>65 years) is 20 times that of the all-age mortality rate. Further considering the age structure of the population is crucial because of the increasing proportion of the aging population in China.[31] Third, this study focused on the short-term (ie, less than 1 week) health impact of landscape fire-related $PM_{2·5}$ in China. If the concentration–response relationships between wildfire-related $PM_{2·5}$ long-term exposure and mortality are available in China, further investigation of both short-term and long-term effects is possible. Fourth, this study did not include an analysis of the potential drivers of landscape fires when investigating the future mortality rate due to landscape fire-related $PM_{2·5}$. The attribution analysis of factors such as land use, climate, and atmospheric CO_2, is still in the exploratory phase.[32] Further investigating $PM_{2·5}$ changes caused by different fire types, such as forest fires and prescribed forest fires is also warranted to inform the development of more effective mitigation and adaptation strategies. Fifth, the re-gridding process and zonal analysis at national and provincial levels introduce the modifiable areal unit problem (MAUP),[33] caused by spatial variation within the original grid and different delineation of geographical boundaries. Since the issue of MAUP and its propagation might lead to statistical bias in numbers of landscape fire-related deaths, developing scale-insensitive analytical techniques and use Monte Carlo simulation and Taylor series approximation to estimate these biases need further exploration (appendix p 9).[34]

In conclusion, future landscape fires are predicted to result in increased mortality risks in China if substantial mitigation is not implemented to reduce climate change. Our findings establish a foundation for a systematic approach to future mitigation and adaptation planning, supported by policies to control landscape fires in the long term, with the aim of improving the health of China's residents.

Contributors

YB, FL, and SL conceived and designed the study. FL and XD conducted the surface fire emission modelling and population data processing to provide input to the analysis. GL and LX performed the fire-related $PM_{2·5}$ concentration modelling to provide input to the analysis. YC and CW contributed to SSP scenario design in the population modelling. SL and YL performed the analysis and interpreted the results. SL did the literature review and wrote the draft paper. YL, YB, FL, GL, LX, ZL, XD, MZ, LW, and MJ revised the manuscript. YB and FL proofread the manuscript. WC and ZL provided the coordination, strategic direction, and editorial support for this paper. PG and YL provided supervision for this paper. YB, FL, and SL directly accessed all the data used in the study, which were verified by SL and YL. All the authors had access to all the data. All authors contributed to the revision of the manuscript and were jointly responsible for the decision to submit the manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

All data and code used in this work are available on request from the authors.

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Editorial note: The Lancet Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

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