# Projected extreme temperature event-attributable dementia deaths in China: a climate–ageing–adaptation framework

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## Summary

**Background** Climate change is increasing health risks worldwide, but how extreme temperature events affect Alzheimer's disease and other dementias (ADD) remains poorly understood. We aimed to project future extreme temperature event-attributable ADD deaths in China, accounting for the combined effects of climate change, population ageing, and adaptation methods.

**Methods** We analysed 399,036 ADD deaths among adults aged ≥60 years in China during 2013–2020, using a time-stratified case-crossover design to estimate ADD mortality risks associated with extreme temperature events. We subsequently developed an integrated climate–ageing–adaptation framework that combined exposure–response functions, high-resolution climate projections, and demographic forecasts. Using this framework, we projected county-level ADD deaths attributable to heatwaves and cold spells among individuals aged ≥60 years across China under multiple SSP–RCP and adaptation scenarios for the 2030s, 2050s, and 2080s

**Findings** Without adaptation, ADD heatwave-attributable deaths are projected to rise sharply, especially under rapid socioeconomic development with high greenhouse gas emissions scenario (SSP5–RCP8.5) in the 2080s, which reach 59,088—an 11-fold (+1003%) increase comparing to 2010s levels. Cold spell-attributable deaths generally decline but reductions are insufficient to offset the sharp rise in heatwave mortality, leading to a net increase in total attributable deaths. Adaptation strategies could avert up to 76.4% of heatwave-attributable deaths compared to no-adaptation scenario.

**Interpretation** The convergence of climate change and population ageing is projected to substantially magnify dementia-related mortality in China. Under SSP5–RCP8.5, deaths attributable to extreme temperature events are projected to reach unprecedented levels by the end of the 21st century, especially without adaptation measures. These findings underscore the urgent need for massive greenhouse gases emission reductions alongside balanced, region-specific adaptation measures, and highlight dementia care as an essential component of climate resilience planning. Our study provides guidance for designing climate-resilient public health policies, particularly for ageing populations in climate-vulnerable counties and regions.

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### Research in context

**Evidence before this study**

We searched PubMed and Web of Science up to June 30, 2025, using the search terms ("heatwave" OR "extreme heat" OR "cold spell" OR "extreme cold" OR "temperature") AND ("Alzheimer's disease" OR "dementia") AND ("mortality" OR "death") AND ("climate change" OR "global warming"). We found no national-scale projections of dementia deaths attributable to heatwaves or cold spells, and very limited evidence for non-optimal temperatures. Existing studies largely focused on all-cause mortality, rarely accounting for climate change, ageing, and adaptation simultaneously.

**Added value of this study**

To our best knowledge, this is the first nationwide projection of heatwave- and cold spell-attributable Alzheimer's disease and other dementias (ADD) deaths in an ageing population, explicitly integrating climate change, population ageing, and multiple adaptation scenarios. By quantifying risks across nearly 3000 counties, we demonstrate that heatwave-attributable deaths will rise dramatically across all emission pathways, only partly offset by modest declines in cold spell deaths, resulting in a net increase. Our study highlights substantial regional disparities and identifies high-burden hotspots, providing critical evidence for dementia-inclusive adaptation planning.

**Implications of all the available evidence**

Older adults with dementia face compounded risks from both climate change and population ageing, putting increasing challenges to society. Our findings emphasise the urgent need for integrated massive greenhouse gases mitigation and climate adaptation strategies to reduce climate-related dementia deaths, including incorporating dementia care into climate resilience planning, particularly in rapidly ageing and climate-vulnerable countries. This study also establishes a methodological template for assessing climate-health risks in neurodegenerative populations and offers actionable insights for policymakers seeking to protect vulnerable groups.

## Introduction

Climate change is one of the most pressing global challenges of the 21st century. Driven by human activities, global temperatures have risen by over 1.2 °C above pre-industrial levels, posing growing threats to public health.[1] Rising temperatures not only directly impact mortality and morbidity but also disrupt ecosystems and social systems, leading to long-term health challenges.[2] Meanwhile, China is undergoing one of the fastest demographic transitions in the world. According to the 2020 national census, 264 million individuals—18.7% of the population—were aged ≥60 years.[3] By 2035, China is expected to become a severely ageing society, with 21% of the population aged ≥60 years.[4] These demographic shifts will significantly influence public health in the context of climate change, especially for age-related conditions. Neurodegenerative diseases, particularly Alzheimer's disease and other dementias (ADD), have seen marked increases in incidence, prevalence, and mortality in recent years.[5] Alzheimer's disease is now the fifth leading cause of death in both urban and rural areas in China, placing growing burdens on individuals, families, and the healthcare system.[3] The convergence of climate change and an ageing population may further exacerbate the health burden of ADD, highlighting the urgent need for integrated public health strategies.

Current research has primarily focused on the effects of non-optimal temperatures—both extreme heat and cold—on mortality from ADD.[5,6] While some studies have explored the association between heatwaves and AD-related health outcomes,[7,8] the specific impact of cold spells on ADD mortality remains largely under-explored. Furthermore, how the combined influences of future climate change, population ageing, and human adaptation will shape the spatiotemporal dynamics of ADD-related mortality in China's ageing population is still unclear. These research gaps hinder our ability to accurately assess the burden of extreme temperature events on ADD mortality in older adults amid ongoing climate and demographic transitions.

This study develops a framework for projecting nationwide heatwave- and cold spell-attributable ADD deaths in China, integrating the combined effects of climate change, population ageing, and human adaptation. Unlike previous studies based on continuous temperature metrics, we modelled heatwaves and cold spells as discrete events and developed a threshold-based approach with three adaptation assumptions (no-, partial-, and full-adaptation) to realistically assess population responses. Using multiple global climate models and advanced statistical methods, we projected event-based attributable deaths across 2975 counties under SSP1–RCP2.6, SSP2–RCP4.5, and SSP5–RCP8.5 scenarios for the 2030s, 2050s, and 2080s. This integrated climate–ageing–adaptation framework allows us to quantify the relative contributions of climate, ageing, and adaptation, providing actionable insights for region-specific adaptation strategies and dementia-inclusive public health policy.

## Methods

### Study area

We conducted a nationwide analysis across China, covering six administrative regions: North China, Northeast China, East China, Southcentral China, Southwest China and Northwest China (Figure S1).

### Mortality data

Daily individual death records from 2013 to 2020 were obtained from the China Cause of Deaths Reporting System (CDRS), managed by Chinese Center for Disease Control and Prevention (China CDC). The core data sources for CDRS is the 605 disease surveillance points (DSP), covering a population of over 300 million—approximately 24% of China's total population—with broad geographic distribution (Figure S1).[9] The DSPs were selected using a multistage stratified sampling strategy to ensure provincial representativeness and data quality. Causes of death were coded according to the International Classification of Diseases, 10th Revision (ICD-10). Deaths attributed to ADD were identified using the following ICD-10 codes: F01 (vascular dementia), F03 (unspecified dementia), G30 (Alzheimer's disease), and G31 (other degenerative diseases of the nervous system, not elsewhere classified). For each decedent, the following demographic variables were collected: date of death, sex, age, and residential address.

### Historical meteorological data

Daily meteorological data from 2013 to 2020 were obtained from the Resource and Environmental Science Data Platform (https://www.resdc.cn), which compiles observations from 2417 national-level meteorological stations across China. The geographic distribution of these stations is shown in Figure S1. The dataset includes daily mean temperature, relative humidity, and atmospheric pressure.

Environmental exposures were estimated for each individual based on the interpolated values at their residential location. Point-based measurements from meteorological stations were converted into continuous gridded surfaces with a spatial resolution of 15 km × 15 km using inverse distance weighting (IDW).[6] Each individual was assigned the corresponding grid-level exposure according to their residential address.

### Future temperature data

The climate projection data used in this study were obtained from the high-resolution (6.25 km × 6.25 km) regional future climate change projection dataset developed by the National Climate Center of China.[10,11] This dataset was generated through dynamic downscaling using the RegCM4 regional climate model driven by global climate models from the Coupled Model Intercomparison Project Phase 5 (CMIP5), followed by statistical downscaling to further refine spatial accuracy. The final dataset offers daily temporal resolution and spans the period from 1980 to 2099.

In this study, we selected the MPI-ESM-MR global climate model as the basis for projection. The primary variable extracted was daily mean temperature. Projections were analysed under three Representative Concentration Pathways (RCPs)—RCP2.6, RCP4.5, and RCP8.5—representing low-, medium-, and high-emission scenarios, respectively. For spatial aggregation, daily county-level average temperatures were calculated using MATLAB and ArcGIS 10.4 for three future time slices: the 2030s (2030–2039), 2050s (2050–2059), and 2080s (2080–2089). These data were subsequently used to identify future extreme temperature event exposures.

The dataset was bias-corrected prior to analysis; detailed descriptions of the downscaling and bias-adjustment procedures are provided in the Supplementary Materials.

### Future population data

Based on published research,[12] we obtained annual spatially explicit population grids under three SSP–RCP scenarios (SSP1–RCP2.6, SSP2–RCP4.5, and SSP5–RCP8.5) for the 2030s, 2050s, and 2080s (spatial resolution: 30 arc-seconds, WGS84).

We performed spatial aggregation of the gridded population data to estimate annual county-level total population figures for each projection year. In addition, the dataset provides provincial-level population projections with age structure information under each SSP–RCP scenario and future time slice. Since the smallest available unit for age-specific population data is at the provincial level, we applied the provincial age structure (i.e., the proportion of the population aged ≥60 years) to each county within the same province. This approach allowed us to estimate the population aged ≥60 years at the county level for each scenario and time point. The calculation formula for the projected elderly population in each county is as follows:

$$P_{c,\geq 60} = P_c \times S_{p,\geq 60} \quad (1)$$

where $P_{c,\geq 60}$ represents the annual population aged ≥60 years in county $c$ for the designated year and SSP–RCP scenario, $P_c$ is the total population in county $c$ for the designated year and scenario, and $S_{p,\geq 60}$ is the proportion of the population aged ≥60 years in province $p$ for the designated year and scenario.

## Definitions of heatwaves and cold spells

Following established methodologies in the field,[13,14] heatwaves were identified when daily mean temperatures exceeded the 90th, 95th, or 97.5th percentile for at least 2–4 consecutive days, whereas cold spells were defined when daily mean temperatures fell below the 10th, 5th, or 2.5th percentile for the same durations. In total, nine heatwave definitions (P90, P95, and P97.5 combined with 2, 3, or 4 consecutive days) and nine cold spell definitions (P10, P5, and P2.5 combined with 2, 3, or 4 consecutive days) were created. Detailed methods and formulae are provided in the Supplementary Materials.

## Estimation of exposure-response relationship

We used a time-stratified case-crossover design to quantify the effects of heatwaves and cold spells on mortality from ADD. Conditional logistic regression combined with distributed lag non-linear models (DLNM) was applied to capture both lagged and cumulative effects of exposure. Detailed methodological descriptions for the heatwave analyses are provided in our previous publication.[15–18]

For cold spells, mortality risk on cold spell days was compared with non-cold spell days using conditional logistic regression, incorporating a lag of 0–14 days to account for delayed effects and potential short-term mortality displacement. Daily mean relative humidity, daily mean pressure, and public holidays were adjusted to control for potential confounding. Natural spline functions in DLNMs were applied to capture non-linear exposure–response relationships and lagged effects. Further details of the exposure–response modelling for both heatwaves and cold spells are provided in the Supplementary Materials.

## Projections of attributable deaths

For each day $t$ and county $c$, we computed the projected attributable deaths $AN_{t,c}$ as follows:

$$AN_{t,c} = \left(\frac{P_{c,\geq 60} \times M_{p,\geq 60}}{365.25}\right) \times \left(\frac{COR - 1}{COR}\right) \qquad (2)$$

where $P_{c,\geq 60}$, derived from equation (1), represents the county-level annual population projection for individuals aged ≥60 years during the 2030s, 2050s, and 2080s under SSP1–RCP2.6, SSP2–RCP4.5 and SSP5–RCP8.5 scenarios. $M_{p,\geq 60}$ represents the baseline mortality rate for ADD among individuals aged ≥60 years in each province, serving as a reference for the mortality rates across counties within that province. The product $P_{c,\geq 60} \times M_{p,\geq 60}$ is adjusted by dividing by 365.25 to convert annual deaths into daily estimates, assuming a uniform distribution across each day.[19] $CORs$ were derived using the P95 & 2-day definition for heatwaves and the P5 & 2-day definition for cold spells, and then applied at the county level for projections.[13,14] These two definitions were chosen to estimate attributable deaths because they provide robust and statistically reliable exposure-response estimates, capture the predominant population-level health burden while minimising bias from rare or overly mild events, and generate evidence most relevant for public health planning and climate adaptation policy.

## Definitions of human adaptation

To capture plausible human responses to future extreme temperatures, we considered three adaptation scenarios: no-adaptation, partial-adaptation, and full-adaptation. In the no-adaptation scenario, thresholds for defining heatwave and cold spell days remain at baseline percentiles (95th for heatwaves, 5th for cold spells). In the partial-adaptation scenario, thresholds are set as the arithmetic mean of baseline and projected decade percentiles, representing intermediate adaptation. In the full-adaptation scenario, thresholds are fully updated to the projected decade percentiles, assuming complete physiological, behavioural, technological, and infrastructural adjustment.

Specific threshold definitions and calculations are provided in the Supplementary Materials. These adaptation scenarios may correspond to feasible public health measures, such as increasing air conditioning coverage, establishing cooling or warming centres, enhancing community support for vulnerable populations, and implementing early warning systems for extreme temperature events.

## Sensitivity analysis

The primary source of uncertainty in our analysis stemmed from the estimation of cumulative odds ratios (CORs) for cold spell-related mortality risks. To evaluate the robustness of our findings, we performed a series of sensitivity analyses. These included variations in model covariates (e.g., degrees of freedom for relative humidity, inclusion/exclusion of pressure, and temperature) and temporal exclusions (e.g., removing data from 2020 to account for the COVID-19 pandemic). Detailed methods and alternative thresholds and durations used for sensitivity analyses are provided in the Supplementary Materials.

All data analyses were performed by R software, version 4.1.2 (R Project for Statistical Computing, Vienna, Austria, http://www.r-project.org).

Statistical significance was defined as $p < 0.05$ for all statistical tests.

## Ethics approval

The ethical approval was granted by the Ethics Committee of the National Institute of Environmental Health, Chinese Center for Disease Control and

Prevention with the approval number 201606. Individual patient consent was not required for our analysis of de-identified data collected from CDRS.

### 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.

## Results

### Summary statistics

Fig. 1A presents data on 399,036 deaths from ADD among individuals aged ≥60 years, stratified by cold spell days under nine different definitions. Across all definitions, the number of deaths on cold spell days was consistently lower than on non-cold spell days. However, female deaths on cold spell days outnumbered male deaths, and individuals aged ≥75 years had substantially higher death counts compared to those aged 60–74 years. Among the six administrative regions, East China recorded the highest number of cold spell–related deaths under all definitions.

Fig. 1B shows the number of ADD deaths occurring on heatwave days under nine different heatwave definitions. Similarly, female deaths exceeded male deaths, and the ≥75 age group experienced significantly more deaths than those aged 60–74 years. Regional disparities were also observed, with East China showing the highest number of deaths on heatwave days across most definitions.

### Associations between heatwaves/cold spells, and mortality

The lag-response and exposure-response relationships between heatwaves and ADD mortality among individuals aged ≥60 years were detailed in our previous study.[15] For the P95 & 2-day heatwave definition, the CORs were: 1.250 (95% CI: 1.220–1.281) nationwide; 1.303 (1.195–1.420) in North China; 1.359 (1.236–1.494) in Northeast China; 1.359 (1.308–1.412) in East China; 1.176 (1.114–1.242) in Southcentral China; 1.093 (1.018–1.174) in Southwest China; and 1.322 (1.156–1.512) in Northwest China.

Fig. 2 illustrates the lagged effects of cold spell exposure on ADD mortality under nine cold spell definitions. Overall, cold spells were associated with elevated mortality risks and showed consistent lag patterns across all definitions. Odds ratios (ORs) became significant at lag0, peaked at lag6, and gradually declined to non-significant levels before lag14. Therefore, a lag period of 0–14 days was used for subsequent analyses to capture the full delayed effects.

As shown in Fig. 3, the nationwide CORs under all cold spell definitions indicated a consistent increase in mortality risk. The CORs ranged from 1.102 (95% CI: 1.077–1.127) for the P10 & 4-day definition to 1.218 (1.165–1.273) for the P2.5 & 3-day definition.

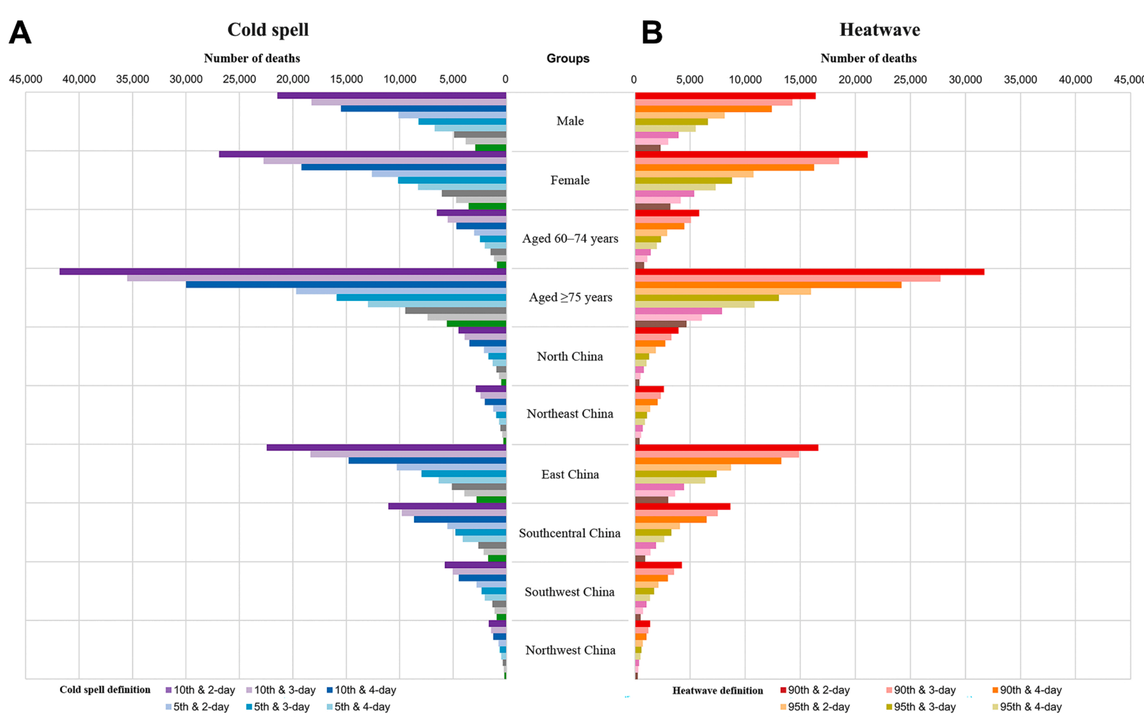


***Fig. 1:*** **Mortality from ADD stratified by cold spell (A) and heatwave days (B) across nine definitions.**

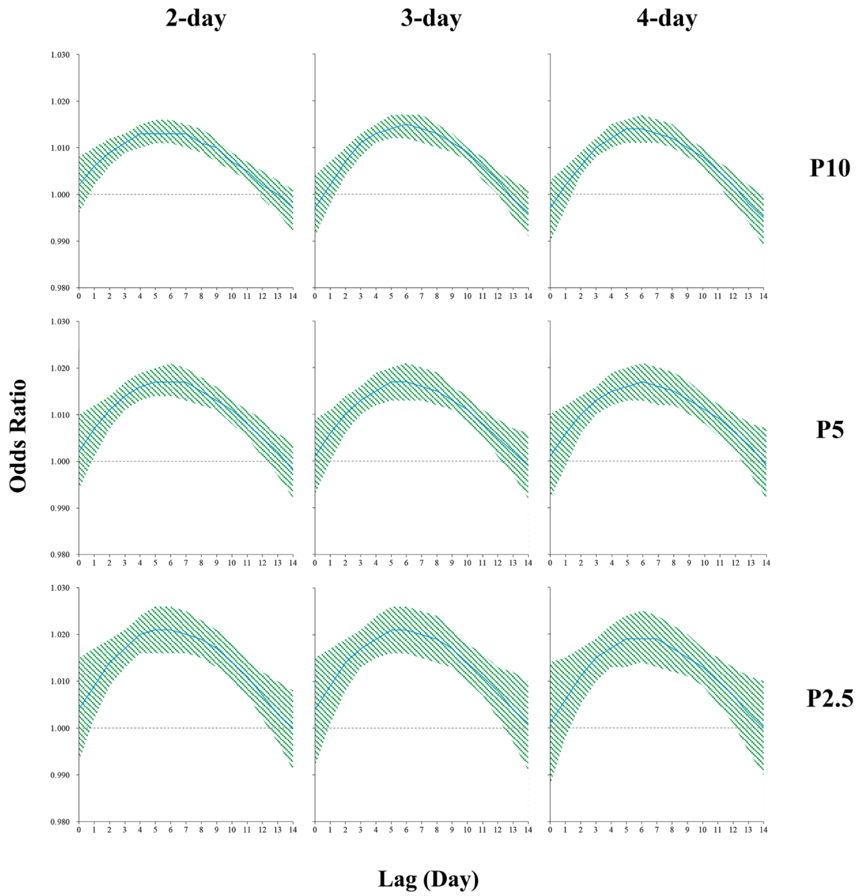


*Fig. 2:* **Lagged effects of cold spell exposure on ADD mortality under different definitions**.

Stratified analyses revealed regional variations in cold spell-related mortality were evident. The CORs for the P5 & 2-day cold spell definition were 1.163 (95% CI: 1.129–1.198) nationwide, 1.041 (0.942–1.151) in North China, 1.162 (1.011–1.336) in Northeast China, 1.237 (1.179–1.298) in East China, 1.205 (1.132–1.282) in Southcentral China, 1.126 (1.034–1.226) in Southwest China, and 0.995 (0.849–1.166) in Northwest China.

## Projections of extreme temperature event days

Under the no-adaptation assumption, Figure S2B–C shows that the number of heatwave days increases most significantly under RCP8.5, nearly doubling in the 2050s and 2080s. RCP4.5 also shows a notable increase in heatwave days, while RCP2.6 shows a slight decline followed by a modest increase. Conversely, cold spell days decline sharply under RCP8.5, particularly by the 2080s, with RCP4.5 showing a steady decrease, whereas RCP2.6 unexpectedly exhibits an increase over time.

Under the partial-adaptation assumption, the trends in heatwave and cold spell days become more moderate compared with no-adaptation, though variations are still evident under different emission scenarios.

Under the full-adaptation assumption, the trends in heatwave and cold spell days are generally more stable. The variations in extreme temperature event days are relatively smaller and more balanced, depending on the emission scenario and decade.

## Projections of attributable deaths

Between 2010 and 2020, an estimated 5355 (95% CI: 4155–6478) ADD-related deaths were attributable to heatwaves and 3527 (2379–4592) to cold spells nationwide in China. These values served as the baseline for projections.

Fig. 4 presents the projected heatwave-attributable deaths across 2975 counties in China. Under the no-adaptation assumption, heatwave-attributable deaths among individuals aged ≥60 years with ADD are projected to increase throughout the 21st century. Specifically, under SSP5–RCP8.5 scenario, heatwave-attributable deaths are expected to increase most significantly. Deaths rise from 19,469 (95% CI: 15,052–23,602)

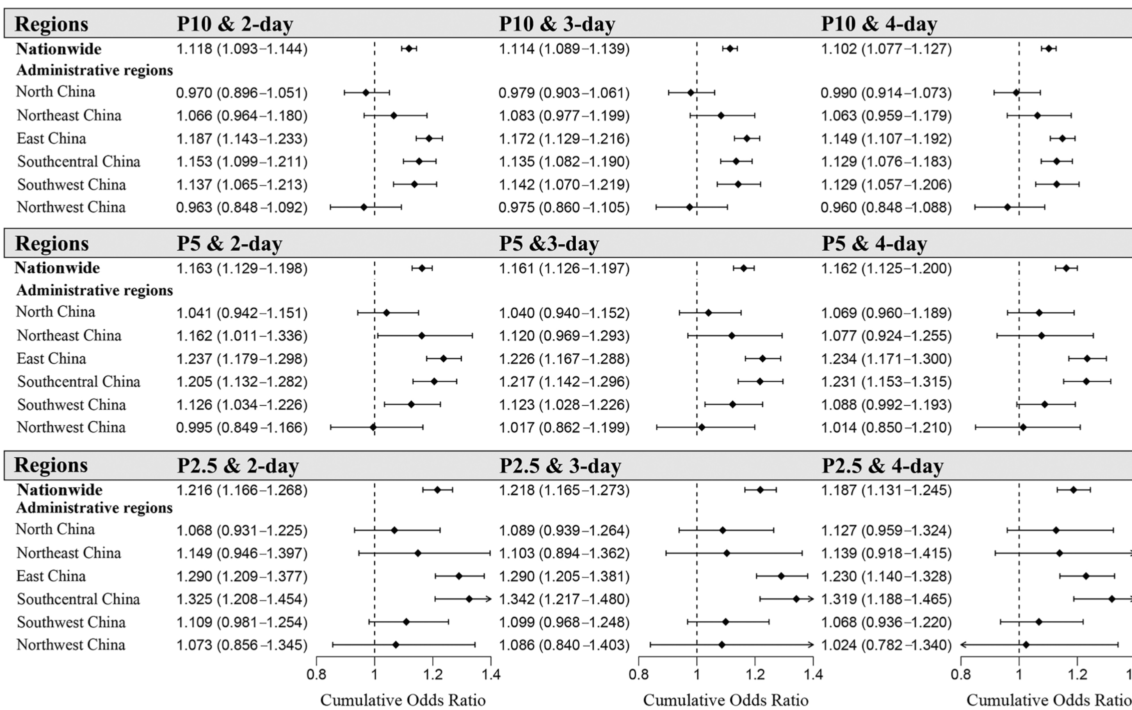


***Fig. 3:*** **Nationwide and regional CORs for cold spell-related mortality under different definitions**.

in the 2030s, marking a 3.6-fold increase (+264%) compared to the baseline, and are projected to reach 59,088 (44,195–73,006) in the 2080s, an 11-fold increase (+1003%). Under SSP2–RCP4.5 scenario, heatwave-attributable deaths show a clear upward trend, particularly in the 2050s and 2080s. Although under SSP1–RCP2.6 scenario, heatwave-attributable deaths are projected to increase at a slower pace and may even decline at times, they still remain higher than baseline levels. In the 2080s, deaths under SSP1–RCP2.6 are projected to reach 17,753 (13,458–21,766), a 3.3-fold increase (+232%) relative to the baseline of 5355. Adaptation measures are expected to significantly reduce heatwave-attributable deaths. Under SSP5–RCP8.5, partial adaptation is projected to reduce deaths by approximately 13–42%, while full adaptation could avert 22–76% of deaths across all scenarios.

Due to the statistically insignificant COR values for North China and Northwest China, projections of future cold spell-attributable deaths were not calculated for these two regions. Fig. 4 displays the projected cold spell-attributable deaths across 2173 counties. Cold spell-attributable deaths exhibit non-linear changes across scenarios, generally lower numbers. Under the high-emission SSP5–RCP8.5 scenario, cold spell-attributable deaths are projected to decrease, falling below baseline levels in the 2080s. Deaths decrease from 8424 (95% CI: 5588–11,053) in the 2030s, a 2.4-fold increase (+139%) relative to the baseline, to 2515 (1664–3304) by the 2080s, a 0.7-fold decrease (–29%) from baseline levels. Under the low-emission (SSP1–RCP2.6) and moderate-emission (SSP2–RCP4.5) scenarios, cold spell-attributable deaths initially rise slightly but ultimately decrease, although they remain higher than baseline levels. Only in a few scenarios, such as SSP1–RCP2.6 in the 2050s and 2080s, do adaptation measures produce modest reductions in cold spell-attributable deaths. In other scenarios, both the no-adaptation and partial adaptation assumptions result in higher cold spell-attributable mortality compared to the full adaptation assumption.

Overall, adaptation has a stable and pronounced effect on heatwave mortality but an inconsistent impact on cold spell mortality, which can even be exacerbated under certain conditions.

Fig. 5 presents the projected county-level deaths attributable to heatwaves and cold spells across China under the no-adaptation assumption. At the regional level, East China exhibits the largest increase in heatwave-attributable deaths. Under SSP5–RCP8.5, deaths rise from 3005 (95% CI: 2678–3319) at baseline to 27,363 (24,391–30,224) in the 2080s, representing a 9.1-fold increase. Southcentral China also shows a pronounced rise, from 797 (545–1038) to 13,716 (9379–17,858) deaths, corresponding to a 17.2-fold increase. North China follows a similar trend, with heatwave deaths reaching 7177 (5036–9128) in the 2080s under SSP5–RCP8.5, an 11.9-fold increase relative to the baseline value of 601 (422–765).

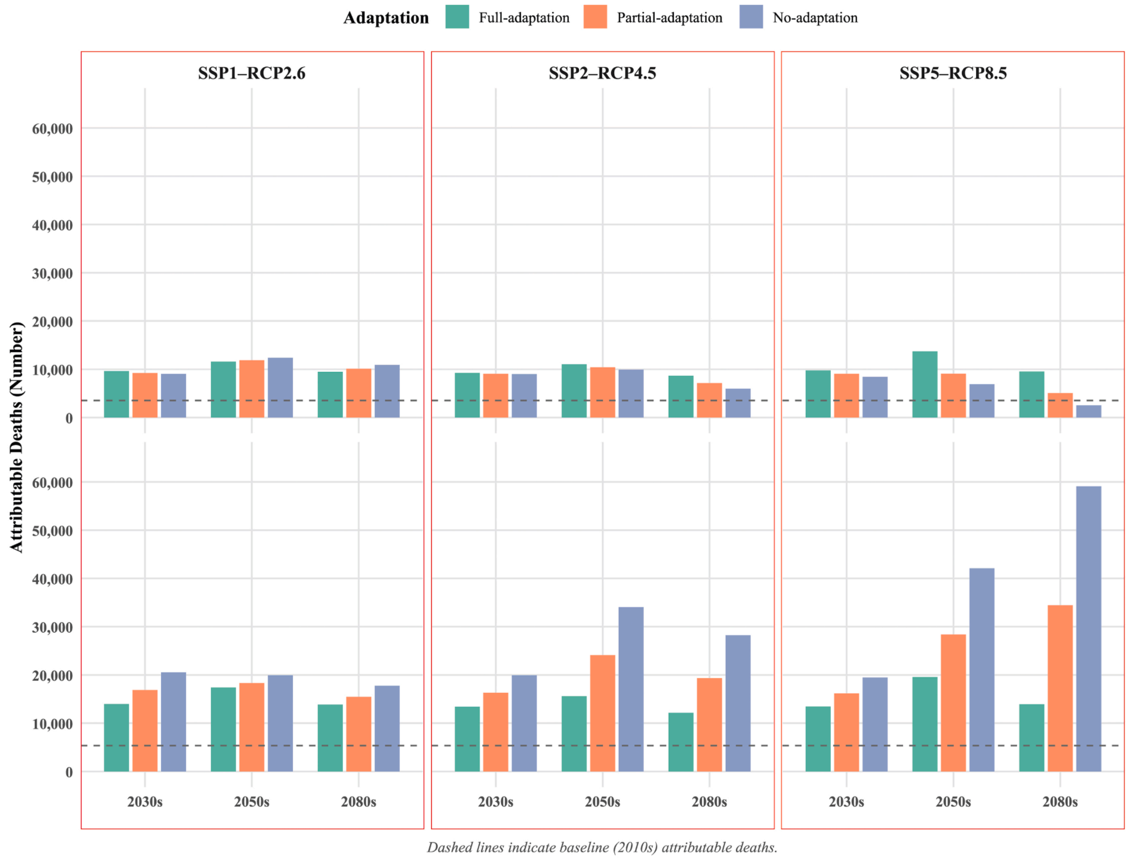


***Fig. 4:*** **Projected heatwave and cold spell-attributed deaths in China at county-level under different adaptation scenarios.**

In contrast, cold spell-attributable deaths decline substantially, especially in Northeast China, where deaths decrease from 214 (95% CI: 17–386) at baseline to 82 (6–148) in the 2080s under SSP5–RCP8.5, representing a reduction to 0.38 times the baseline. East China also shows a sharp decline in cold spell deaths, from 2050 (1625–2457) to 1191 (943–1427), corresponding to 0.58 times the baseline, while other regions, such as Southcentral and Southwest China, experience more moderate decreases.

The corresponding percent changes relative to the baseline are provided in Figure S7.

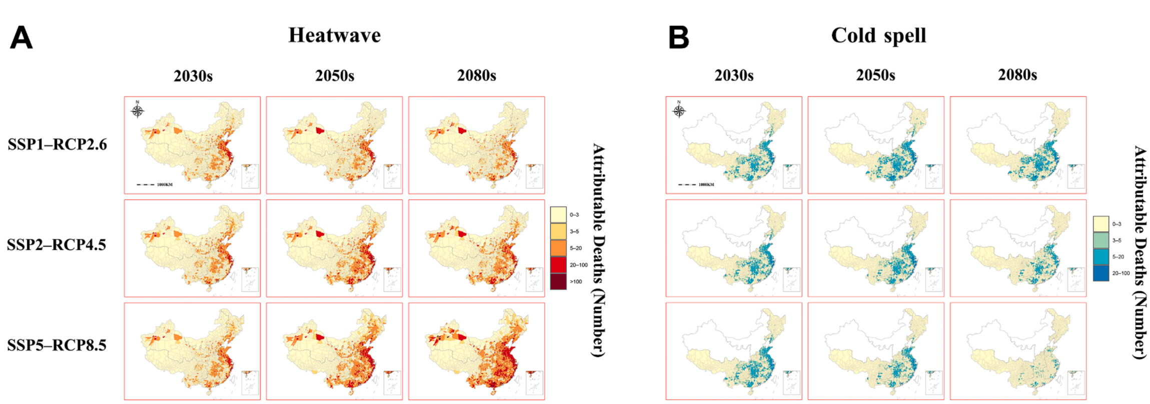


***Fig. 5:*** **Projected county-level deaths attributable to heatwaves (A) and cold spells (B) in China under the no-adaptation scenario.**

### Sensitivity analysis

The sensitivity analysis results showing the stability of nationwide COR estimates under different modelling choices are presented in Table S1 of the Supplementary Materials.

## Discussion

This study addresses the intersecting crises of climate change and population ageing—two defining forces shaping global health in the 21st century. By projecting dementia-specific mortality attributable to both heatwaves and cold spells, our findings provide new insights into how extreme temperature events may amplify the health burden of ADD in China. Although mortality associated with cold spells is projected to decline, this reduction is insufficient to offset the pronounced rise in heatwave-attributable deaths, leading to a net increase in overall attributable mortality.

Our findings are consistent with previous evidence that extreme temperatures elevate mortality risks.[5,6,20,21] However, most earlier studies examined continuous temperature exposures rather than discrete temperature events. By explicitly defining heatwaves and cold spells and integrating a nationwide climate–ageing–adaptation framework, our analysis provides the first event-based projections of ADD mortality under future climate scenarios in China, thereby situating our results within and extending the evolving literature on climate-related health risks.

Our previous study found that heatwaves had a particularly acute impact on ADD mortality, with effects typically lasting about one week.[15] In contrast, the current study revealed that cold spells have a significant delayed effect on mortality risk among the study population, exhibiting a distinct temporal pattern. The risk began to increase significantly at lag1, peaked at lag6, and gradually declined to non-significant levels before lag14. These findings suggest that the impact of cold spells on individuals with ADD manifests more gradually, potentially due to delayed physiological responses, worsening of preexisting chronic conditions, and increased susceptibility to infections—especially in a population with compromised stress responses and immune function.[21,22] Therefore, while immediate precautions are essential during heatwaves to reduce mortality risk, addressing the health risks associated with cold spells requires prolonged vigilance and interventions lasting up to two weeks after the event.

Epidemiological evidence demonstrates that heatwaves significantly increase mortality risk among individuals with ADD.[8,15] Our findings corroborate that cold spells pose similar risks. Biologically, exposure to cold environments can reduce core body temperature and trigger hypothermia.[21] Certain medications commonly prescribed to patients with ADD may further lower body temperature, compounding this risk.[23–25] Additionally, individuals with ADD often have reduced awareness and impaired judgement, limiting their ability to recognise and respond to cold weather. Wandering behaviour further increases their risk, and evidence suggests that nearly half of cognitively impaired individuals exposed to cold weather for more than 24 h could die.[26,27] Furthermore, the non-significant cold spell–related mortality in North and Northwest China may reflect regional adaptation. Populations in these regions are more physiologically acclimatized to cold, benefit from widespread indoor heating, and engage in consistent protective behaviours, while lower population density may also reduce exposure.[28] Together, these contextual factors mitigate cold-related risks and highlight the importance of accounting for regional heterogeneity when projecting temperature–mortality associations and developing targeted public health adaptation strategies.

The results of attributable death projections indicate that heatwaves pose a substantial threat to the study population under the no-adaptation scenario. The declining trend of attributable deaths under low-emission scenarios suggests that robust mitigation strategies can effectively kerb global warming, reducing the frequency and intensity of heatwaves and, in turn, heatwave-attributable mortality. Under SSP2–RCP4.5, the number of attributable deaths rises from the 2030s to the 2050s before declining in the 2080s, yet it remains significantly higher than under SSP1–RCP2.6. This trend may reflect a combination of factors, including short-term climate variability, increased population vulnerability due to ageing, and the intensifying urban heat island effect driven by rapid urbanisation.[20] Under the high-emission scenario, heatwaves are projected to become increasingly frequent and severe, resulting in a sharp rise in attributable deaths and emphasising the grave public health risks associated with continued high emissions.[29] Furthermore, regional disparities in projected heatwave-attributable deaths highlight the necessity for tailored policy responses. In regions such as East China, where mortality is projected to rise significantly, it is critical to enhance elderly care infrastructure, promote urban greening, improve building energy efficiency, and increase investment in public health resources.

Cold spell-attributable deaths exhibit distinct trends across different emission scenarios under the no-adaptation assumption. First, despite the overall warming trend, cold spells are projected to remain a threat, particularly under low-emission pathways, posing significant risks to vulnerable populations.[30] Second, population ageing further heightens societal vulnerability to cold-related mortality, contributing to increased deaths during extreme cold events. Lastly, under high-emission scenarios, the projected decline in attributable deaths may be largely driven by continued climate warming, which reduces the frequency of cold spells and lessens their health impacts.[5] Together, these factors shape the trajectory of cold spell-related mortality and underscore the importance of understanding their interplay in order to inform effective public health strategies for managing future risks associated with extreme cold weather.

The primary driver of the net attributable deaths increase is heatwave-related deaths, while the impact of cold spells is smaller and gradually diminishes over time. Although cold spell-attributable deaths are projected to decrease in the coming decades, their impact remains significant during certain phases, especially in vulnerable regions and populations, such as East China. The threat posed by heatwaves, particularly under high-emission scenarios, far outweighs the reduction in cold spell deaths, leading to a significant net increase in mortality. As climate change intensifies, the gap between the impacts of heatwaves and cold spells is expected to widen, requiring targeted public health interventions at different stages to address the challenges posed by both extreme temperature events.

Under the full-adaptation assumption, heatwave-attributable deaths decline significantly compared to scenarios without adaptation. This positive outcome likely reflects the successful implementation of various adaptive measures, such as improved building standards, strengthened public health systems, and increased public awareness of climate-related risks. These strategies enhance societal resilience to extreme heat, mitigating the adverse health impacts of rising temperatures.[31–34] For cold spells, however, the model paradoxically projects an increase in attributable deaths under the same adaptation scenarios. Part of this pattern likely reflects a methodological artifact: in our framework, adaptation is primarily parameterised for high temperatures, and in a warming climate, the absolute thresholds defining cold spells rise, resulting in more days classified as cold spells and hence higher estimated mortality. Beyond this technical explanation, physiological mechanisms may also contribute. Populations acclimatized to warmer conditions could exhibit reduced tolerance to cold, particularly in low-latitude regions, as suggested by epidemiological evidence.[5,20,35] Importantly, in reality, human adaptation to cold may improve over time through behavioural and infrastructural measures such as wider adoption of indoor heating, improved building insulation, and appropriate clothing. Therefore, the model's projections may conservatively estimate the potential benefits of cold adaptation, highlighting the need for integrated strategies that simultaneously address heat- and cold-related risks in a changing climate.

Several limitations should be acknowledged. First, the projections of attributable deaths are based on a set of assumptions, including the absence of adaptation measures and the continuation of current demographic trends. These assumptions may not fully capture real-world dynamics. Second, our projections assume that both ADD mortality and extreme temperature event–related mortality risks remain constant over time, without accounting for potential increases in disease incidence or non–climate-related mortality, which could lead to underestimation of future attributable deaths. Third, although we considered three adaptation scenarios, these represent simplified assumptions. Actual adaptation will be more gradual, context-dependent, and potentially constrained by resource inequality. Fourth, the mortality data used in this study were derived from the national CDRS, which may be subject to underreporting or misclassification, potentially leading to errors in cause-of-death classification and a modest underestimation of dementia-related mortality.

In conclusion, our findings show that dementia mortality in China will be profoundly shaped by the dual crises of climate change and rapid population ageing. Heatwaves are projected to dominate the future extreme temperature event-attributable deaths burden, but cold spells will remain an underappreciated threat in specific regions. Ambitious mitigation to kerb emissions, combined with dementia-inclusive adaptation strategies, is essential to prevent avoidable deaths. Protecting older adults with dementia from these converging risks is not only a matter of public health, but also of social justice and health equity. Our study provides a scientific foundation for building climate-resilient health systems in China and beyond, and underscores the urgency of integrating neurodegenerative care into global climate–health policy agendas.

#### Contributors
RuiZ: Writing—original draft, Software, Methodology, Formal analysis. SWW: Writing—review & editing, Resources, Funding acquisition. QG: Resources, Funding acquisition. QH and BL: Software, Methodology, Formal analysis. AJ, JZ, HZ, CW, XD, LJ, SL, QC, YM, LW, YH, MC and RN: Writing—original draft, Visualisation. SYW and RuiZ: review & editing, Conceptualisation. PB: review & editing. YL and RongZ: review & editing, Conceptualisation, Funding acquisition. JW: review & editing, Conceptualisation. All authors approve the final version of the manuscript. The author JW and RuiZ verified the data and had full access to all the raw data in the study. JW had final responsibility for the decision to submit for publication.

#### Data sharing statement
The mortality data can only be applied from National Population and Health Science Data Sharing Platform: https://www.phsciencedata.cn/Share/ky_sjml.jsp?id=6b5fc8c0-cffb-4a57-af26-a72070c65954.

#### Declaration of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Appendix A. Supplementary data**

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ebiom.2025.106072.

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