Journal of Infection 91 (2025) 106547

Contents lists available at ScienceDirect

Journal of Infection

journal homepage: www.elsevier.com/locate/jinf

Infectious Disease Practice

Impact of climate change and extreme temperature on the incidence of infectious disease among children and adolescents in China: A nationwide case-crossover study with over 8.7 million cases between 2008 and 2019

Li Chen [a], Duanke Liu [b], Yuchen Guo [c], Bo Wen [d], Yao Wu [d], Yi Xing [a], Yi Zhang [a], Xinli Song [a], RuoLin Wang [a], Jianuo Jiang [a], Yang Qin [a], Jun Ma [a], Mengjie Geng [e,*], Yanhui Dong [a,*], Yi Song [a,*], Daniel Prieto-Alhambra [c,f,1], Junqing Xie [c,1]

[a] Institute of Child and Adolescent Health, School of Public Health, Peking University, National Health Commission Key Laboratory of Reproductive Health, Beijing 100191, China

[b] Beijing Institute of Ophthalmology, Beijing Tongren Eye Center, Beijing Tongren Hospital, Capital Medical University, Beijing Key Laboratory of Ophthalmology and Visual Sciences, Beijing 100730, China

[c] Centre for Statistics in Medicine and The NIHR Oxford Biomedical Research Centre, NDORMS, University of Oxford, Oxford, England

[d] School of Public Health and Preventive Medicine, Monash University, Melbourne 3004, Australia

[e] Division of Infectious Disease Control and Prevention, Key Laboratory of Surveillance and Early Warning on Infectious Disease, Chinese Center for Disease Control and Prevention, Beijing 102206, China

[f] Department of Medical Informatics, Erasmus University Medical Center, Rotterdam, the Netherlands

A R T I C L E I N F O

Article history:
Accepted 2 July 2025
Available online 4 July 2025

Keywords:
Respiratory diseases
Gastrointestinal and enterovirus diseases
Vector-borne diseases
Temperature
Children and adolescents

S U M M A R Y

Background: The relationship between ambient temperature and infectious disease incidence lacks comprehensive documentation. Our study, therefore, sought to systematically determine the national association between temperature and the incidence of infectious diseases, categorized into respiratory, gastrointestinal and enterovirus, and vector-borne categories. We aimed to study the association between extreme cold and heat extreme temperature on infectious disease occurrence among children and teenagers, and to evaluate the secular trends in these diseases in relation to temperature extremes.

Methods: We accessed the dataset encompassing 8,731,930 cases of 27 distinct infectious diseases, spanning respiratory, gastrointestinal and enterovirus infections, and vector-borne categories, across 507 Chinese cities from 2008 to 2019. Employing a time-stratified case-crossover design, we quantified the association between temperature exposure and the risk of infectious diseases specific to each city. The attributable fractions for temperature-related risks were determined by identifying extreme temperatures exceeding the 90th percentile and falling below the 10th percentile of the respective city-specific temperature distributions, indicative of heat and cold effects. A comparative analysis of these attributable fractions between the periods 2008–2010 and 2017–2019 was conducted to evaluate the secular changes of infectious diseases associated with cold and heat.

Findings: Our analysis revealed significant non-linear associations between temperature and the incidence of specific infectious diseases. Cold temperatures were found to be responsible for 1.35% (95% CI: 1.18 to 1.51%) of respiratory infectious disease cases. In contrast, heat was attributed to a lower proportion, with 0.29% (95% CI: 0.25 to 0.33%) of such cases. Among gastrointestinal and enterovirus diseases, a more substantial 4.93% (95% CI: 4.82 to 5.04%) of cases were linked to heat exposure. Notably, vector-borne diseases demonstrated the highest attributable fraction to heat, with 22.12% (95% CI: 21.82 to 22.41%) of cases affected. Specifically, five diseases—scarlet fever, tuberculosis, mumps, leprosy, and typhus—exhibited an increased incidence associated with cold temperatures. Notably, for scarlet fever, leprosy, and typhus, the attributable fraction escalated from the period 2008–2010 to 2017–2019. However, findings for leprosy should be interpreted with caution due to its low incidence. As for heat-related diseases, thirteen were

* Corresponding authors.
E-mail addresses: gengmj@chinacdc.cn (M. Geng), dongyanhui@bjmu.edu.cn (Y. Dong), songyi@bjmu.edu.cn (Y. Song).

[1] Daniel Prieto Alhambra and Junqing Xie are Joint senior authors.

https://doi.org/10.1016/j.jinf.2025.106547

identified, with the attributable fraction for nine diseases—tuberculosis, pertussis, hand, foot, and mouth disease, infectious diarrhea, dysentery, hepatitis A, typhoid and paratyphoid, dengue, and Japanese encephalitis—showing a marked increase over the same comparative timeframes.

Interpretation: The temperature increase observed from 2008–2010 to 2017–2019 has been accompanied by a rising trend in heat-related infections. Among all infectious diseases in Chinese children and adolescents, more than half (13 out of 24) are heat-related, compared to five infections linked to extreme cold. The risk of gastrointestinal and enterovirus infections was associated with extreme hot temperatures, with vector-borne diseases particularly responsive to extreme heat. These findings highlight an urgent requirement for proactive public health measures to address the potential impact of temperature variability on infectious disease outbreaks, safeguarding vulnerable demographics in the context of climate change.

Introduction

Climate change, driven by rising global temperatures, profoundly affects human health, with extreme temperature fluctuations exacerbating infectious disease risks.[1,2] The World Health Organization (WHO) and United Nations (UN) have urgently called for action to mitigate these impacts, prioritizing vulnerable populations like children, who face disproportionate risks from climate-sensitive diseases.[3–7] Ambient temperature variations influence pathogen survival, transmission dynamics, and host susceptibility,[8–14] with studies linking heat and cold exposures to elevated risks of respiratory, gastrointestinal, and vector-borne infections—such as acute lower respiratory infections, hand, foot, and mouth disease, and malaria.[15–19] Yet, prior research has largely overlooked these associations in children, a critical gap given that 99% of the world's youth are exposed to climate hazards,[7] and nearly 1 billion face heightened risks under worsening scenarios like Representative Concentration Pathway (RCP) 8.5, which projects a 4 °C rise by 2100.[20,21]

Despite this urgency, comprehensive, long-term assessments of climate-driven infectious disease impacts in children remain scarce.[22–24] Existing studies often rely on short-term data, conflating transient effects with sustained climate trends, and fail to address discrepancies in scale—where climate change operates over decades and vast spatial extents, while disease dynamics are typically measured over months and smaller areas.[21,25] Moreover, the lack of standardized, child-focused frameworks has hindered identification of climate-sensitive diseases,[26] leaving non-vector infections (e.g., respiratory and gastrointestinal) understudied across diverse climates.[27–32] This gap is stark given the Sustainable Development Goals (SDGs), particularly Target 13.1, which calls for enhanced resilience to climate-related hazards—a priority unmet by the lack of national-scale evidence on child health.[33] This is particularly concerning as infectious diseases—pneumonia, diarrhea, and malaria—account for nearly 30% of global under-five mortality, a burden intensified by climate shifts like rising temperatures and extreme weather events that contaminate water and food sources.[34,35]

Our study bridges these gaps by leveraging 8.7 million verified cases from China's National Notifiable Infectious Disease Surveillance System (2008–2019) to examine the impact of temperature extremes on 27 infectious diseases in children and adolescents across 507 prefecture-level cities. Spanning China's equatorial-to-temperate climates, we provide a standardized, nationwide analysis of respiratory, gastrointestinal, enterovirus, and vector-borne infections—addressing the SDG Target 13.1 for climate resilience.[33] The study's objective is twofold: first, to quantify the national associations between temperature variations and specific infectious disease etiologies, identifying those associated with both cold and heat exposures; second, to examine secular trends in the relationship between temperature extremes on the incidence of infectious diseases. This dual approach not only advances understanding of temperature-disease dynamics but also informs adaptive public health strategies for a warming world, fulfilling international calls for rigorous evidence on this pressing climate-health nexus.

Methods

Data collection

The China Information System for Disease Control and Prevention (CISDCP) is a comprehensive repository that systematically compiles and updates data on the incidence and mortality rates of notifiable infectious diseases. This data is derived from a network of over 168,000 health facilities across all 31 provinces of mainland China, encompassing 507 prefecture-level cities (Fig. S1).[36] The system boasts a coverage rate of over 95% for health institutions at or above the county level, with an average reporting time of 4 h in 2022.[37,38] All cases were diagnosed and reported by qualified healthcare professionals in accordance with standardized national diagnostic criteria issued by the Chinese Center for Disease Control and Prevention (China CDC) and the National Health Commission, as detailed previously.[36] Our study extracted data on the daily incidence and mortality of 27 notifiable infectious diseases within the pediatric and adolescent population, aged 4 to 22 years, over a 12-year period from 2008 to 2019. The lower age boundary of 4 years was selected to align with the typical age of kindergarten entry, while excluding infants and very young children (under 4 years) whose healthcare-seeking behaviors and vaccination schedules may introduce additional heterogeneity in disease reporting. The upper age limit of 22 years was chosen to capture adolescents and young adults consistent with international definitions of youth.[39] Cases reported from regions such as Hong Kong, Macao, Taiwan, and other international sources lacking verified records were excluded to ensure data integrity. The analysis was conducted on data from a total of 507 prefecture-level cities, aligned with China's 2021 administrative divisions. This includes the districts and counties within direct-controlled municipalities (Beijing, Shanghai, Tianjin, Chongqing) and special administrative regions, which are not included in the standard list of 334 prefecture-level cities. Infectious diseases were categorized into three distinct groups: respiratory, gastrointestinal and enterovirus, and vector-borne diseases (Supplementary methods). Supplementary Table S1 provides a detailed list of identifiers and abbreviations for each disease. It is noteworthy that diphtheria, poliomyelitis, and filariasis had no reported cases during the study period and, consequently, were excluded from the analysis.

Meteorological data

We procured hourly meteorological data with a spatial resolution of 0.25° × 0.25° from the ERA5 reanalysis dataset, the fifth generation European Centre for Medium-Range Weather Forecasts.[40] This dataset was meticulously processed to derive a suite of daily meteorological parameters for each grid, adjusted to correspond with local time zones. The parameters encompassed daily mean 2-meter ambient temperature (aggregated from hourly records) and daily mean 2-meter dew point temperature. Although our primary focus is on the impact of temperature, we also extracted relative humidity and particulate matter (PM2.5) as they are key environmental factors that may confound or modify the association between temperature and infectious disease risk. Humidity and $PM_{2.5}$ were included in the analysis because they have been shown to independently influence infectious disease transmission and may interact with temperature to amplify or mitigate its effects. The daily mean relative humidity was calculated from the mean temperature and dew point measurements using the Humidity R package.[41]

Concurrent with the meteorological dataset, we sourced global annual population counts from the WorldPop project, ranging from 2000 to 2019, at a 30 arc-second spatial resolution, which were then upscaled to a 0.25° × 0.25° resolution to match the granularity of the meteorological data.[42] For each city in our study, daily $PM_{2.5}$ concentrations and weather variables were determined by averaging the daily exposures across all grids within the city's boundaries at a 0.25° × 0.25° resolution, with refinements made according to the population density of each grid cell. Specifically, daily population-weighted averages of $PM_{2.5}$ concentrations was calculated for each city, weighting the value from each grid cell by its population share within the city, to better reflect the population-level exposure.

Statistical analysis

To evaluate long-term changes in temperature, we calculated the average number of days with daily temperatures exceeding 28 °C and below −5 °C for each city during the periods 2008–2010 and 2017–2019. Normality was assessed using the Shapiro-Wilk test. If the data were not normally distributed, the Wilcoxon signed-rank test was applied; otherwise, a paired t-test was used. To further examine variations in the number of days exceeding specific temperature thresholds across different temperature ranges, we calculated the number of days surpassing each threshold for each city and employed generalized additive models (GAM) to assess differences in fitted curves between the two periods.

The case data used in this study were individual-level, with each record representing a diagnosed case of an infectious disease, including the date and location of diagnosis (prefecture-level). The time-stratified case-crossover design was used to quantify the association between temperature exposure and city-specific infectious disease risks. This epidemiological approach leverages each individual as their own control, referencing the average condition of the entire population. Each case was juxtaposed with three or four control periods occurring on the same day of the week within the same calendar month, thereby accounting for confounding variables including gender, age, and lifestyle factors. The comparison was made between the daily mean temperatures of the case and control periods, with the association measured using a conditional logistic regression model. The logistic model utilized in this study posits the log-odds of an infectious disease case occurring within a stratum, indexed by *i* for fixed time in city *j* (with matching by calendar month for both case and control days), as a function of environmental covariates. These include $PM_{2.5}$, a known modifier of temperature-related infectious disease risk, and humidity, which may influence pathogen survival and transmission.[15,43,44] The model is formalized as follows:

[$\text{logit}(P(\text{case}=1|\text{temp}, \text{humidity}))=\beta_{0,\text{stratum}ij}+\text{cb}(\text{temp})+\text{cb}(\text{humidity})+\beta\times PM_{2.5}0x$]. Here, $\beta_{0,\text{stratum}ij}$ signifies the intercept for stratum *i* in city *j*, reflecting inherent regional disparities. $PM_{2.5}0x$ denotes the average concentration of $PM_{2.5}$ over specific lag days x. The functions cb(temp) and cb(humidity) are cross-basis functions that capture the complex exposure-response and lag-response relationships for temperature and humidity, respectively.

A maximum lag period of 21 days was selected to account for the incubation periods of most infectious diseases. To determine the optimal lag for each disease, we initially conducted a review of the existing literature to identify relevant lag periods (ranging from 0 to 21 days), based on evidence suggesting that both cold and hot weather can exert delayed effects lasting several weeks[14,45–47] and then applied the Akaike Information Criterion (AIC) within the incubation period to refine the selection. For example, the incubation period for influenza ranges from 1 to 7 days, while that for hand, foot, and mouth disease is 3 to 5 days. The final lag periods used in the analysis are detailed in Table S1. We adopted a natural B-spline with three degrees of freedom (df) to model the exposure-response relationship for daily mean temperature and relative humidity using a cross-basis function. Similarly, a natural cubic spline with three degrees of freedom was used for the lag-response relationship, with knots placed at equidistant logarithmic intervals determined by the "logknots" function in the "dlnm" R package, adhering to a formula of df minus two for knot placement. Relative Risks (RRs) and 95% confidence intervals (CIs) were calculated relative to designated reference values. The minimum mortality temperature (MMT) was used as the reference temperature when observed; otherwise, the 50th percentile (P_{50}) or a specific temperature, such as 10 °C, was utilized. The reference temperature was selected based on the exposure-response relationship curve. The MMT was used for U-shaped curves, as it represents the lowest health risk. If MMT was not identified, P50 was chosen for standardization. For example, for hand, foot, and mouth disease (HFMD), where risk increased monotonically with temperature, the 50th percentile (P50) was used as the reference temperature. For N-shaped curves where P50 was near peak risk, 10 °C was used to facilitate attributable risk calculation.

In the sensitivity analysis, we performed age-stratified analyses to examine age-related differences in the association between ambient temperature and infectious disease incidence. Age categories were defined based on educational stages—kindergarten and primary school (4–12 years), middle school (13–15 years), high school (16–18 years), and university (19–24 years)—to reflect shared behavioral patterns and social interactions that influence infection risk. This classification aligns with the typical kindergarten entry age of 3–4 years and the United Nations definition of 'youth' (15–24 years). Additionally, we conducted subgroup analyses stratified by economic indicators (urbanization rate, educational attainment rate, and GDP, based on 2019 data) and by Köppen–Geiger climate zones (tropical, arid, temperate, cold temperate, and polar),[48] to further explore heterogeneity in temperature–-disease associations across socioeconomic and climatic contexts. For vector-borne diseases, rainfall is a key factor affecting pathogen survival and transmission; therefore, we included rainfall in the main analysis to evaluate of the associations. In addition, we conducted complementary analyses without rainfall adjustment to explore the robustness of the observed associations. To evaluate the temporal stability of associations, we conducted separate analyses for the periods 2008–2010 and 2017–2019. To examine geographic variation in temperature-disease relationships, we stratified the analysis by region (northern vs. southern). An additional sensitivity analysis extended the maximum lag period of daily mean temperature to assess its impact on infectious diseases.

We assessed the attributable fraction (AF) and number of cases linked to temperature, evaluating the impact across different temperature ranges—moderate heat (P_{90}), extreme heat (P_{95}), moderate cold (P_{10}), and extreme cold (P_5)—based on the city-specific temperature distribution.[49] AF were estimated based on the method described by Gasparrini and Leone.[50]

$$AF_{x,t} = 1 - \exp\left(-\sum_{l=l_0}^{L} \beta_{x_{t-l},l}\right)$$

$AN_t = n_t \cdot AF_{x,t}$

Where: $AF_{x,t}$ is the AF of the health outcome for city x on day t; L is the longest lag time for the exposure factor (e.g., how many previous days are considered for the lag effect); l_0 is the starting lag, typically l_0=0 (representing the current day t); $\beta_{x_{t-l},l}$ is the effect parameter for the exposure index on city x on day $t - l$ at lag l. This represents the effect of the exposure at lag l on the health outcome; The summation$\sum_{l=l_0}^{L}$ accumulates the effects of the exposure across multiple lags from day t backward to t-L.

These cutoff points facilitated the risk assessment associated with temperature variations. Empirical CIs for the temperature-mortality association were generated through Monte Carlo simulations. To evaluate the influence of climate change on infectious diseases, a comparative analysis of AF and case numbers between the periods 2008–2011 and 2017–2019 was performed using consistent analytical methods. The analyses were performed using R software, version 4.2.2, leveraging the "gnm", "dlnm", "FluMoDL" packages for conditional logistic regression, distributed lag non-linear models, and AF calculation. Statistical significance was ascertained by a two-sided p-value of less than 0.05.

Results

General characteristics of infectious diseases and ambient temperature

From the years 2008 to 2019, China documented a cumulative total of 8,731,930 instances of children and adolescents aged 4–22 years with respiratory illnesses, gastrointestinal and enterovirus infections, along with vector-borne diseases. The demographic data indicates a mean patient age of 9.6 years, with a significant female predominance, accounting for 67.4% of the reported cases (Table S2). An analysis of the spatial distribution unveils a notable disparity, with a higher concentration of infectious diseases in the southeastern regions in contrast to the northwestern regions of the country. This pattern is observed uniformly across the three aforementioned categories of diseases, each exhibiting a unique seasonal prevalence: respiratory diseases exhibit peak incidence during the winter season, gastrointestinal and enterovirus infections surge in the summer, and vector-borne diseases are most prevalent during the warmer months, as depicted in Fig. 1 A-H. Respiratory diseases are identified as the most common, representing 69.7% of the total cases, with gastrointestinal and enterovirus infections following at 29.8%, and vector-borne diseases at a comparatively lower incidence rate of 0.4%. Within the respiratory disease category, seasonal influenza, mumps, and tuberculosis are the most frequently diagnosed conditions. In the realm of gastrointestinal and enterovirus infections, hand, foot, and mouth disease, infectious diarrhea, and dysentery are the leading ailments. For vector-borne diseases, dengue, malaria, and hemorrhagic fever with renal syndrome are the most frequently reported, as illustrated in Fig. 1 I-L.

The spatial analysis of annual temperatures in China from 2008 to 2019 delineates a consistent pattern of higher mean daily temperatures in the southern regions as opposed to the north, as illustrated in Fig. 2A. The southern regions consistently record a substantial number of days per year where temperatures surpass 28 °C, while the frequency of days with temperatures plummeting below −5 °C is significantly reduced ($p < 0.001$ for both), a trend observed across both the 2008–2010 and 2017–2019 periods (Fig. 2 B-E). A comparative examination of the temperature distribution curves from these two timeframes reveals a subtle yet significant rightward shift in the distribution of annual daily temperatures across 507 Chinese cities during 2017–2019, signifying an escalation in peak temperatures (Fig. 2 F and G). This shift is corroborated by an increase in the frequency of high-temperature days and a concurrent decline in low-temperature days, underscoring a discernible warming trend (Fig. 2 H and I). Specifically, the period from 2008–2010 to 2017–2019 witnessed an upswing in the occurrence of high-temperature days, defined as those exceeding 28 °C, and a reciprocal decrease in the days with temperatures below −5 °C. This trend is graphically manifested in the temperature distribution curve's rightward displacement and the elevation of peak values in 2017–2019, thereby corroborating a pronounced warming trajectory throughout the study's temporal scope.

Association between ambient temperature and infectious diseases

Fig. 3 presents a comprehensive examination of the correlation between temperature fluctuations and the incidence of infectious diseases across various categories from 2008 to 2019 at the national scale. It is evident that the interplay between ambient temperature and disease occurrence is nuanced and varies substantially among different disease types. In the case of respiratory infections, a bimodal relationship emerges, with both extremes of temperature-low and high-tending to escalate the incidence rates. Intriguingly, the incidence rate reaches its nadir at a temperature that corresponds to the 92nd percentile (Fig. 3A). This overarching trend is mirrored in the incidence of specific respiratory diseases such as influenza and tuberculosis, while mumps exhibit an inverted U-shaped relationship with temperature (Fig. 4). Gastrointestinal and enterovirus infections demonstrate a positive correlation with temperature, with the incidence rate escalating as temperatures rise, reaching a zenith at the 95.4th percentile before experiencing a modest decline (Fig. 3B). This pattern holds true for individual gastrointestinal diseases, where the risk escalates in tandem with temperature increases (Fig. 4). Vector-borne diseases exhibit a distinct relationship with temperature, with the risk diminishing at lower temperatures and then surging rapidly between 20–30 °C, with a peak around 30 °C, after which it begins to recede (Fig. 3C). The specific correlation between temperature and individual vector-borne diseases, such as dengue fever and malaria, diverges; while dengue fever follows the general trend, malaria risk patterns should be interpreted with caution given its low incidence and the influence of imported cases (Fig. 4). More details are provided in Table S2 -S7 and Fig. S2-S4.

Examination of extreme temperature ranges indicated that, under extreme cold, the risks of gastrointestinal and vector-borne diseases increased in an approximately linear fashion. Under extreme heat, respiratory infections showed a positive association with temperature, whereas gastrointestinal and vector-borne disease risks exhibited near-linear decreasing trends. Substantial heterogeneity in temperature-risk associations was observed across individual diseases. (Figs. 3–4 and Fig. S2).

The robustness of our findings was supported through sensitivity analyses using different lag periods (Fig. S5–S8). For vector-borne diseases, without adjusting for rainfall as a covariate in the sensitivity analysis demonstrated consistent temperature-disease relationships (Fig. S9).

Subgroup analyses stratified by economic indicators, including urbanization rate, educational attainment rate, and GDP, revealed that respiratory and vector-borne diseases exhibited more pronounced temperature-related risks in cities with higher economic levels, particularly under extreme heat. In contrast, gastrointestinal diseases showed broadly consistent temperature–response patterns across different economic strata (Figs. S10–S12). Subgroup analyses stratified by Köppen–Geiger climate zones further revealed heterogeneity in temperature–response relationships across climatic contexts. For respiratory diseases, both temperate and cold temperate zones exhibited pronounced risk increases at temperature extremes, while arid regions showed a generally decreasing risk with higher temperatures. For gastrointestinal diseases, a consistent positive association with temperature was observed across most climate

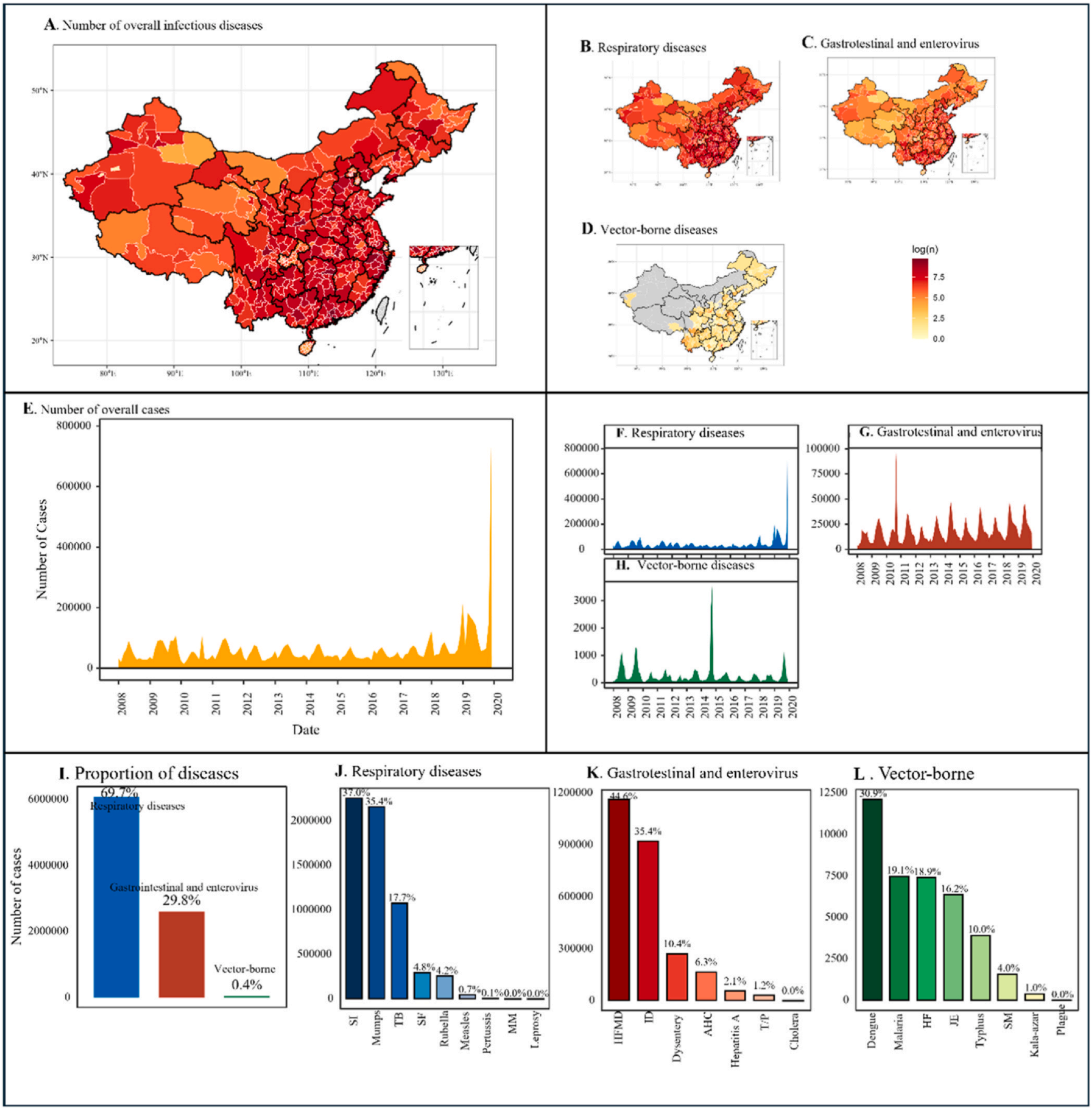

Fig. 1. Spatial and temporal distribution of infectious disease cases in China. Notes: The abbreviations and full names of diseases are provided in Table S1; Panel A illustrates the geographical distribution of total infectious disease cases. Panels B-D show the spatial distribution of respiratory diseases, gastrointestinal and enterovirus diseases, and vector-borne diseases, respectively. Panel E depicts the temporal distribution of total infectious disease cases. Panels F-H present the temporal distribution of respiratory diseases, gastrointestinal and enterovirus diseases, and vector-borne diseases, respectively. Panel I represents the proportion of disease classifications. Panels J-L detail the proportion of individual diseases within the categories of respiratory diseases, gastrointestinal and enterovirus diseases, and vector-borne diseases, respectively.

zones. For vector-borne diseases, risk patterns were bell-shaped in most zones, with peak risks at moderate to high temperatures (Figs. S13–S15).

Subgroup analyses stratified by age group revealed distinct temperature-response curves for respiratory infectious diseases between adults and children, particularly for seasonal influenza and mumps (Figs. S16–S18). In contrast, no significant age-related differences were observed in the temperature-response relationships for gastrointestinal and vector-borne diseases (Figs. S16, S19, and S20).

Geographic variation in associations was more pronounced for respiratory diseases, especially seasonal influenza, while no significant regional differences were identified for gastrointestinal diseases, except for hand, foot, and mouth disease, or for vector-borne diseases (Figs. S21–S24). Temporal subgroup analysis comparing 2008–2010 and 2017–2019 revealed notable shifts in the temperature-response curves for several infectious diseases, including seasonal influenza, meningococcal meningitis, and hepatitis A (Figs. S25–S28).

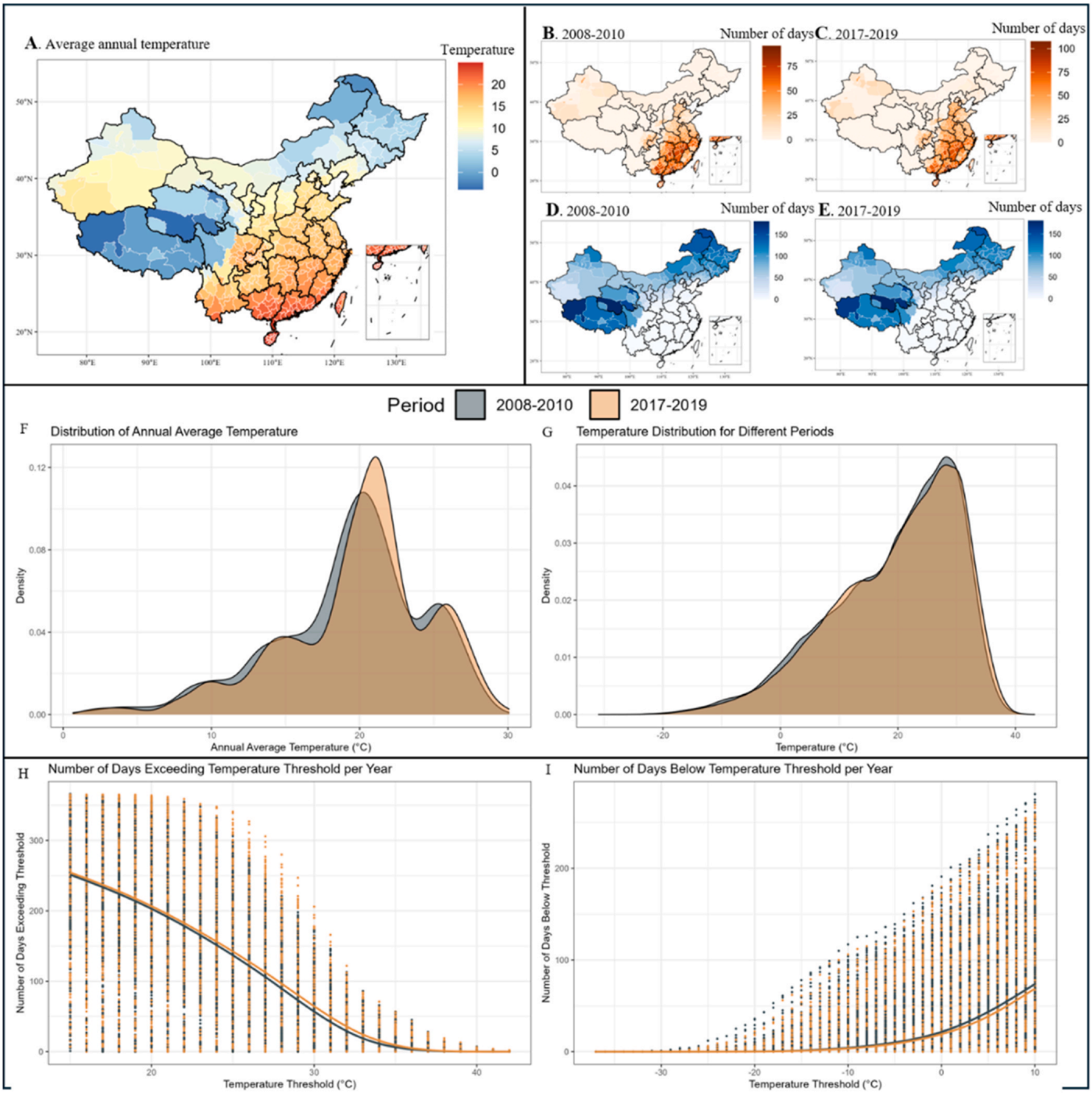

Fig. 2. Comparative Analysis of Temperature Variability and Extremes Across China. Notes: Panel A: Geographical distribution of annual daily temperatures from 2008–2019. Panels B and C: Geographical distribution of the average number of days with daily temperatures exceeding 28 °C for 2008–2010 and 2017–2019, respectively. Panels D and E: Geographical distribution of the average number of days with daily temperatures below −5 °C for 2008–2010 and 2017–2019, respectively. Panel F: Density distribution of annual average temperatures for 507 cities in 2008–2010 and 2017–2019. Panel G: Density distribution of daily temperatures for 507 cities in 2008–2010 and 2017–2019. Panel H: Number of days exceeding specific temperature thresholds in 2008–2010 and 2017–2019. Panel I: Number of days below specific temperature thresholds in 2008–2010 and 2017–2019. Panels H and I: Each scatter point represents the number of days per year for a single city exceeding (H) or below (I) the corresponding temperature threshold on the x-axis. The solid black curve indicates the smoothed average trend across all cities.

Number and proportion attributed extreme temperatures (cold and heat) by the disease's classification

Fig. 5 and Table S8 delineate the AF of specific infectious diseases in relation to extreme temperatures, both hot and cold, at the national level, alongside the respective case counts. Assuming a causal link, the analysis estimates that 1.35% (95% CI: 1.18 to 1.51%) of respiratory infectious disease cases are attributable to cold temperatures (below the 10th percentile in each city), and 0.61% (95% CI: 0.51 to 0.69%) to temperatures below the 5th percentile. In contrast, 0.29% (95% CI: 0.25 to 0.33%) of cases are attributed to hot temperatures (above the 90th percentile), with 0.18% (95% CI: 0.15 to 0.20%) linked to temperatures exceeding the 95th percentile. We presented the geographic distribution of attributable annual case numbers for specific diseases. Respiratory diseases were most affected by cold temperatures in northern regions and by heat in southern regions, whereas gastrointestinal and vector-borne diseases were primarily associated with high temperatures in southern

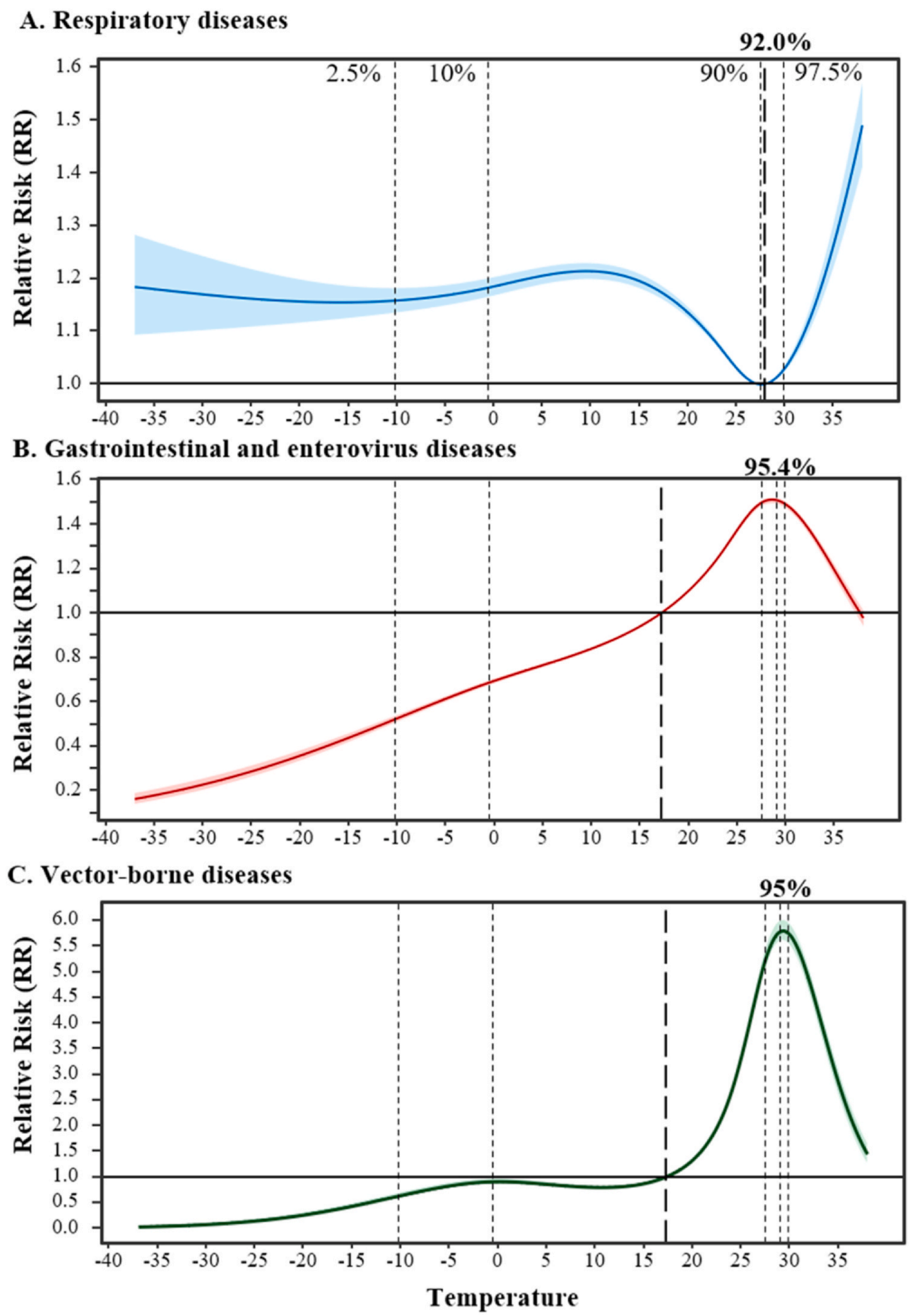

Fig. 3. Temperature-Dependent Relative Risk for Respiratory, Gastrointestinal and Enterovirus, and Vector-borne Diseases. Notes: In Panel A, the first dotted line represents the 2.5th percentile, the second dotted line represents the 10th percentile, the third dotted line represents the 90th percentile, and the fourth dotted line represents the 97.5th percentile. These dotted lines are consistent in Panels B and C. The thicker dotted line indicates the reference temperature.

and central areas. Notably, the impacts of high and low temperatures varied across regions for certain diseases (Figs. S31–S32).

Notably, the AF for both cold and hot temperatures was higher in the period 2017–2019 compared to 2008–2010, as depicted in Fig. 5A-D. For gastrointestinal and enterovirus diseases, the AF for cases linked to temperatures above the 90th percentile is 4.93% (95% CI: 4.82 to 5.04%), and for those above the 95th percentile, it is 2.58% (95% CI: 2.51 to 2.65%). The AF for high temperatures was notably higher in 2008–2010 than in 2017–2019, with respective changes of 0.51 and 0.81 for the 90th and 95th percentiles, as illustrated in Fig. 5E-F. In the case of vector-borne diseases, a significant 22.12% (95% CI: 21.82 to 22.41%) of cases are attributable to temperatures above the 90th percentile, and 12.57% (95% CI: 12.35 to 12.79%) to temperatures above the 95th percentile. The AF for high temperatures showed a greater impact in 2008–2010 compared to 2017–2019, with respective changes of 0.85 and 2.49 for the 90th and 95th percentiles, as indicated in Fig. 5G-H.

Our investigation into the temporal changes in the AF for each infectious disease from 2008–2010 to 2017–2019 reveals that at lower temperatures, the AF for specific infectious diseases such as seasonal influenza (SI), tuberculosis, mumps, and typhus have increased, with a rise in AF values observed for SI and typhus (Fig. 5 I

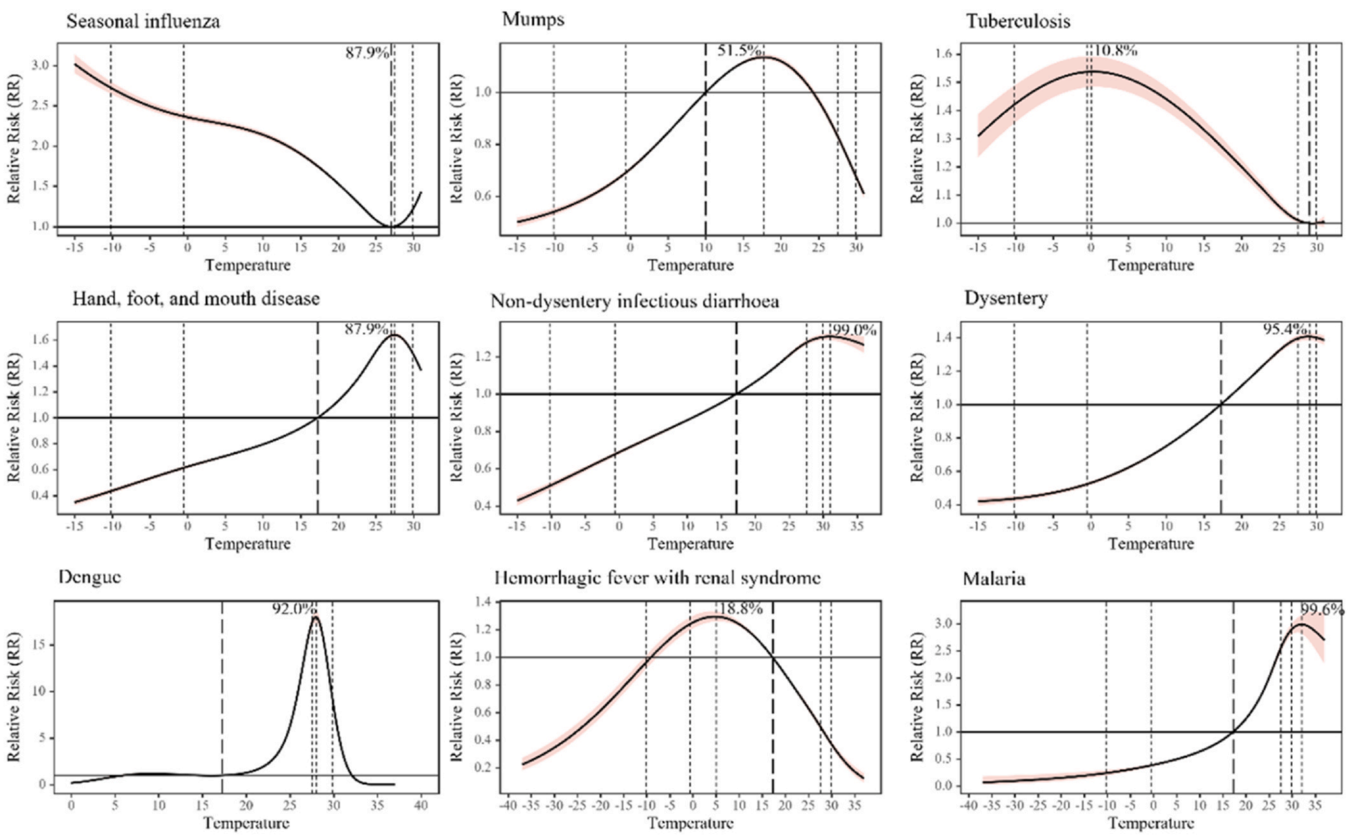

Fig. 4. Temperature-Associated Relative Risks for Select Infectious Diseases. Notes: In all Panels, the first dotted line represents the 2.5th percentile, the second dotted line represents the 10th percentile, the third dotted line represents the 90th percentile, and the fourth dotted line represents the 97.5th percentile. The thicker dotted line indicates the reference temperature.

and K). A similar trend was observed for leprosy, though its low incidence necessitates cautious interpretation. Conversely, at higher temperatures, an increase in AF was observed for nine infectious diseases, including tuberculosis, pertussis, hand, foot, and mouth disease, infectious diarrhea, dysentery, hepatitis A, typhoid and paratyphoid, dengue, and Japanese encephalitis, from 2008–2010 to 2017–2019 (Fig. 5 J and K). These findings suggest that the increase in high-temperature days and the consequent rise in annual average temperatures may be associated with a heightened incidence of these infectious diseases.

Discussion

This pioneering study leverages a robust, large-scale, nationally representative surveillance dataset encompassing over 8 million pediatric and adolescent infectious disease cases to elucidate the impact of ambient temperature and its extremes on the risk of various infectious diseases in China. Our analysis, the first of its kind, quantitatively and qualitatively assesses the influence of temperature variations on disease incidence while delineating the considerable heterogeneity in these associations across 27 diseases in 507 cities in China. This study covers the most extensive range of infectious disease types and categories, including both high-incidence and relatively rare diseases, providing comprehensive and systematic evidence based on national surveillance data. Our findings underscore a significant association between temperature fluctuations and the incidence of infectious diseases. Notably, we have identified that the risk for five infectious diseases—SI, tuberculosis, mumps, leprosy, and typhus—tends to escalate in colder environments. Moreover, for three of these diseases-SI, leprosy, and typhus—the risk has been observed to intensify over time. In contrast, in warmer climates, the incidence risk for a broader spectrum of 13 infectious diseases has been found to increase. The study's implications are profound, particularly in the context of climate change, which is driving an increase in the frequency of high-temperature days and a concomitant rise in annual average temperatures. This climatic shift has been associated with an elevated risk for nine specific infectious diseases: tuberculosis, pertussis, hand, foot, and mouth disease, infectious diarrhea, dysentery, hepatitis A, typhoid and paratyphoid, dengue, and Japanese encephalitis. The observed increase in attributable risk for these diseases underscores the critical need for public health strategies that are responsive to the changing climate. The significance of this research extends beyond the immediate implications for public health. It provides a foundation for evidence-based policymaking, enabling authorities to develop targeted interventions that mitigate the impact of climate-sensitive diseases, including the implementation of climate-based early warning systems, optimized resource allocation during extreme weather events, and the development of disease-specific preventive measures for the conditions identified in this study.

The influence of climate change on the epidemiology of infectious diseases has become a focal point of scientific inquiry.[51] From 2011 to 2020, a discernible increase in global average temperatures, reaching 1.1 °C above pre-industrial levels, has been recorded, with an anticipated further increase to 1.5 °C by 2040.[52] These temperature increments are expected to induce global shifts in pathogen prevalence, vector activity, and human behavior patterns.[16] Our study presents a meticulous analysis of the correlation between extreme temperatures and the incidence rates of respiratory, gastrointestinal, and vector-borne infectious diseases, alongside the secular trends in temperature-attributable case

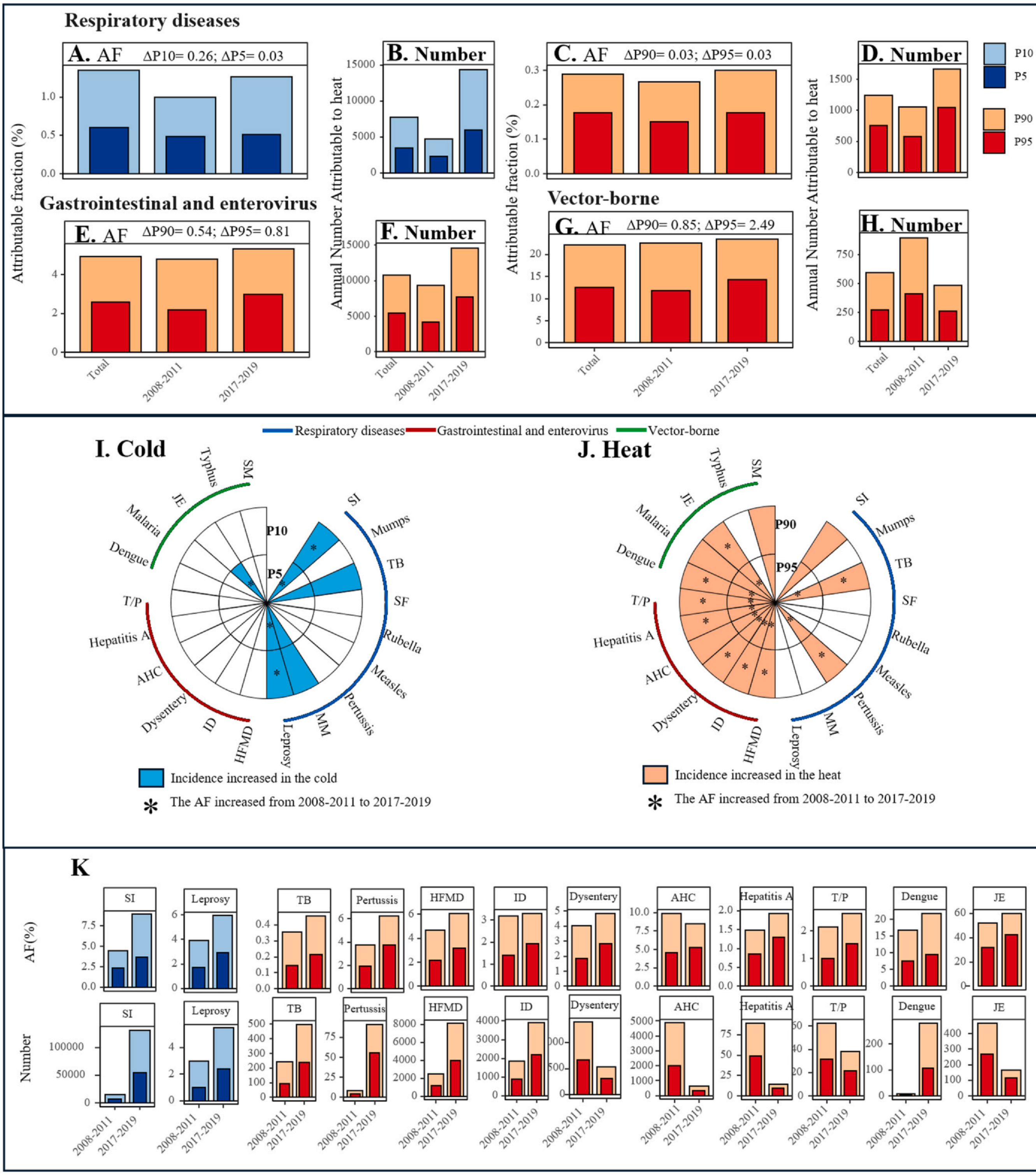

Fig. 5. Attributable Fractions and Annual Case Numbers for Key Disease Categories Across Different Temperature Scenarios and Time Periods. Notes: P_{10} denotes the 10th percentile of temperature, P_5 represents the 5th percentile, P_{90} indicates the 90th percentile, and P_{95} signifies the 95th percentile. ΔP10 refers to the change in the attributable fraction (AF) for P_{10} from 2008–2010 to 2017–2019, ΔP_5 to the change in AF for P_5, ΔP_{90} to the change in AF for P_{90}, and ΔP_{95} to the change in AF for P_{95} over the same periods. In Panels I and J, blue indicates an increased risk of specific diseases at low temperatures, while orange signifies an increased risk at high temperatures. An asterisk (*) denotes a rise in AF from 2008–2010 to 2017–2019. The different colored bands in the middle panels represent various modes of disease transmission. Abbreviations: SI (Seasonal Influenza), TB (Tuberculosis), HFMD (Hand, Foot, and Mouth Disease), ID (Non-dysentery infectious diarrhoea), AHC (Acute Hemorrhagic Conjunctivitis), T/P (Typhoid and Paratyphoid), JE (Japanese Encephalitis), SM (Schistosomiasis).

proportions. Of the 24 diseases scrutinized, a majority—over 50%—demonstrated heightened risk in warmer climates, particularly vector-borne diseases, which showed the most pronounced sensitivity to temperature elevations. Gastrointestinal infections also revealed an increased risk under high-temperature conditions. Notably, for nine diseases, an uptick in the attributable fraction was observed, corresponding to the escalating annual frequency of high-temperature days, a consequence of ongoing climate change. The findings underscore the necessity for a proactive approach to public health strategies that anticipate and adapt to the shifting landscape of disease risk in a warming world.

Ambient temperature is a pivotal environmental determinant of respiratory health, with both extreme heat and cold, as well as temperature variability, linked to heightened morbidity and mortality from respiratory conditions.[53–58] Notably, low temperatures exert a more significant negative impact on respiratory infections compared to their high-temperature counterparts.[55,59] Climate change projections suggest an intensification of temperature fluctuations, with increasing frequency and severity of both heatwaves and cold spells, particularly in the North China Plain,[60–62] which could consequently amplify the prevalence of respiratory infections.[63–65] While existing literature has extensively reported the increased hospitalization risk for chronic respiratory diseases such as pneumonia, COPD, and asthma due to daily extreme temperature exposures,[58,66–69] there remains a dearth of evidence pertaining to respiratory infectious diseases. Our study fills this gap, revealing that in colder conditions, diseases like scarlet fever and tuberculosis exhibit a marked rise in risk, aligning with previous findings. Cold temperatures can suppress immune function, increasing susceptibility to influenza and tuberculosis.[70] Laboratory studies indicate that cold, dry weather enhances influenza virus survival and transmission.[71] These results highlight the susceptibility of respiratory infections to cold weather, a risk that climate change may further aggravate.

Gastrointestinal infectious diseases have been consistently linked to high ambient temperatures across diverse geographies, including the United States, Spain, and Shanghai, China.[72–76] This robust correlation implies a stable interaction between temperature elevations and the incidence of such diseases. Extreme heat can exacerbate dehydration and biological stress, increasing susceptibility to gastrointestinal infections.[77] Warmer temperatures also promote pathogen survival and growth, raising the risk of cholera and hepatitis A in areas with poor sanitation.[78] The mechanistic insights suggest that increased temperatures may alter pathogen behavior, transmission efficacy, and host vulnerability.[79,80] For instance, bacterial growth and the production of staphylococcal enterotoxins accelerate in warmer environments, peaking at 37 °C and 40–45 °C, respectively. These conditions facilitate the spread of gastrointestinal pathogens, increasing the incidence of related diseases. As temperatures rise, the risk of hand, foot, and mouth disease increases, with the temperature range that promotes higher activity levels also facilitating pathogen survival. However, extreme heat and ultraviolet radiation can reduce pathogen viability, resulting in a decline in risk when temperatures surpass a certain threshold.[81] Geographical and climatic nuances significantly influence the epidemiological patterns of gastrointestinal infections, affecting pathogen distribution and disease dynamics.[82,83] Our study corroborates the substantial impact of temperature on gastrointestinal disease incidence, highlighting how the escalating frequency of high-temperature days and the upward trend in annual average temperatures, potentially propelled by climate change, have augmented the risk and prevalence of these diseases.

Vector-borne infectious diseases exhibit pronounced sensitivity to temperature fluctuations, with a notable proportion of cases linked to elevated temperatures. Higher temperatures can increase vector reproduction, shorten pathogen incubation, and boost mosquito survival and feeding, amplifying disease transmission.[84] For instance, temperatures may influence hantavirus by altering rodent populations, breeding patterns, and distribution, with rising temperatures potentially extending the breeding season in cooler regions.[85] Conditions such as dengue and Japanese encephalitis demonstrate a marked escalation in incidence as temperatures rise, suggesting that climate change could potentially broaden the geographic reach and seasonal patterns of these maladies. Since 1950, there has been a significant increase in the global climate suitability for dengue transmission for its primary vectors, *Aedes aegypti* and *Aedes albopictus*, by 8.9% and 15.0%, respectively, by 2018.[86] Empirical research has delineated the influence of temperature on the spatial and temporal distribution of vectors, contributing to the proliferation of diseases like African trypanosomiasis, Lyme disease, tick-borne encephalitis, yellow fever, plague, and dengue.[87] In China, the warming of winters has facilitated the northward migration of Oncomelania hupensis, the snail host for Schistosoma japonicum,[88] illustrating the ecological shifts in species distribution in response to climate change. The relationship between vector-borne diseases and temperature appears to have a threshold effect; surpassing this threshold may precipitously reduce the risk of disease transmission. This implies that extreme temperatures could restrict vector populations. For instance, mosquitoes, the vectors for diseases like dengue and yellow fever, are susceptible to mortality when temperatures surpass 40 degrees Celsius.[15] As a result, the continued progression of global warming may lead to the local extinction of vectors such as *Aedes aegypti* in areas where temperatures exceed their survival thresholds.[89] Consistent with these biological patterns, our subgroup analyses stratified by Köppen–Geiger climate zones revealed marked heterogeneity in temperature–vector-borne disease associations across different climatic contexts. Notably, tropical and temperate zones exhibited bell-shaped risk curves with peak risks at moderate to high temperatures, whereas arid and cold temperate zones demonstrated lower and more attenuated risk patterns. This underscores the necessity for a nuanced understanding of the complex dynamics between climate change, vector ecology, and disease transmission.

The health impacts of climate change disproportionately affect populations with limited adaptive capacity, particularly children and adolescents in low-resource and climate-vulnerable regions. Children and adolescents are more sensitive to temperature fluctuations, notably for diseases like seasonal influenza and mumps. While climate-related health risks are rising, many impacts can be mitigated through targeted interventions, including early warning systems, climate-adaptive infrastructure, and improved sanitation.[90,91] These measures can reduce the burden of diseases, such as waterborne diseases and heat-related mortality. However, current adaptation efforts may not suffice for future climate risks. Strengthening climate-health surveillance, integrating climate modeling with epidemiological forecasting, and ensuring equitable access to adaptation resources will be crucial. Scaling up collaboration across public health, environmental science, and urban planning is essential to building climate-resilient health systems.

Strengths and limitations

This study has several notable strengths. Firstly, it is the first systematic investigation to explore the relationship between ambient temperature and the incidence of 24 infectious diseases—encompassing respiratory, gastrointestinal, and vector-borne diseases—in a country with one of the largest populations in the world. Secondly, the study's extensive coverage, which includes over 95% of medical institutions nationwide and the largest infectious disease dataset in terms of sample size and geographical scope, ensures the representativeness and robustness of the findings. Thirdly, China's diverse climatic zones, ranging from equatorial to temperate, make the results of this regional analysis potentially applicable to other countries with similar climatic conditions. Nevertheless, the study is subject to certain limitations. The reliance on city-level average temperatures may introduce exposure measurement errors, which may not fully capture individual variations in temperature exposure due to differences in housing conditions, occupational environments, or daily mobility patterns. Such non-differential exposure misclassification tends to underestimate the true effect measures. In areas with significant temperature gradients or microclimates, this approach may underestimate the true temperature-disease association. Our findings are anchored in historical climate data; however, evolving climate change dynamics may precipitate unforeseen variables and uncertainties beyond the purview of our analysis. Variability in the quality and completeness of the infectious disease data across different regions and times could impact the findings' robustness, given potential inconsistencies in reporting and data collection methodologies. Moreover, the national surveillance system does not distinguish between locally acquired and imported cases. Additionally, while we used time-stratified case-crossover models to control for confounders, we did not explicitly model autocorrelation in the time series of temperature and disease data. As some diseases, such as cholera and malaria, are primarily imported, results for non-endemic infections should be interpreted with caution. Due to data limitations, we could not exclude imported cases from the analysis; however, foreigners and individuals from Hong Kong, Macao, and Taiwan were excluded during screening, minimizing the potential influence of imported cases. Furthermore, our model did not account for all potential confounders associated with each disease. Specifically, factors such as vector ecology, water quality, and sanitation infrastructure may influence the transmission dynamics of certain diseases, particularly vector-borne and waterborne diseases. To achieve a more comprehensive understanding of disease-specific transmission pathways, future studies should integrate these critical variables. Additionally, we lacked individual-level data on factors such as mobility patterns, housing characteristics, and access to air conditioning, which may modulate personal exposure to ambient temperature. Future studies incorporating such data would be valuable for further refining estimates of temperature-related disease risk and for disentangling the relative contributions of ambient temperature and other risk factors. Although the time-stratified case-crossover design controls for long-term trends, we acknowledge that unmeasured time-varying confounders such as healthcare access, vaccination coverage, and reporting practices may influence observed associations. Our sensitivity analyses stratified by province-level socioeconomic indicators partially address this concern, but future studies incorporating more granular data on healthcare and infrastructure factors are warranted.

Conclusion

Our findings demonstrate that temperature variability, particularly extreme heat, significantly influences the incidence and patterns of infectious diseases among children and adolescents. The increase in high-temperature days and annual average temperatures has been associated with a higher incidence of over half of the diseases studied (13 out of 24), affecting categories including respiratory, gastrointestinal, enterovirus, and vector-borne infections. High temperatures have notably increased the risk for gastrointestinal and enterovirus infections, while vector-borne diseases show exceptional sensitivity to temperature shifts. The observed rise in heat-related infections from 2008–2010 to 2017–2019 underscores the growing public health challenge posed by climate change. This study underscores the urgent need for adaptive public health strategies to mitigate the rising threat of climate-sensitive diseases, especially among vulnerable populations such as children and adolescents. Strengthening surveillance and developing early warning systems are crucial for timely detection and response. Targeted interventions, including improving access to healthcare and enhancing community resilience, are essential to protect these vulnerable groups. Integrating climate change considerations into health policies and investing in climate-resilient health infrastructure will further build adaptive capacity. Future research should focus on understanding the mechanisms linking temperature extremes to infectious disease risk and developing tailored mitigation programs, particularly for rural and remote areas where adaptive capacity is limited.

Funding and acknowledgements

The present study was supported by National Key R&D Program of China (2024YFC3308300) and National Natural Science Foundation of China (Grant 82103865 and 82373593), Natural Science Foundation of Beijing (Grant 7222244), Peking University Talent Introduction Program Project (BMU2023YJ011 to Yanhui Dong), National Ten Thousand Talents Program Youth Talent Excellence. The authors would like to acknowledge the support from all the team members and all the health staff involved in the China National Notifiable Infectious Disease Surveillance System. DPA and JX received partial support from the Oxford National Institute for Health and care Research (NIHR) Biomedical Research Centre.

Declaration of Competing Interest

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.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jinf.2025.106547.

References

1. Cheng H. *Future earth and sustainable developments. Innovation* 2020;**1**(3):100055.
2. Zhou T. *New physical science behind climate change: what does IPCC AR6 tell us? Innovation* 2021;**2**(4):100173.
3. United Nations. Goal 13: Take urgent action to combat climate change and its impacts. 2025 [cited 2025 July 9]. Available from: https://www.un.org/sustainabledevelopment/climate-change/.
4. World Health Organization. Climate change and health. 2025 [cited 2025 July 9]. Available from: https://www.who.int/teams/environment-climate-change-and-health/climate-change-and-health/about.
5. World Health Organization. Environment, Climate Change and Health: Children. 2025 [cited 2025 July 9]. Available from: https://www.who.int/teams/environment-climate-change-and-health/settings-and-populations/children.
6. World Health Organization. Climate change [fact sheet]. 2025 [cited 2025 July 9]. Available from: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health.
7. UNICEF. The Climate Crisis is a Child Rights Crisis: Introducing the Children's Climate Risk Index; 2021: New York: UNICEF. 2025 [cited 2025 July 9]. Available from: https://www.unicef.org/reports/climate-crisis-child-rights-crisis.
8. GBD 2019 Risk Factors Collaborators. *Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet* 2020;**396**(10258):1223–49.
9. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Beagley J, Belesova K, et al. *The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. Lancet* 2021;**397**(10269):129–70.
10. Zhao Q, Guo Y, Ye T, Gasparrini A, Tong S, Overcenco A, et al. *Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. Lancet Planet Health* 2021;**5**(7):e415–25.
11. Zhao Q, Zhang Y, Zhang W, Li S, Chen G, Wu Y, et al. *Ambient temperature and emergency department visits: time-series analysis in 12 Chinese cities. Environ Pollut* 2017;**224**:310–6.
12. Zhao Q, Li S, Coelho M, Saldiva P, Hu K, Huxley RR, et al. *The association between heatwaves and risk of hospitalization in Brazil: a nationwide time series study between 2000 and 2015. PLoS Med* 2019;**16**(2):e1002753.
13. Zhao Q, Li S, Coelho M, Saldiva P, Hu K, Arblaster JM, et al. *Geographic, demographic, and temporal variations in the association between heat exposure and hospitalization in Brazil: a nationwide study between 2000 and 2015. Environ Health Perspect* 2019;**127**(1):17001.
14. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. *Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet* 2015;**386**(9991):369–75.
15. Wu X, Lu Y, Zhou S, Chen L, Xu B. *Impact of climate change on human infectious diseases: empirical evidence and human adaptation. Environ Int* 2016;**86**:14–23.
16. Mora C, McKenzie T, Gaw IM, Dean JM, von Hammerstein H, Knudson TA, et al. *Over half of known human pathogenic diseases can be aggravated by climate change. Nat Clim Chang* 2022;**12**(9):869–75.

17. Xu B, Wang J, Li Z, Xu C, Liao Y, Hu M, et al. *Seasonal association between viral causes of hospitalised acute lower respiratory infections and meteorological factors in China: a retrospective study. Lancet Planet Health* 2021;**5**(3):e154–63.
18. Fletcher IK, Grillet ME, Moreno JE, Drakeley C, Hernández-Villena J, Jones KE, et al. *Synergies between environmental degradation and climate variation on malaria re-emergence in southern Venezuela: a spatiotemporal modelling study. Lancet Planet Health* 2022;**6**(9):e739–48.
19. Smith CJ. *Pediatric thermoregulation: considerations in the face of global climate change. Nutrients* 2019;**11**(9):2010.
20. One billion children at 'extremely high risk' of the impacts of the climate crisis. 2025 [cited 2025 July 9]. Available from: https://www.unicef.org.uk/press-releases/onebillion-children-at-extremely-high-risk-of-the-impacts-of-the-climate-crisis-unicef.
21. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Belesova K, Boykoff M, et al. *The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. Lancet* 2019;**394**(10211):1836–78.
22. UNICEF. Climate mobility and children. 2025 [cited 2025 July 9]. Available from: https://www.unicef.org/innocenti/projects/climate-mobility-and-children.
23. Perera F, Nadeau K. *Climate change, fossil-fuel pollution, and children's health. N Engl J Med* 2022;**386**(24):2303–14.
24. Chazalnoel MT, Ionesco D, Duca E. Children on the move: why, where, how. 2025 [cited 2025 July 9] Available from: https://environmentalmigration.iom.int/sites/g/files/tmzbdl1411/files/documents/children-on-the-move_-why-where-how.pdf.
25. Pfenning-Butterworth A, Buckley LB, Drake JM, Farner JE, Farrell MJ, Gehman AM, et al. *Interconnecting global threats: climate change, biodiversity loss, and infectious diseases. Lancet Planet Health* 2024;**8**(4):e270–83.
26. Helldén D, Andersson C, Nilsson M, Ebi KL, Friberg P, Alfvén T. *Climate change and child health: a scoping review and an expanded conceptual framework. Lancet Planet Health* 2021;**5**(3):e164–75.
27. Chersich MF, Pham MD, Areal A, Haghighi MM, Manyuchi A, Swift CP, et al. *Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis. BMJ* 2020;**371**:m3811.
28. Ebi KL, Paulson JA. *Climate change and children. Pediatr Clin North Am* 2007;**54**(2):213–26. (vii).
29. Philipsborn RP, Chan K. *Climate change and global child health. Pediatrics* 2018;**141**(6):e20173774.
30. Kistin EJ, Fogarty J, Pokrasso RS, McCally M, McCornick PG. *Climate change, water resources and child health. Arch Dis Child* 2010;**95**(7):545–9.
31. Anderko L, Chalupka S, Du M, Hauptman M. *Climate changes reproductive and children's health: a review of risks, exposures, and impacts. Pediatr Res* 2020;**87**(2):414–9.
32. Phalkey RK, Aranda-Jan C, Marx S, Höfle B, Sauerborn R. *Systematic review of current efforts to quantify the impacts of climate change on undernutrition. Proc Natl Acad Sci USA* 2015;**112**(33):E4522–9.
33. Fund, U.N.C.s. Goal 13: Climate Action: Take urgent action to combat climate change and its impacts. 2025 [cited 2025 July 9]. Available from: https://data.unicef.org/sdgs/goal-13-climate-action/.
34. Perin J, Mulick A, Yeung D, Villavicencio F, Lopez G, Strong KL, et al. *Global, regional, and national causes of under-5 mortality in 2000-19: an updated systematic analysis with implications for the Sustainable Development Goals. Lancet Child Adolesc Health* 2022;**6**(2):106–15.
35. Childhood diseases. 2025 [cited 2025 July 9]. Available from: https://www.unicef.org/health/childhood-diseases.
36. Dong Y, Wang L, Burgner DP, Miller JE, Song Y, Ren X, et al. *Infectious diseases in children and adolescents in China: analysis of national surveillance data from 2008 to 2017. BMJ* 2020;**369**:m1043.
37. Wang L, Wang Y, Jin S, Wu Z, Chin DP, Koplan JP, et al. *Emergence and control of infectious diseases in China. Lancet* 2008;**372**(9649):1598–605.
38. P.R.China T.S.C.o. China has established the world's largest surveillance network for diseases and health risk factors; 2022. 2025 [cited 2025 July 9]. Available from: https://www.gov.cn/xinwen/2022-06/21/content_5696881.htm.
39. United Nations. DEFINITION OF YOUTH. 2025 [cited 2025 July 9]. Available from: https://www.un.org/esa/socdev/documents/youth/fact-sheets/youth-definition.pdf.
40. ECMWF. ERA5 hourly data on single levels from 1979 to present; 2021 [Sep 28th, 2021]. Available from: ⟨https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview⟩.
41. Cai J. humidity: Calculate Water Vapor Measures from Temperature and Dew Point. R package version 0.1.4; 2018 2018-12-01; 2018-06-10. 2025 [cited 2025 July 9]. Available from: https://CRAN.R-project.org/package=humidity.
42. Lloyd CT, Chamberlain H, Kerr D, Yetman G, Pistolesi L, Stevens FR, et al. *Global spatio-temporally harmonised datasets for producing high-resolution gridded population distribution datasets. Big Earth Data* 2019;**3**(2):108–39.
43. de Souza WM, Weaver SC. *Effects of climate change and human activities on vector-borne diseases. Nat Rev Microbiol* 2024;**22**(8):476–91.
44. Chen L, Yuan W, Geng M, Xu R, Xing Y, Wen B, et al. *Differentiated impacts of short-term exposure to fine particulate constituents on infectious diseases in 507 cities of Chinese children and adolescents: a nationwide time-stratified case-crossover study from 2008 to 2021. Sci Total Environ* 2024;**928**:172299.
45. Guo Y, Gasparrini A, Armstrong B, Li S, Tawatsupa B, Tobias A, et al. *Global variation in the effects of ambient temperature on mortality: a systematic evaluation. Epidemiology* 2014;**25**(6):781–9.
46. Gasparrini A, Armstrong B. *Reducing and meta-analysing estimates from distributed lag non-linear models. BMC Med Res Method* 2013;**13**:1.
47. Feng F, Ma Y, Zhang Y, Shen J, Wang H, Cheng B, et al. *Effects of extreme temperature on respiratory diseases in Lanzhou, a temperate climate city of China. Environ Sci Pollut Res Int* 2021;**28**(35):49278–88.
48. Beck HE, McVicar TR, Vergopolan N, Berg A, Lutsko NJ, Dufour A, et al. *High-resolution (1 km) Koppen-Geiger maps for 1901-2099 based on constrained CMIP6 projections. Sci Data* 2023;**10**(1):724.
49. Hu K, Wang S, Fei F, Song J, Chen F, Zhao Q, et al. *Modifying temperature-related cardiovascular mortality through green-blue space exposure. Environ Sci Ecotechnol* 2024;**20**:100408.
50. Gasparrini A, Leone M. *Attributable risk from distributed lag models. BMC Med Res Method* 2014;**14**:55.
51. Phillips MC, LaRocque RC, Thompson 3rd GR. *Infectious diseases in a changing climate. JAMA* 2024;**331**(15):1318–9.
52. Intergovernmental Panel on Climate Change. Climate Change 2023: Synthesis Report; 2023. 2025 [cited 2025 July 9]. Available from: https://www.ipcc.ch/report/ar6/syr/.
53. Achebak H, Garcia-Aymerich J, Rey G, Chen Z, Méndez-Turrubiates RF, Ballester J. *Ambient temperature and seasonal variation in inpatient mortality from respiratory diseases: a retrospective observational study. Lancet Reg Health Eur* 2023;**35**:100757.
54. D'Amato G, Cecchi L, D'Amato M, Annesi-Maesano I. *Climate change and respiratory diseases. Eur Respir Rev* 2014;**23**(132):161–9.
55. Chen R, Yin P, Wang L, Liu C, Niu Y, Wang W, et al. *Association between ambient temperature and mortality risk and burden: time series study in 272 main Chinese cities. BMJ* 2018;**363**:k4306.
56. Michelozzi P, Accetta G, De Sario M, D'Ippoliti D, Marino C, Baccini M, et al. *High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. Am J Respir Crit Care Med* 2009;**179**(5):383–9.
57. Xu R, Zhao Q, Coelho M, Saldiva P, Abramson MJ, Li S, et al. *Socioeconomic inequality in vulnerability to all-cause and cause-specific hospitalisation associated with temperature variability: a time-series study in 1814 Brazilian cities. Lancet Planet Health* 2020;**4**(12):e566–76.
58. Xu R, Zhao Q, Coelho M, Saldiva P, Abramson MJ, Li S, et al. *Socioeconomic level and associations between heat exposure and all-cause and cause-specific hospitalization in 1,814 Brazilian cities: a nationwide case-crossover study. PLoS Med* 2020;**17**(10):e1003369.
59. Martinez-Solanas E, Basagana X. *Temporal changes in the effects of ambient temperatures on hospital admissions in Spain. PLoS One* 2019;**14**(6):e0218262.
60. Wei J, Han W, Wang W, Zhang L, Rajagopalan B. *Intensification of heatwaves in China in recent decades: roles of climate modes.* 2023;**6**(1).
61. Simolo C, Corti S. *Quantifying the role of variability in future intensification of heat extremes. Nat Commun* 2022;**13**(1):7930.
62. Kang S, Eltahir EAB. *North China Plain threatened by deadly heatwaves due to climate change and irrigation. Nat Commun* 2018;**9**(1):2894.
63. Lim YH, Hong YC, Kim H. *Effects of diurnal temperature range on cardiovascular and respiratory hospital admissions in Korea. Sci Total Environ* 2012;**417-418**:55–60.
64. Lee W, Kim Y, Sera F, Gasparrini A, Park R, Michelle Choi H, et al. *Projections of excess mortality related to diurnal temperature range under climate change scenarios: a multi-country modelling study. Lancet Planet Health* 2020;**4**(11):e512–21.
65. Zhan Z, Zhao Y, Pang S, Zhong X, Wu C, Ding Z. *Temperature change between neighboring days and mortality in United States: a nationwide study. Sci Total Environ* 2017;**584-585**:1152–61.
66. Anderson GB, Dominici F, Wang Y, McCormack MC, Bell ML, Peng RD. *Heat-related emergency hospitalizations for respiratory diseases in the Medicare population. Am J Respir Crit Care Med* 2013;**187**(10):1098–103.
67. Wise RA, Calverley PM, Carter K, Clerisme-Beaty E, Metzdorf N, Anzueto A. *Seasonal variations in exacerbations and deaths in patients with COPD during the TIOSPIR((R)) trial. Int J Chron Obstruct Pulmon Dis* 2018;**13**:605–16.
68. Keller K, Hobohm L, Münzel T, Konstantinides SV, Lankeit M. *Sex-specific and age-related seasonal variations regarding incidence and in-hospital mortality of pulmonary embolism in Germany. ERJ Open Res* 2020;**6**(2):00181–2020.
69. Ho ATN, Shmelev A, Charbek E. *Trends and seasonal variation of hospitalization and mortality of interstitial lung disease in the United States from 2006 to 2016. Respir Res* 2020;**21**(1):152.
70. Shephard RJ, Shek PN. *Cold exposure and immune function. Can J Physiol Pharmacol* 1998;**76**(9):828–36.
71. Lowen AC, Mubareka S, Steel J, Palese P. *Influenza virus transmission is dependent on relative humidity and temperature. PLoS Pathog* 2007;**3**(10):1470–6.
72. Lin S, Sun M, Fitzgerald E, Hwang SA. *Did summer weather factors affect gastrointestinal infection hospitalizations in New York State? Sci Total Environ* 2016;**550**:38–44.
73. Zhao Q, Li S, Coelho M, Saldiva P, Huxley RR, Guo Y. *High ambient temperature and risk of hospitalization for gastrointestinal infection in Brazil: a nationwide case-crossover study during 2000-2015. Sci Total Environ* 2022;**849**:157836.
74. Zhou X, Zhou Y, Chen R, Ma W, Deng H, Kan H. *High temperature as a risk factor for infectious diarrhea in Shanghai, China. J Epidemiol* 2013;**23**(6):418–23.
75. Phung D, Rutherford S, Chu C, Wang X, Nguyen M, Nguyen NH, et al. *Temperature as a risk factor for hospitalisations among young children in the Mekong Delta area, Vietnam. Occup Environ Med* 2015;**72**(7):529–35.
76. Morral-Puigmal C, Martínez-Solanas È, Villanueva CM, Basagaña X. *Weather and gastrointestinal disease in Spain: a retrospective time series regression study. Environ Int* 2018;**121**(Pt 1):649–57.
77. Akerman AP, Tipton M, Minson CT, Cotter JD. *Heat stress and dehydration in adapting for performance: good, bad, both, or neither? Temperature* 2016;**3**(3):412–436.

78. Balta I, Lemon J, Murnane C, Pet I, Vintila T, McCleery D, et al. *The One Health aspect of climate events with impact on foodborne pathogens transmission. One Health* 2024;**19**:100926.
79. Altizer S, Ostfeld RS, Johnson PT, Kutz S, Harvell CD. *Climate change and infectious diseases: from evidence to a predictive framework. Science* 2013;**341**(6145):514–9.
80. National Research Council (US) Committee on Climate Ecosystems. Infectious Diseases, and Human Health. Under the Weather: Climate, Ecosystems, and Infectious Disease. Washington, DC: National Academies Press (US); 2001 (DC2025) [cited 2025 July 9]. Available from:. https://www.ncbi.nlm.nih.gov/books/NBK222255/.
81. Bertrand I, Schijven JF, Sánchez G, Wyn-Jones P, Ottoson J, Morin T, et al. *The impact of temperature on the inactivation of enteric viruses in food and water: a review. J Appl Microbiol* 2012;**112**(6):1059–74.
82. Wang S, Liu Z, Tong M, Xiang J, Zhang Y, Gao Q, et al. *Real-time forecasting and early warning of bacillary dysentery activity in four meteorological and geographic divisions in China. Sci Total Environ* 2021;**761**:144093.
83. Levy K, Woster AP, Goldstein RS, Carlton EJ. *Untangling the impacts of climate change on waterborne diseases: a systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. Environ Sci Technol* 2016;**50**(10):4905–22.
84. Caminade C, McIntyre KM, Jones AE. *Impact of recent and future climate change on vector-borne diseases. Ann N Y Acad Sci* 2019;**1436**(1):157–73.
85. Klempa B. *Hantaviruses and climate change. Clin Microbiol Infect* 2009;**15**(6):518–23.
86. The Lancet Microbe. *Climate change: fires, floods, and infectious diseases. Lancet Microbe* 2021;**2**(9):e415.
87. Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, et al. *Climate warming and disease risks for terrestrial and marine biota. Science* 2002;**296**(5576):2158–62.
88. Zhou Y-B, Zhuang JL, Yang MX, Zhang ZJ, Wei JG, Peng WX, et al. *Effects of low temperature on the schistosome-transmitting snail Oncomelania hupensis and the implications of global climate change. Mollusca Res* 2010;**30**.
89. Beck-Johnson LM, Nelson WA, Paaijmans KP, Read AF, Thomas MB, Bjørnstad ON. *The effect of temperature on Anopheles mosquito population dynamics and the potential for malaria transmission. PLoS One* 2013;**8**(11):e79276.
90. Rojas-Rueda D, Nieuwenhuijsen MJ, Gascon M, Perez-Leon D, Mudu P. *Green spaces and mortality: a systematic review and meta-analysis of cohort studies. Lancet Planet Health* 2019;**3**(11):e469–77.
91. Hess JJ, Errett NA, McGregor G, Busch Isaksen T, Wettstein ZS, Wheat SK, et al. *Public health preparedness for extreme heat events. Annu Rev Public Health* 2023;**44**:301–21.