

Review Article

Ambient heat exposure and heatstroke mortality: a state-level spatio-temporal assessment

Meghna Choudhury¹, Jayakumar C.¹, Kailash Ganga², Sairah James², Bala Shanthi Nikketha¹, Dayal Narayan³, Helen Christina⁴, Syed Shabab Wahid⁵

¹Department of Psychosocial Support in Disaster Management, National Institute of Mental Health and Neuro Sciences, Bengaluru, India

²Department of Psychiatric Social Work, National Institute of Mental Health and Neuro Sciences, Bengaluru, India

³Department of Psychiatry, Government Medical College, Kozhikode, India

⁴Department of Zoology, Sri Meenakshi Government Arts College for Women (Autonomous), Madurai, India

⁵Department of Global Health, Georgetown University, Washington, DC

Received: 02 September 2026

Accepted: 19 October 2026

*Correspondence:

Dr. Jayakumar C.,

E-mail: jaipsy@gmail.com

Copyright: © the author(s), publisher and licensee Medip Academy. This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

ABSTRACT

Increasing temperatures and subsequent heatwaves are significant public health issues in India. Given region-specific variations, temporal, spatial, and statistical associations between heat exposure and heat-related deaths is key to targeted adaptation and prevention measures. The current longitudinal study using secondary data analysed an unbalanced panel dataset comprising temperature indicators, heatwave days, heatwave deaths, and heatstroke mortality in India between 2013 and 2018. Temporal analyses, spatial parameters and bivariate correlations were used to assess interannual variation, risk, and the relationship between heat exposure and mortality. Fixed-effects negative binomial regression models accounted for state- and year-specific heterogeneity. Slight changes in mean temperatures nationwide and significant variations in the number of heatwave days (>37 degrees Celsius), with the highest mortality around 2015. A moderate positive association between the average number of heatwave days and mortality from heatstroke ($p=0.55$, $p=0.006$) was identified at the state level. Each additional heatwave day was associated with a 19% increase in heatstroke fatalities (IRR=1.19, $p<0.001$). The spatial heterogeneity in heatwave exposure indicates the need for state-specific heat action plans, including reducing the duration of high-temperature exposure and enhancing early warning and response networks.

Keywords: Heatwaves, Heatstroke mortality, Climate change, Public health, Psychosocial impacts

INTRODUCTION

Climate change poses a serious threat not only to the environment and the economy but also to people's health, mental well-being, and various physiological issues worldwide.¹ Among the numerous detrimental effects of global warming, one that is especially concerning is the rise in the frequency and intensity of heatwaves. Extreme heat is considered the most detrimental climate-related

hazard globally. It contributes to the excess mortality rate due to heat stress and various physiological issues like an increase in cardiovascular, respiratory, renal and neurological conditions.²

India's tropical climate, dense population, extensive outdoor labour and socioeconomic disparities limit people's adaptive capacity, making them more vulnerable to extreme heat. According to observational evidence,

heatwaves in India are increasing in duration, frequency, and intensity, particularly in the northern, central, and eastern regions of the country.³ However, death due to heat-related conditions gets minimal attention and recognition, as they are generally recorded as accidental death or natural mortality.⁴

Previous research conducted in India has primarily focused on case-based analyses of specific heatwave events or descriptive evaluations and observational studies of heatstroke deaths.^{5,6}

The number of cases of heat-related diseases has increased consistently in recent years, mainly due to several environmental factors, including climate change and air pollution. The development of heat-related illnesses is a natural process that can progress to the terminal stage, heat stroke, the most severe condition. Heat stroke is characterised by a core body temperature of more than 40 °C and dysfunction of the central nervous system. The existing literature suggests that the pathogenesis of heat stroke is complex and multifaceted, involving inflammatory responses, oxidative stress, cell death, and coagulation dysfunction.⁷ There are two types of heat stroke, namely exertional heat stroke (EHS) and classic heat stroke (CHS). EHS is a neuropsychiatric state characterised by elevated core body temperature and is a common occurrence among healthy young adults who engage in strenuous activities during hot weather. In contrast, CHS is triggered by high atmospheric and/or humidity, often without strenuous physical activity.

Limited global research has systematically investigated the spatiotemporal evolution of heat exposure alongside mortality trends using quantitative exposure-response frameworks, despite evidence that heat-related deaths are significant and unevenly distributed across regions. Therefore, despite growing evidence that composite measures, such as the heat index, which combines ambient temperature and humidity, better capture physiological stress under the high humidity typical of India, most analyses focus on temperature thresholds.⁸ Heat stroke is a life-threatening disorder that is clinically characterised by an extreme increase in body temperature and dysfunction of the central nervous system that, in most cases, manifests itself in combativeness, delirium, seizures and coma.⁹ This longitudinal study, using secondary data, analyses the temporal and spatial patterns of heatwaves, extreme temperatures, and heatstroke deaths in India and identifies emerging hotspots and high-risk states and union territories within the country.

The longitudinal study also examines the association between heatwaves (measured by temperature, heat index, and the number of heatwave days) and heatstroke mortality using statistical and panel analysis. Thus, this longitudinal study using secondary data is expected to fill these gaps by utilising long-term weather and mortality data to examine both patterns and relationships between

heat exposure and heatstroke deaths at the national and state levels.

METHODS

The current research employed a longitudinal study using secondary data to analyse trends and associations between heat exposure and heatstroke deaths across Indian states and union territories between 2013 and 2018. The research period (2013-2018) was 6 years, chosen mainly for the availability and uniformity of complete, comparable data on exposure to heatwaves and heatstroke mortality across Indian states. By adopting a longitudinal approach, secondary data are analytically examined to understand the relationship between heatwaves and heatstroke deaths, primarily by exploring patterns, trends, and state-wise variation over the six years (2013-2018) to identify relationships rather than establish causality.

The secondary data were obtained from the Government of India's website, 'data.gov.in,' and from Open Government Data (OGD) platforms, an initiative of the Union Government of India. The website, data.gov.in, provides essential datasets and important documents published by the ministries, departments and organisations of the Government of India. The mortality data on heatstroke and heat-related deaths are also taken from the Open Government Data (OGD) platform of India. The reference lists of the included literature and commentary articles were also thoroughly screened for additional information related to the phenomenon.

Statistical analysis

Data analysis was performed using Microsoft Excel and R (version 4.5.2). Descriptive statistics was used for continuous variables such as annual temperature, average heatwave days, heatstroke deaths and heatwave deaths. For data visualisation, trend graphs and Indian state-wise choropleth maps were prepared. To determine the normality of the continuous variables, a Q-Q plot was plotted, and the Shapiro-Wilk test was performed. For variables that did not follow a normal distribution, nonparametric tests were used.

Spearman's correlation analysis was done to examine the relationship between continuous variables. For count data outcomes, a Poisson regression model was initially used. Overdispersion (variance exceeding the mean) was identified; therefore, negative binomial regression was employed, as it is suitable for over-dispersed outcomes.¹⁰

Multicollinearity among exposure variables was assessed using variance inflation factors, and state- and year-fixed effects were included to account for unobserved heterogeneity. Model adequacy was assessed using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC), with lower values indicating better model fit. A $p < 0.05$ was considered statistically significant.

RESULTS

Descriptive overview of heat exposure and mortality in India

The analysis covered the period from 2013 to 2018 and included all Indian states for which heatstroke mortality, heatwave occurrence, and temperature data were available. The panel dataset is unbalanced, as some states

were not observed in all years due to administrative changes or data availability. Across the review period, substantial variation was observed in heatwave days, temperature extremes, and heatstroke mortality across states. Summary statistics for the key variables are presented in Table 1. Continuous variables are summarised using mean and standard deviation, while heatwave days and mortality outcomes are skewed distributions (counts) and are summarised using median and interquartile range (Q1, Q3).

Table 1: Summary statistics for heat exposure variables and heat-related mortality.

Variables	Mean $\pm$ SD/ Median (Q ₁ , Q ₃)	Minimum	Maximum
Temperature (°C)			
Minimum	20.7 $\pm$ 0.15	20.52	20.87
Maximum	31.2 $\pm$ 0.25	30.84	31.54
Average heatwave days	5 (2, 9)	0	19
Heatwave deaths	624 (418, 1249)	20	2081
Heatstroke deaths	1 (1, 45)	0	654

Note. SD=Standard deviation; Q1, Q3 First and third quartiles.

Minimum and maximum temperatures showed relatively low variability, with mean minimum and maximum temperatures of 20.7°C (SD=0.15) and 31.2°C (SD=0.25), respectively. The median number of heatwave days was 5 (Q1=2, Q3=9), with a range of 0 to 19. According to the WHO, “heatwaves are periods of unusually hot, dry, or humid weather lasting several days that can significantly impact health, society, and infrastructure”.¹¹ In comparison, heatstroke deaths were

relatively infrequent, with a median of 1 death (Q1=1, Q3=45), though extreme values reached as high as 654 deaths.

Temporal trends in heat exposure and mortality

National temporal trends in heat exposure and heat-related mortality variables in India from 2013-18 are represented visually in Figure 1.

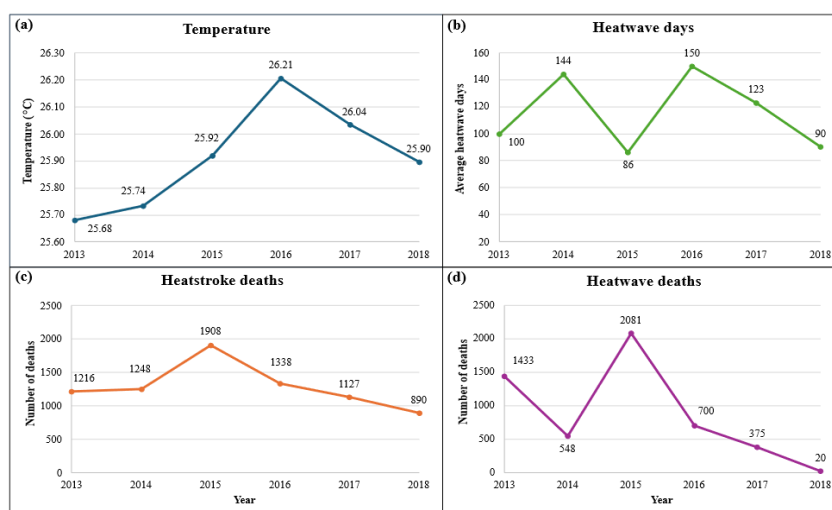


Figure 1: National temporal trends in temperature, heatwave exposure and heat-related mortality in India, 2013–2018.

Note. Panels show trends in (a) temperature, (b) average number of heatwave days, (c) heatwave deaths, and (d) heatstroke deaths.

Mean annual temperature increased gradually from 25.68°C in 2013 to a peak in 2016 (26.21°C), then declined slightly through 2018 (25.90°C). The number of heatwave days fluctuated substantially over the review period, with notable peaks in 2014 (144 days) and 2016

(150 days). Heatstroke deaths increased from 1,216 in 2013 to a peak in 2015 (1,908 deaths), before declining steadily to 890 deaths in 2018. Similarly, heatwave-related deaths showed marked interannual variability,

with a sharp peak in 2015 (2,081 deaths) followed by a pronounced reduction, reaching 20 deaths in 2018.

Spatial patterns and identification of high-risk states

Spatial variation in the distribution of average heatwave days across Indian states and Union Territories was shown in Table 2 and Figure 2. In Figure 3, the spatial pattern in heatstroke mortality across Indian states was represented.

Rajasthan experienced the highest heatwave burden, with 75 heatwave days and the highest mean annual occurrence (12.5 days; SD=3.33). Odisha (mean: 11.5 days; SD=5.58) and Andhra Pradesh (mean: 10.33 days; SD=3.14) also showed consistently high heatwave exposure, with Odisha exhibiting substantial interannual variability, as it reflected a wide range (4–19 days). States such as Haryana, Jharkhand and Punjab formed an intermediate-risk cluster, with mean heatwave days ranging from 7.8 to 8.8 days.

Table 2: State and union territory–wise distribution of average heatwave days in India.

State / UT	Total	Mean	SD	Minimum	Maximum
Rajasthan	75	12.5	3.33	9	17
Odisha	69	11.5	5.58	4	19
Andhra Pradesh	62	10.33	3.14	7	16
Haryana	53	8.83	2.93	4	13
Jharkhand	50	8.33	4.55	3	16
Punjab	47	7.83	4.26	3	12
Madhya Pradesh	43	7.17	2.48	4	10
Maharashtra	40	6.67	1.51	5	8
Uttar Pradesh	38	6.33	1.86	4	9
Bihar	35	5.83	3.71	1	11
Delhi	34	5.67	2.66	2	9
Telangana	34	5.67	4.84	0	14
Tamil Nadu	25	4.17	2.14	2	8
Uttarakhand	25	4.17	2.64	2	9
West Bengal	25	4.17	4.07	1	12
Gujarat	16	2.67	1.03	1	4
Chhattisgarh	15	2.5	2.07	0	6
Karnataka	7	1.17	1.17	0	3

Note. UT=Union territory; SD=Standard deviation

Central and western states, including Madhya Pradesh, Maharashtra, and Uttar Pradesh, showed moderate heatwave exposure with mean values ranging from 6.3 to 7.2 days and relatively low variability. In contrast, eastern and southern states such as Bihar, Delhi, Telangana, Tamil Nadu, Uttarakhand and West Bengal experienced lower average heatwave exposure, with mean heatwave days ranging from 4 to 6 days.

The highest mean number of heatwave days was observed in Rajasthan (75 days), followed by Odisha (69 days) and Andhra Pradesh (62 days), identifying these states as high-risk regions. Several central and north-central states, including Jharkhand, Madhya Pradesh, Maharashtra and Haryana, also experienced elevated heatwave exposure. At the same time, Uttar Pradesh, Bihar, Telangana, Delhi, Tamil Nadu and West Bengal showed moderate exposure. In contrast, Gujarat, Chhattisgarh and Karnataka recorded relatively low heatwave days and Assam and Himachal Pradesh reported no heatwave exposure.

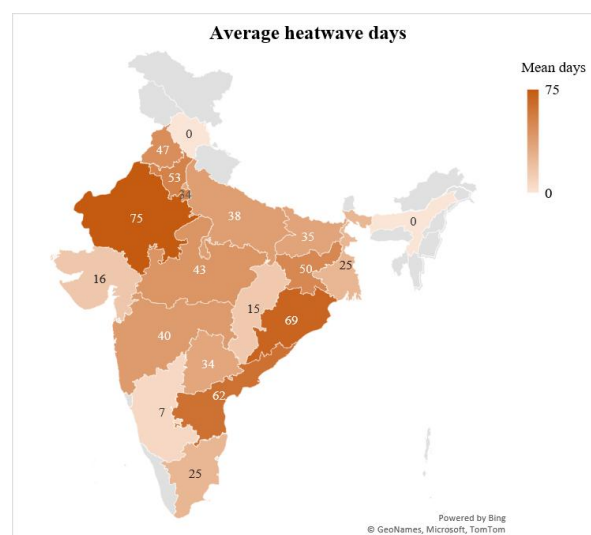


Figure 2: Mean heatwave exposure across Indian states, 2013-18.

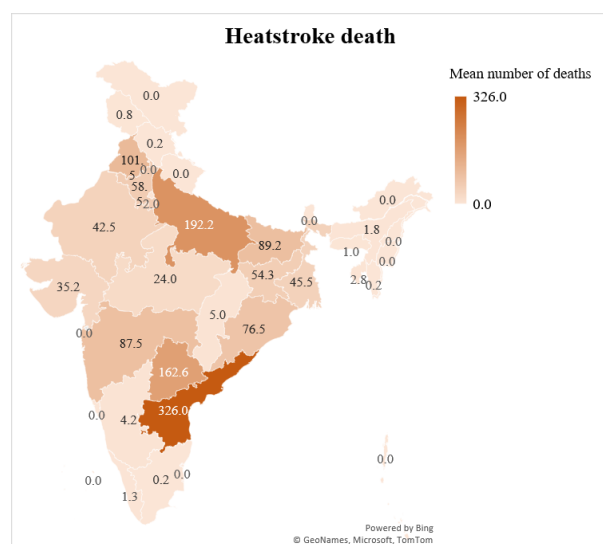


Figure 3: State-wise mean distribution of heatstroke mortality in India.

The highest mean number of heatstroke deaths was recorded in Andhra Pradesh (326 deaths), followed by Telangana (162.6 deaths) and Uttar Pradesh (192.2 deaths). Several northern and eastern states, including Maharashtra, Odisha, Bihar, West Bengal, and Madhya Pradesh, also reported moderate mortality levels. In contrast, several states, including Assam, Himachal Pradesh, Jammu & Kashmir, Kerala, and northeastern states, reported negligible or zero mean heatstroke deaths in 2013-2018, indicating substantial inter-state heterogeneity.

Association between heat exposure and heat-related mortality

Bivariate correlations between heat exposure indicators and heatwave and heatstroke deaths are presented in Table 3 and 4, respectively. The annual change in mean temperature and heatstroke deaths from 2013 to 2018 is depicted in Figure 4.

Table 3: Relationship between national temperature trends and heatwave mortality.

Variable		Minimum temperature	Maximum temperature
Heatwave deaths	ρ	-0.08	-0.37
	p-value	0.919	0.497

Note. ρ =Correlation coefficient

Annual heatwave deaths show a very weak negative correlation with minimum temperature ($\rho=-0.08$; $p=0.919$) and a weak negative correlation with maximum temperature ($\rho=-0.37$; $p=0.497$); neither association is

statistically significant, indicating that national-level variations in minimum or maximum temperature are not associated with changes in annual heatwave mortality.

Table 4: State-wise bivariate associations between average heatwave days and heatstroke deaths.

Variable		Average heatwave days
Heatstroke death	ρ	0.55**
	P value	0.006

Note. ρ =Correlation coefficient

State-wise heatstroke deaths show a moderate positive correlation with average heatwave days ($\rho=0.55$), which is statistically significant ($p=0.006$), indicating that states with more heatwave days tend to report higher heatstroke mortality.

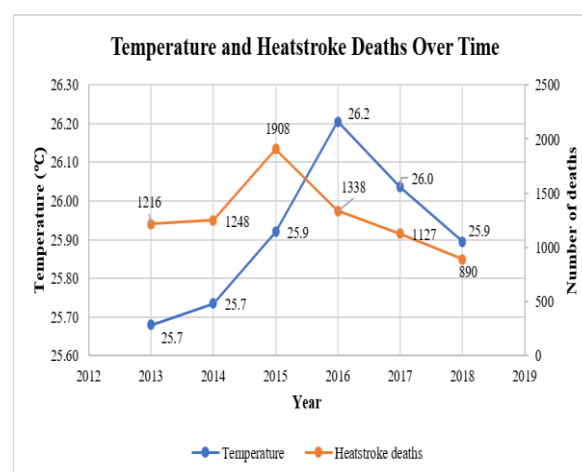


Figure 4: Annual variation in temperature and heatstroke mortality.

The annual mean temperature shows a steady increase from 2013 (25.7 °C) to a peak in 2016 (26.2 °C), followed by a decline through 2018 (25.9 °C). From 1,216 deaths per year in 2013, heatstroke mortality increased to a maximum of about 1,908 deaths in 2015, followed by a consistent decline to 890 deaths by 2018. The peak in heatstroke deaths precedes the peak in temperature by one year, indicating that the highest mortality burden occurred before the year with the highest average temperature. Post 2015, despite relatively elevated temperatures, there was a dip in heatstroke mortality, indicating a non-linear, lagged relationship between temperature and heatstroke deaths.

Table 5 presents results from fixed-effects negative binomial regression models examining the association between heat exposure indicators and heatstroke mortality across states and years.

Table 5: Fixed-effects negative binomial regression of heatstroke mortality on heat exposure variables.

Variables	Model 1		Model 2	
	IRR [95%CI]	P value	IRR [95%CI]	P value
Average heatwave (in days)	1.19 [1.09, 1.29]	<0.001	1.19 [1.1, 1.3]	<0.001
Maximum temperature (°C)			0.81 [0.21, 3.1]	0.739
Model fit:				
AIC	1133.8		1135.7	
BIC	1142.1		1146.8	
Dispersion	140.93		140.93	

Note. IRR=Incidence rate ratio; CI=confidence interval. Model 1 included heatwave days as the exposure variables. Model 2 provides heatwave days and maximum temperature. Fixed effects were specified at the state and year levels.

In Model 1, each additional day of an average heatwave is associated with a 19% increase in heatstroke mortality (IRR=1.19; $p<0.001$), indicating a statistically significant positive association. In Model 2, after additionally adjusting for maximum temperature, the association between average heatwave duration and heatstroke mortality remains unchanged and statistically significant, with each extra heatwave day still associated with a 19% higher mortality rate (IRR=1.19; $p<0.001$). In contrast, maximum temperature shows no statistically significant association with heatstroke mortality (IRR=0.81; $p=0.739$).

Model fit statistics showed lower AIC and BIC values for Model 1 than for Model 2, indicating that including maximum temperature did not improve model performance. The dispersion parameter is identical across models (140.93), suggesting comparable handling of overdispersion.

DISCUSSION

This research paper has analysed temporal and spatial trends in heat exposure and heatwave-related mortality across India between 2013 and 2018, with a special focus on how the duration of heat waves, temperature variables, and heatstroke are associated with heat-related mortality.⁵ These findings include: extensive interstate variability in heatwave exposure and mortality; significant inter-temporal variations in heatwave-related mortality; and a consistent, statistically significant relationship between heatwave occurrence and heatstroke deaths in fixed-effects regression models, the independent role of heatwave days, and the declining mortality rate post 2015, possibly because of the Heat Action Plans (HAPs).¹² The panel analysis needs to use reliable measurements of essential variables over time, and the specified time is the most recent continuous time frame for which both indicators have data.

The descriptive analysis reveals that heat exposure in India during the review period was neither uniform geographically nor temporally. Even though the mean minimum and maximum temperatures showed relatively low variability at the national level, the number of heatwave days varied significantly across states and

years. Rajasthan, Odisha, and Andhra Pradesh have borne the brunt of the heatwave, while various states in the northeastern and hilly regions have reported minimal or no exposure.¹³ This geographical distribution corresponds to the climatic gradient in India, with arid and semi-arid areas in the northwest and central regions being more susceptible to longer, more severe heatwaves. However, mortality from heatstroke is not apportioned solely by exposure, suggesting that the health effects of extreme heat are likely influenced by vulnerability, preparedness, and demographic factors.

Temporal trends further complicate the relationship between heat and mortality. A study by Mazdiyasn et al stated that when the mean summer temperature increases by 0.5 °C, the probability of heat-related mortality increases by 146% in India.¹⁴ The annual temperature increased gradually between 2013 and 2016, then decreased slightly until 2018. On the other hand, the number of heatstroke deaths rose sharply in 2015 and declined thereafter, despite relatively high temperatures in the following years. The trend indicates that the ambient temperature and mortality data exhibit a non-linear, possibly lagged relationship. The mortality peak precedes the mean-temperature peak, suggesting that it is not annual averages but extreme events that may be more relevant in assessing heat-related health impacts. Possibly, the extreme heatwave events recorded in 2015 were unusually high or prolonged, which may not have been fully reflected in the annual temperature values. This points to the need to clearly separate average climatic conditions from discrete extreme events when assessing heat-associated health risks.

The weak and non-significant correlations between heatwave mortality and national-level temperature indicators further support this interpretation. Minimum and maximum temperatures did not have a statistically significant relationship with annual deaths in heatwaves at the national level. This may be indicative of constraints in aggregated national data that mask substantial subnational variability. Also, the mean temperature is not a perfect proxy for heat stress because it fails to account for humidity, nighttime cooling, and consecutive hot days, which have been known to affect physiological strain and the risk of mortality. Therefore, the non-

significant correlation at the national level does not necessarily indicate the absence of relationships; instead, it highlights the need for more detailed exposure measures.

In contrast, the state-wise analysis indicated a moderate, statistically significant positive relationship between instances of heatwave days and heatstroke mortality. This association was further confirmed in the fixed-effects negative binomial regression models. Once unobserved, time-invariant state characteristics and common-year effects were accounted for, the additional days of a heatwave were associated with a 19% increase in the heatstroke mortality incidence rate. Notably, even after controlling for maximum temperature, this association remained unchanged, indicating that the duration of exposure to heatwaves has a significant independent impact on absolute temperature levels.

Interestingly, the maximum temperature does not show a strong association with heatstroke mortality, as indicated by the multivariate model. The reason could be that the maximum temperature provides minimum additional explanatory value beyond the days of the heatwave. Heatwaves include thresholds and persistence, which are potentially more relevant to chronic physiological stress than one-day high temperature events. Moreover, consecutive days of high heat that inhibit recovery may have a greater impact on populations, especially in places where people are more vulnerable (due to housing, limited access to cooling devices, and workplace exposures). The model fit statistics, which were favoured toward the simplified model using heatwave days alone, support the main argument that cumulative exposure, but not single extreme temperature waves, is central.

The observed decrease in mortality after 2015, despite ongoing heat exposure in some regions, may be associated with greater preparedness in public health and the use of adaptive measures. Over the last decade, heat action plans, early warning systems, and mass sensitisation have been introduced in several Indian states to reduce morbidity and mortality from heat. In this review, however, there was no explicit analysis of the effectiveness of such interventions; the temporal pattern, however, aligns with the idea that the higher a community's awareness of emergency response and its adaptation, the greater the potential reduction in mortality in later years. However, the fact that the effects of heatwave days on mortality remain substantial suggests the risk remains high, especially in high-risk areas.

The relatively high interstate heterogeneity in both exposure and mortality also indicates the influence of contextual factors, such as demographic structure, urbanisation, occupational patterns, access to healthcare, and socioeconomic conditions. For example, states that are more exposed to heat but have been relatively less exposed to mortality will be better represented by stronger health infrastructure or more efficient adaptive

mechanisms. In contrast, states with relatively less exposure but high mortality will indicate population vulnerability. The covariates would be helpful in future research to separate these interacting determinants and include socioeconomic and demographic covariates.

There are several limitations to acknowledge. The use of aggregated state-level data can also mask within-state differences, particularly between urban and rural regions, especially among states with large geographical areas. The panel was skewed by constraints on data availability and by administrative changes that could introduce bias. In addition, the use of reported cases of heatstroke deaths could be misleading about the actual burden of heat-related deaths, since there is misclassification and underreporting of heat-related deaths in the standard surveillance systems. Lastly, the 6-year research period is informative but does not allow probing into longer-term climatic trends and adaptation processes.

However, the longitudinal study sheds light on the health effects of heat exposure in India. It is also important to note that the duration of heatwaves and heatstroke mortality exhibit a consistent relationship, underscoring the need for targeted prevention strategies to address prolonged heat events. Policymakers should focus on early warning, community outreach, workplace safety, and enhanced surveillance in high-burden states such as Rajasthan, Odisha, and Andhra Pradesh. The central government has adopted fundamental strategies as priorities for action since 2015, such as: assessing disaster risk; improving disaster risk governance to manage disasters; advancing disaster risk reduction for resilience; and strengthening disaster preparedness for effective response and to 'build back better' during recovery, rehabilitation, and reconstruction. These strategies for action have been incorporated from the Sendai Framework for Disaster Risk Reduction, adopted at the Third UN World Conference on Disaster Risk Reduction, held in Sendai, Japan.¹⁵ An administrative tool, the heat action plan, is being developed by the government to address different heat-level emergencies and to incorporate a strong community outreach campaign.¹⁶ Since climate change is likely to increase the frequency and severity of heatwaves, understanding and addressing the determinants of heat-related mortality will help protect vulnerable populations at risk.

Limitations and future directions

The limitations of this longitudinal study are that it uses secondary mortality information that may also underestimate the actual number of heat-related deaths in terms of misclassification and underreporting. The secondary data was restricted to the 2013-2018-time frame due to the uniformity of comparable data on heatwave days and heatstroke-related mortality. There were no vulnerability factors (at the individual level) that could be investigated: age, comorbidity, occupation, housing conditions, or access to cooling. Socioeconomic

and demographic vulnerability associated with these indicators was also not included in this review. However, the similarity of the associations across descriptive, correlational, and regression analyses supports the core findings.

Future research should include both individual- and district-level data and incorporate heat index or humidity-adjusted values. The effectiveness of adaptation measures, such as heat action plans, needs to be explicitly examined. This rigorous approach will be crucial for refining risk assessments and informing targeted interventions in a warming climate.

CONCLUSION

In conclusion, this article demonstrates that exposure time to heatwaves is a stronger and more meaningful predictor of heatstroke mortality in India than average temperature. Further, it indicates that average temperature cannot explain mortality patterns. The findings highlight the importance of attention to extreme events, spatial heterogeneity, and adaptive capacity in shaping the public health and systemic response to rising temperatures in India.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Government of India's website, 'data.gov.in,' the Open Government Data (OGD) Platforms initiative of the Union Government of India, and all the authors who are part of the study.

Funding: No funding sources

Conflict of interest: None declared

Ethical approval: Not required

REFERENCES

1. Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, et al., editors. Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2021.
2. Basu R. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environ Health*. 2009;8:40.
3. Singh S, Mall RK. Frequency dominates intensity of future heat waves over India. *iScience*. 2023;26(11):108263.
4. Azhar GS, Mavalankar D, Nori-Sarma A, Rajiva A, Dutta P, Jaiswal A, et al. Heat-related mortality in India: excess all-cause mortality associated with the 2010 Ahmedabad heat wave. *PLoS One*. 2014;9(3):e91831.
5. de Bont J, Nori-Sarma A, Stafoggia M, Banerjee T, Ingole V, Jaganathan S, et al. Impact of heatwaves on all-cause mortality in India: a comprehensive multi-city study. *Environ Int*. 2024;184:108461.
6. Guin P, Bhan N, Sethi K. Mortality due to heatstroke and exposure to cold: evidence from India. *Temperature (Austin)*. 2025;12(2):179-99.
7. Zhang Z, Wu X, Zou Z, Shen M, Liu Q, Zhangsun Z, et al. Heat stroke: pathogenesis, diagnosis, and current treatment. *Ageing Res Rev*. 2024;100:102409.
8. Buzan JR, Oleson K, Huber M. Implementation and comparison of a suite of heat stress metrics within the Community Land Model version 4.5. *Geosci Model Dev*. 2015;8(2):151-70.
9. Leon LR, Bouchama A. Heat stroke. *Compr Physiol*. 2015;5(2):611-47.
10. 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.
11. World Health Organization. Heat and health. Geneva: World Health Organization. Available from: <https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health> Accessed on 07 March 2026.
12. Hess JJ, LM S, Knowlton K, Saha S, Dutta P, Ganguly P, et al. Building resilience to climate change: pilot evaluation of the impact of India's first Heat Action Plan on all-cause mortality. *J Environ Public Health*. 2018;2018:7973519.
13. Kumar P, Chakraborty A. Comparative analysis of heatwaves and heat stress in six climatic zones of India based on observed data. *Results Earth Sci*. 2025;3:100076.
14. Mazdiyasni O, AghaKouchak A, Davis SJ, Madadgar S, Mehran A, Ragno E, et al. Increasing probability of mortality during Indian heat waves. *Sci Adv*. 2017;3(6):e1700066.
15. United Nations Office for Disaster Risk Reduction. India's heatwave a lesson for Sendai Framework. 2015. Available from: <https://www.undrr.org/news/indias-heatwave-lesson-sendai-framework> Accessed on 3 August 2026.
16. Knowlton K, Kulkarni SP, Azhar GS, Mavalankar D, Jaiswal A, Connolly M, et al. Development and implementation of South Asia's first heat-health action plan in Ahmedabad (Gujarat, India). *Int J Environ Res Public Health*. 2014;11(4):3473-92.

Cite this article as: Choudhury M, Jayakumar C, Ganga K, James S, Nikketha BS, Narayan D, et al. Ambient heat exposure and heatstroke mortality: a state-level spatio-temporal assessment. *Int J Community Med Public Health* 2026;13:7028-35.