LETTER TO THE EDITOR

Association of mean annual temperature and hot daily highs with death rate for hyperthermia: A 20-year ecological analysis

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To the editor,

Global climate change is modifying environmental exposure patterns and exerting profound, multifaceted effects on population health (1). Among the various climate-sensitive health outcomes, heat-related illnesses (especially hyperthermia) are of growing concern (2). Hyperthermia arises when thermoregulatory mechanisms fail to dissipate excess body heat, resulting in elevated core body temperatures that may lead to heat exhaustion, heat stroke, multi-organ failure, and potentially death (3). As the frequency, duration, and intensity of extreme heat events continue to rise globally, understanding the relationship between climatic variables and hyperthermia-related mortality has become a critical focus of public health research and policy development (4). To this end, this study aims to examine temporal trends in hyperthermia mortality in the US over the past two decades and assess their associations with key climate metrics. This ecological study used two primary data sources. Mortality data were obtained from the US National Center for Health Statistics (NCHS) WONDER Online Database (5,6). The selection criteria included deaths recorded under ICD-10 (International Classification of Diseases, 10th Revision) code X30, corresponding to "exposure to excessive natural heat (hyperthermia)". Records ranging from 2004 to 2023 were extracted as age-adjusted death rate per 100,000 individuals. Climate data were retrieved from publicly available datasets maintained by the US National Weather Service (7) and the US Environmental Protection Agency (8). Two environmental indicators were selected, i.e., mean annual temperature (°C) and proportion of days per year classified as "hot daily highs", defined as days exceeding historical 95th percentile temperature thresholds. All data were collated in Microsoft Excel (Redmond, WA, United States) for preliminary visualization. The relationship between hyperthermia mortality and climate variables was first assessed using Spearman's rank correlation to capture monotonic trends. Subsequently, gamma

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regression models were used to evaluate the independent effects of year, mean annual temperature, and hot daily highs on hyperthermia mortality, accounting for the non-normal distribution of mortality rates, as assessed by the Shapiro-Wilk Test. Statistical analyses were performed using Python (Wilmington, DE, United States). This study was exempt from Institutional Review Board review as all data were retrieved from de-identified and publicly available databases. The US experienced a gradual but consistent rise in average annual temperature during the past 20 years, increasing from 11.1°C to 13.1°C (a 1.2-fold change). The frequency of extreme heat events, measured by hot daily highs, also surged from 0.014 to 0.214, i.e., a 15.3-fold increase (Figure 1a). During the same timeframe, the age-adjusted mortality rate for hyperthermia rose significantly, from 0.068 per 100,000 in 2004 to 0.290 in 2023, a 4.3-fold increase (Figure 1b). Interestingly, the trends exhibited two distinct peaks in 2006 and 2010–2012, which correspond to similar surges in the frequency of extreme daily maximum temperatures during the same periods. Spearman's correlation showed no statistically significant association between hyperthermia mortality and mean annual temperature (r = 0.21; 95% CI: -0.26 to 0.60; p = 0.364), while a statistically significant positive correlation was observed between hyperthermia mortality and calendar year (r = 0.50; 95% CI: 0.07 to 0.77; p = 0.025) and with the frequency of hot daily highs (r = 0.57; 95% CI: 0.17 to 0.81; p = 0.008). Gamma regression models, used to evaluate the independent effects of the three variables on hyperthermia mortality, showed that hot daily highs (coefficient = 1.62; p = 0.015) and year (coefficient = 0.04; p = 0.017) remained significant predictors of mortality, while mean annual temperature was not a significant independent predictor (coefficient = -0.16; p = 0.189). The results of our study reveal a marked increase in hyperthermia -related mortality in the US over the past two decades, coinciding with a rise in the frequency of extreme heat events. Although the mean annual temperature exhibited a gradual upward trend during this period, it was not significantly associated with mortality outcomes in either correlation or regression analyses. This suggests that short-term, high-intensity heat events, rather than long-term average warming, pose

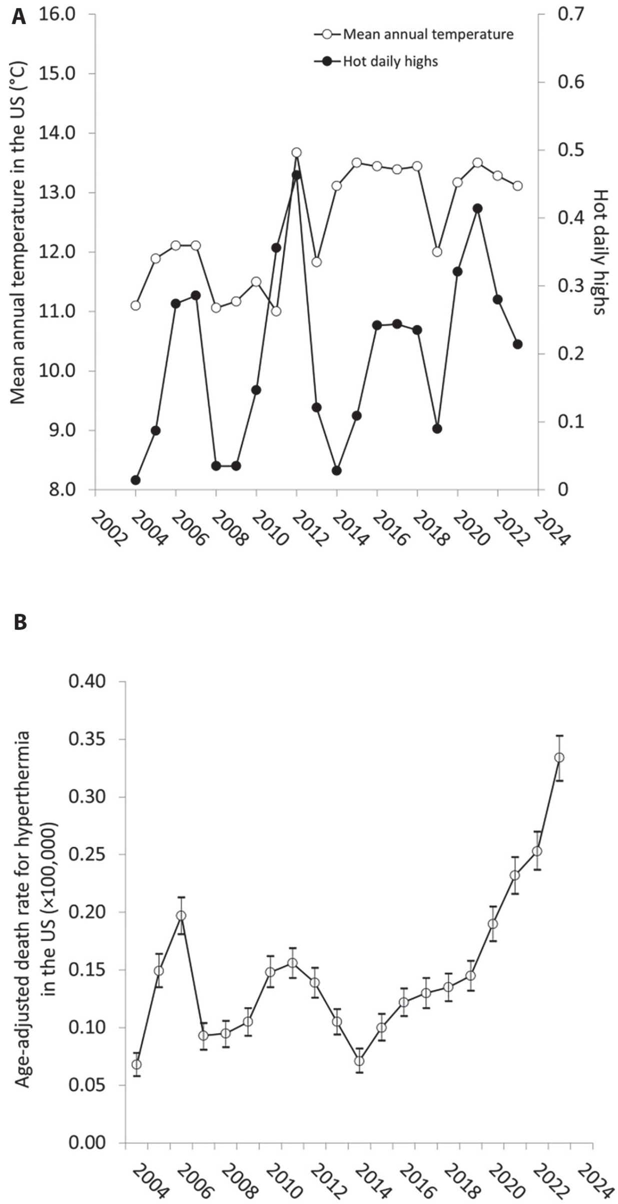

Figure 1. US statistics between the years 2024-2023 for (a) mean annual temperature and proportion of days per year classified as "hot daily highs" and (b) age-adjusted death rate per 100,000 individuals for exposure to excessive natural heat (hyperthermia).

the greatest risk. The strong association between elevated daily maximum temperatures and mortality highlights the critical need for targeted public health interventions. In particular, heat warning systems and climate adaptation strategies should prioritize the timely prediction, effective communication, and mitigation of extreme heat events. The temporal increase in heat-related mortality also underscores the urgency of enhancing community resilience, especially among vulnerable populations, including older adults, outdoor laborers, and individuals lacking access to adequate cooling resources. The increasing burden of heat-related mortality also highlights the urgent necessity of addressing the underlying drivers of climate change. Policies aimed at reducing greenhouse gas emissions and promoting sustainable energy transitions are essential not only to slow long-term warming but also to reduce the frequency and severity of extreme heat events (9). We acknowledge some limitations in this study. First, the ecological design precludes individual-level inference, limiting the ability to establish causality. Second, hyperthermia deaths may be underreported or misclassified in mortality databases, potentially biasing results. Finally, our analysis was limited to US national-level trends and did not account for regional variability or sociodemographic determinants of exposure and vulnerability, because this specific information was unavailable in the public databases that we searched.

Ethic approval: WONDER is an anonymized and publicly available data set, so this study is exempt from Institutional Review Board review

Conflict of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

Authors contribution: C.M.: conceptualization, formal analysis, writing-original draft. G.L.: conceptualization, data extraction; formal analysis, writing-original draft.

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References

1. McMichael AJ. Environmental change, climate and population health: a challenge for inter-disciplinary research. Environ Health Prev Med. 2008 Jul;13(4):183-6. doi: 10.1007/s12199-008-0031-3.
2. Khan AA. Heat related illnesses. Review of an ongoing challenge. Saudi Med J. 2019 Dec;40(12):1195-201. doi: 10.15537/smj.2019.12.24727.
3. Bouchama A, Knochel JP. Heat stroke. N Engl J Med. N Engl J Med. 2002 Jun 20;346(25):1978-88. doi: 10.1056/NEJMra011089.
4. Faurie C, Varghese BM, Liu J, Bi P. Association between high temperature and heatwaves with heat-related illnesses: A systematic review and meta-analysis. Sci Total Environ. 2022 Dec 15;852:158332. doi: 10.1016/j.scitotenv.2022.158332.
5. Centers for Disease Control and Prevention, National Center for Health Statistics. National Vital Statistics System, Mortality 1999-2020 on CDC WONDER Online Database, released in 2021. Data are from the Multiple Cause of Death Files, 1999-2020, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/ucd-icd10.html on October 20, 2025.
6. Centers for Disease Control and Prevention, National Center for Health Statistics. National Vital Statistics System, Mortality 2018-2023 on CDC WONDER Online Database, released in 2024. Data are from the Multiple Cause of Death Files, 2018-2023, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/ucd-icd10-expanded.html on October 20, 2025.
7. US Environmental Protection Agency. Annual Average Temperature by Year. Accessed at https://www.weather.gov/media/slc/ClimateBook/Annual%20Average%20Temperature%20By%20Year.pdf on October 20, 2025.
8. US National Weather Service. Heat Wave. Accessed at https://www.weather.gov/ on October 20, 2025.
9. Bakhsh S, Zhang W, Ali K, Anas M. Energy transition and environmental stability prospects for OECD economies: The prominence role of environmental governance, and economic complexity: Does the geopolitical risk matter? J Environ Manage. 2024 Mar;354:120358. doi: 10.1016/j.jenvman.2024.120358.