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Mortality risk attributable to high and low ambient temperature in Pune city, India: A time series analysis from 2004 to 2012

Vijendra Ingole [a,*], Scott C. Sheridan [b], Sanjay Juvekar [c], Hicham Achebak [d], Paula Moraga [a]

[a] Computer, Electrical and Mathematical Sciences and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi Arabia
[b] Department of Geography, Kent State University, Kent, OH, 44242, USA
[c] Vadu Rural Health Program, KEM Hospital Research Centre, Pune, India
[d] ISGlobal, Barcelona, Spain

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ABSTRACT

Background: Exposure to high and low ambient temperatures is associated with morbidity and mortality across the globe. Most of these studies assessing the effects of non-optimum temperatures on health and have been conducted in the developed world, whereas in India, the limited evidence on ambient temperature and health risks and has focused mostly on the effects of heat waves. Here we quantify short term association between all temperatures and mortality in urban Pune, India.
Methods: We applied a time series regression model to derive temperature-mortality associations based on daily mean temperature and all-cause mortality records of Pune city from year January 2004 to December 2012. We estimated high and low temperature-mortality relationships by using standard time series quasi-Poisson regression in conjunction with a distributed lag non-linear model (DLNM). We calculated temperature attributable mortality fractions for total heat and total cold.
Findings: The analysis provides estimates of the total mortality burden attributable to ambient temperature. Overall, 6•5% [95%CI 1.76–11•43] of deaths registered in the observational period were attributed to non-optimal temperatures, cold effect was greater 5.72% [95%CI 0•70–10•06] than heat 0•84% [0•35–1•34]. The gender stratified analysis revealed that the highest burden among men both for heat and cold.
Conclusion: Non-optimal temperatures are associated with a substantial mortality burden. Our findings could benefit national, and local communities in developing preparedness and prevention strategies to reduce weather-related impacts immediately due to climate change.

1. Introduction

Global climate change represents a major environmental challenge for public health and health systems and it is expected to alter the burden of a variety of climate-sensitive health outcomes (Haines and Ebi, 2019). Ambient temperature is an important determinant of daily mortality (Armstrong, 2006). Heat and cold waves are the extreme weather events with highest impact in terms of attributable counts of death (Kinney, 2018) and heat waves in particular are projected to become more frequent, longer and more severe due to climate warning (Meehl and Tebaldi, 2004). These weather-related events influence human health by direct and indirect exposures and the impacts are experienced differently within the population and between geographic locations based on social, physiological and economic factors (Patz and Thomson, 2018). In Europe, the record-breaking 2003 heat wave has probably been the warmest event since 1540. This episode caused more than 70,000 additional deaths in western Europe, around 15,000 and 20, 000 of which in Spain and France, respectively (Robine et al., 2008).

In general South Asian region is more vulnerable to impact of climate change and is projected to face some of the highest increases in average ambient annual temperatures throughout the century (Dimitrova et al., 2021). In developing countries like India and Pakistan has experienced devasting heatwave events in 2015 with more than 1000 attributed deaths during the summer when maximum temperatures exceeded 40 °C (Khadka, 2016). A Recent study showed that India has become a hotspot for heat-related mortality risk, an increasing number of deaths due to

* Corresponding author. CEMSE Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi Arabia.
E-mail address: vijendra.ingole@kaust.edu.sa (V. Ingole).

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heat waves recorded in recent decades from a cumulative of 5330 deaths reported during 1978–1999 to extreme cases of 3054 and 2248 deaths in 2003 and 2015, respectively (Singh et al., 2021). The Populations in India are particularly vulnerable to adverse impacts of climate conditions due to having fewer physical adaptive measures such as air conditioning or heating, and limited access to public health facilities for climate-related health burden (Fu et al., 2018; Romanello et al., 2021) In the state level analysis in India showed that Andhra Pradesh, Bihar, Uttar Pradesh, Maharashtra and West Bengal were most affected state by extreme weather events and should be prioritized for focused interventions. Moreover, there is a need to develop city-specific plans that will help in dealing with specific extreme events by adopting localized mechanisms (Mahapatra et al., 2018). The location, climate, and latitude are of very importance, the previous research has shown the pattern and magnitude of temperature-mortality effects are also highly dependent on local contexts and strongly influenced by the interaction of demographic, socio-economic, and lifestyle indicators, underlying disease burdens of the population, and features of the built environment (Anderson and Bell, 2009; Rodrigues et al., 2020, 2021).

Given the increasing urbanization, the incidences of heat waves are likely to increase, and hence, there is a need to city specific guidelines on urban infrastructure that can help in regulating temperature (Ebi et al., 2021). The vulnerability to heat and cold varies spatially and temporally, so that the factors that are important in rural areas differ from those that put people at risk in cities (Gosling et al., 2007). Urban areas are very vulnerable to climate change impacts, because of the high concentration of people, infrastructure, and economic activity, but also because cities tend to exacerbate climate extremes (Azhar et al., 2014). Research studies have found women at a higher risk of heat-related mortality than men, regardless of the age group and cause-specific diseases (Achebak et al., 2019a, 2020; Ingole et al., 2012; Singh et al., 2019). In terms of socio-economic factors, findings from Bangladesh suggest a more pronounced risk of heat-related all-cause mortality for people with high socio-economic status living in urban areas especially among the elderly, as compared to rural and low socio-economic status areas. Furthermore, some of the underlying factors shaping vulnerabilities are poorly understood and many questions are still to be answer in urban setting of India— for instance, are people in urban areas more affected by heat because of higher exposure or because of urban heat island or due to differences in age and disease patterns? (Dimitrova et al., 2021). Recent evidence suggests that the risk of cold-related mortality has declined in recent years (Burkart et al., 2021), but few studies have assessed the impact of cold temperatures in India at national scale (Fu et al., 2018). Moreover, little is known about the effect of cold and heat exposure on the risk and burden (i.e., heat and cold attributable mortality burden) at city scale in urban population in India.

In the context of climate change and the vulnerabilities in India it is crucial to provide a comprehensive analysis on the city-specific temperature-mortality effects in order to guide adaptation planning, inform targeted health interventions, and support sound and evidence-based health impact projections. The comprehensive analysis of impact, vulnerabilities and their determinants could help to identify more targeted vulnerable groups and cost-effective adaptation strategies. Therefore, in this study we assessed the short-term association between ambient temperature and all cause-mortality risk and burden in the city of Pune, India.

2. Methods

2.1. Study area

Pune is located at a longitude of 73.856° east and a latitude of

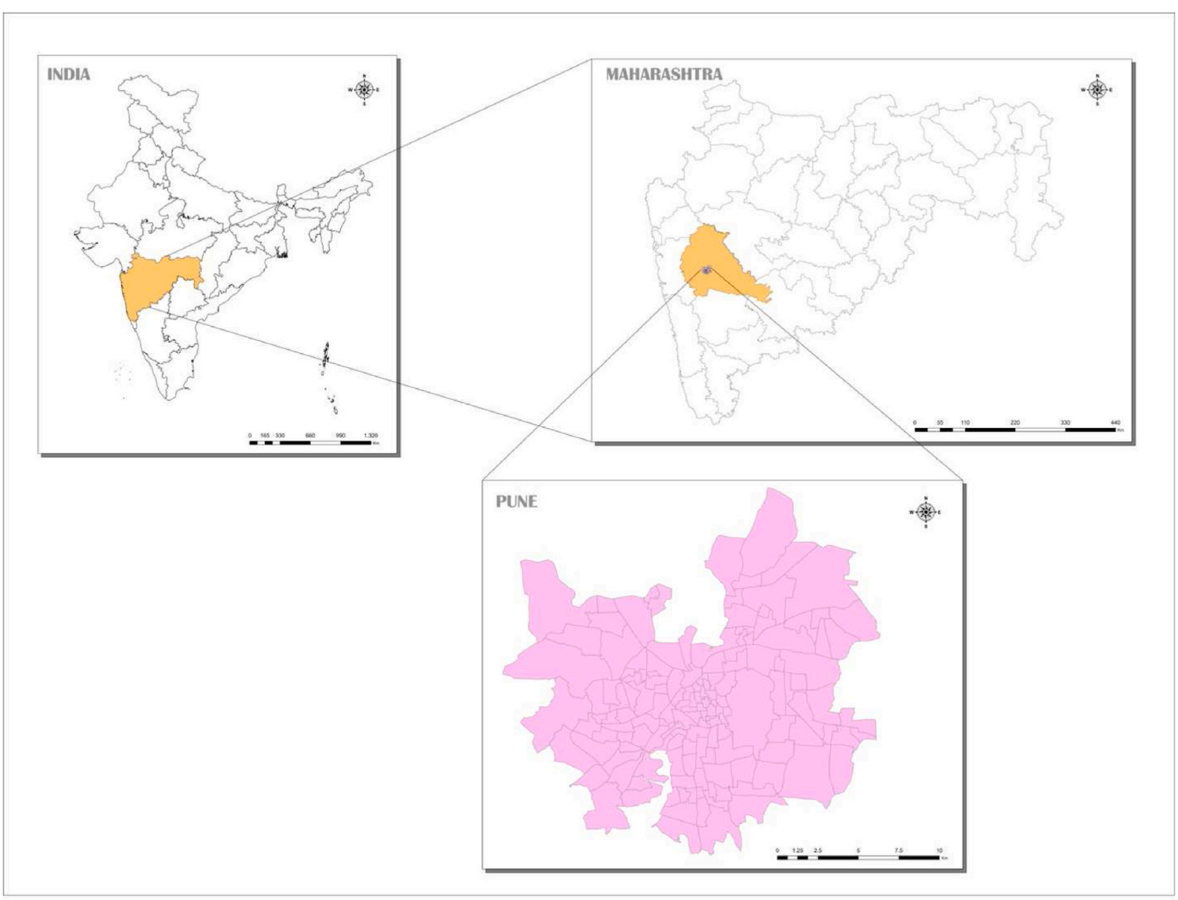

Fig. 1. Location map of Pune, India.

18.520° north and is situated on the Deccan plateau in Maharashtra state, India (Fig. 1). It lies on the side of the Western Ghats and 560 m above sea level near the confluence of the Mula and Mutha rivers (S. B. Nalawade, 2001). The Pune Municipal Corporation (PMC) covers an area of 243.84 km^2 and the city is located 178 km southeast of Mumbai (Krishnamurthy et al., 2016). In 2011, the total population of the Pune metropolitan area was five million. Of the total, men comprised 51.51% and women 48.48% ("Pune City Population Census, 2011–2021 | Maharashtra," n.d.). Pune has a subtropical, semi-arid climate with average annual temperature around 24.6 °C (V. Ingole et al., 2017a, b). In Pune area, the winter season lasts from November to February and is followed by summer that lasts from March to June. The monsoon starts from early June and continues until the beginning of October (Ingole et al., 2012).

2.2. Health and weather data

The Pune Municipal Corporation (PMC) is responsible for registering births and deaths in the city. We acquired anonymized and de-identified daily mortality data (day-wise death counts) from the Department of Health, PMC office, Pune for the years January 2003 to December 2012. These deaths are inclusive of only those that occurred within PMC limits and not those in the outside city of PMC area. The complete time-series of mortality was not available for the year 2003 therefore in this analysis we only included the data from January 2004 to December 2012. There was inconsistency in date of death records which we corrected before using in the final analysis. We also found 12 days in December 2012 for which no deaths were reported (these days were excluded in the analysis). There were only few records which had information on age, cause of death, occupation, place of death (less than 10% among all records and population indicators). Therefore, we did not include any information on age, cause and place of deaths and restrict our analysis with sex stratified only.

We obtained daily meteorological (mean, maximum and minimum temperature, wind speed, wind direction, dew point, rainfall) data for the study period of January 2004 to December 2012 from the National Oceanic and Atmospheric Administration (NOAA) (http://www.ncdc.noaa.gov). We also collected weather data from the local meteorological office of the Indian Meteorological Department (IMD, Pune) for the same period to check its validity with online available (NOAA) data. The authors previously re-computed both datasets, which were reasonably highly correlated ($r = 0.95$) and used in the previous study on temperature and daily mortality (V. Ingole et al., 2017a, b). In this analysis, we have used daily mean temperature data that were collected from NOAA because the IMD data had high proportion of missing values or records. We used ambient mean daily temperature as exposure variable in our analysis as it was a better predictor of temperature–mortality relationships when compared with either maximum or minimum temperature in former studies (Hashizume et al., 2009). The descriptive statistics of weather data were presented in Table 1. There were 16 missing records in daily mean temperature which we computed by averaging previous and following days of observation.

Table 1
Descriptive statistic of weather and mortality data from January 2004 to December 2012 in Pune city, India.

Variables	Mean	Standard Deviation	Minimum	Maximum
Temperature (mean)^{0}C	24.67	3.29	15.27	33.27
Overall Deaths (deaths/day)	59.47	14.38	0	112
Deaths (Men) (deaths/day)	35.1	9.63	0	78.0
Deaths (Women) (deaths/day)	24.37	7.11	0	52

2.3. Statistical approach

To explore the relationship between the temperature and mortality in Pune, we conducted time series analysis. A time-stratified case-crossover design with conditional quasi-Poisson regression model (Armstrong et al., 2014) was applied to estimate the association between daily mean temperature and all-cause mortality by sex, summarized as relative risk (RR). This model included a stratum defined by a three-way interaction term of year, calendar month, and day of the week to control for the seasonal and long-term trends and the weekly cycle of mortality, and a distributed lag non-linear model (DLNM) to characterize the non-linear and delayed effects of temperature (Gasparrini et al., 2010). The DLNM is based on the definition of a 'cross-basis', a bi-dimensional space of functions that describes simultaneously the shape of the relationship along both the space of the predictor (exposure-response function) and the lag dimension of its occurrence (lag-response function) (Gasparrini et al., 2010). Specifically, the exposure-response function was modelled through a natural cubic B-spline, with three internal knots placed at the 10th, 75th and 90th percentiles of the daily temperature distribution. The lag-response function was modelled through a natural cubic B-spline, with an intercept and three internal knots placed at equally spaced intervals in the log scale, with a lag up to 21 days to account for the long-delayed effects of cold temperatures and short-term harvesting. (Hajat et al., 2006; Martínez-Solanas et al., 2021).

In the next stage the RR values obtained from DLNM were used to compute the fraction of deaths attributable to non-optimum temperatures (i.e., attributable fraction) as described in a previous study (Gasparrini and Leone, 2014). The overall attributable fraction was given by the sum of the contributions from all days of the series with temperatures higher or lower than the minimum mortality temperature (MMT), which is the temperature at which the RR of death is at its minimum or lowest value. The components attributable to cold and hot temperatures were in turn computed by separating the associations corresponding to days with temperatures lower or higher than the MMT, respectively. A general definition of the attributable fraction AFx and number ANx for a given exposure x provided in below equation:

$$AFx = 1 - \exp(-\beta x),$$

$$ANx = n.AFx,$$

Where n as the total number of cases. The parameter βx represents the risk associated with the temperature, and it corresponds to the logarithm of a ratio measure of relative risk. βx used here refers to the association with a specific exposure intensity x compared to a reference value of MMT.

The corresponding percentile temperatures were "Extreme cold [17.27 °C], "Moderate cold [18.16 °C], "Moderate hot [30.83 °C]", and "Extreme hot [31.73 °C]". The MMT for overall deaths was 28.6 °C which is the 85.1st percentile of daily mean temperature respectively.

We did sensitivity by varying the number of knots in the exposure-response function, the number of lag days (up to 28 days) which are presented as supplementary materials (Stable 2 and Stable 3). We did sensitivity analysis to check robustness of the results and to test the robustness of the model, sensitivity analysis was performed for temperature-mortality associations accounting for nonlinear and delayed (lag) effects of temperature. All statistical analyses was performed using R software (version 4.0.5) through the use of the dlnm package, developed by (Gasparrini et al., 2010).

3. Results

Fig. 2 presents the daily death count over a study period and Table 1 presents a summary statistic of the weather data collected from NOAA. There were in total 195,618 deaths were included in the analysis out of which 11,5468 (59%) among men and 80,150 (41%) among women.

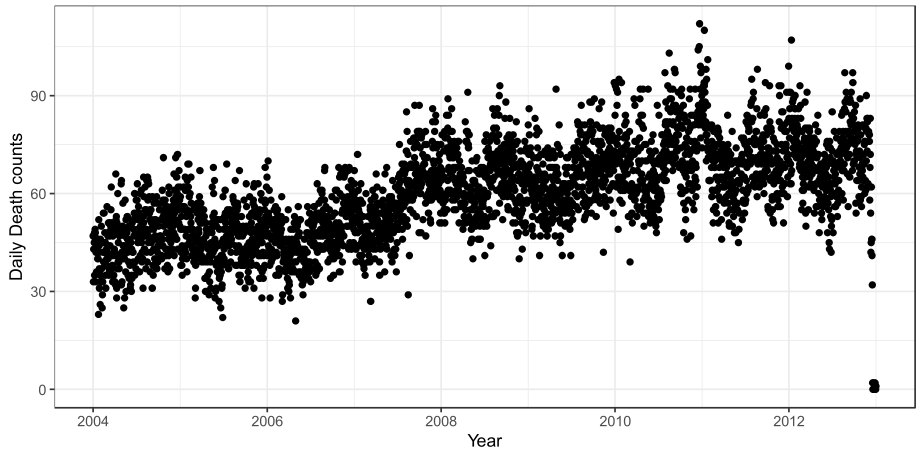

Fig. 2. Daily number of deaths in Pune, during study period January 2004 to December 2012.

The mortality time series had 12 missing days with no recorded deaths in the month of December 2012 as shown in Fig. 1. The daily average all-cause-mortality count for 2004–2012 was 59 and maximum 112. The mean temperature during the study period was 24.6 °C and maximum of 33.2 °C (Table 1).

The overall cumulative associations between daily mean temperature and all-cause mortality is depicted in Fig. 2. The left panels of Fig. 2 show the bi-dimensional exposure-lag-response surfaces, while the right panel display the overall cumulative exposure-response curves, interpreted as the risk cumulated over the entire lag period of 0–21 days. The associations were represented in the RR scale, with the centering point and the cut-off values for defining extreme cold (1st percentile) and extreme heat (99th percentile) displayed as dotted blue and red lines and green line refers to MMT respectively. A non-linear association between temperature and mortality was noted with an overall increase in mortality for both low and high ambient temperature. The association corresponds to U-shaped curve, with monotonically increasing risks for temperatures colder and warmer than the optimum temperature. For example, the risk of death increases by 35% at the extreme cold temperature and 23% at the extreme hot temperature based on percentile of the daily mean temperature distribution, with a much steeper slope for cold than for heat (Fig. 3, right panel and Table 2).

Table 2 shows the RR of death corresponding to the 1st, 2.5th, 97.5th and 99th percentiles of the daily temperature distribution ("extreme cold", "moderate cold", "moderate hot" and "extreme hot"). The results by sex are shown in Table 2 very similar pattern as overall however, men show higher risk [RR = 1.38; 95%CI 1.12–1.54] on extreme cold and [RR = 1.24; 95%CI 1.06–1.45] extreme hot days compare to women [RR = 1.31; 95%CI 1.12–1.54] and [RR = 1.22; 95%CI 1.02–1.45]. Surprisingly moderate cold effects among both groups resulted high risk [RR = 1.27; 95%CI 1.13–1.43] and [RR = 1.24; 95%CI 1.09–1.41] than moderate hot [RR = 1.11; 95%CI 1.03–1.21 and RR = 1.11 95%CI

Table 2
Overall and by sex relative risk (RR) of mortality attributable to non-optimal temperature with 95% confidence interval (CI) in Pune city during study period 2004–2012.

	All deaths	Men	Women
Extreme cold (Percentile 1st)	1.35 (1.19–1.52)	1.38 (1.18–1.60)	1.31 (1.12–1.54)
Moderate cold (Percentile 2.5th)	1.25 (1.14–1.38)	1.27 (1.13–1.43)	1.24 (1.09–1.41)
Moderate hot (Percentile 97.5th)	1.11 (1.04–1.19)	1.11 (1.03–1.21)	1.11 (1.01–1.23)
Extreme Hot (Percentile 99th)	1.23 (1.08–1.40)	1.24 (1.06–1.45)	1.22 (1.02–1.45)

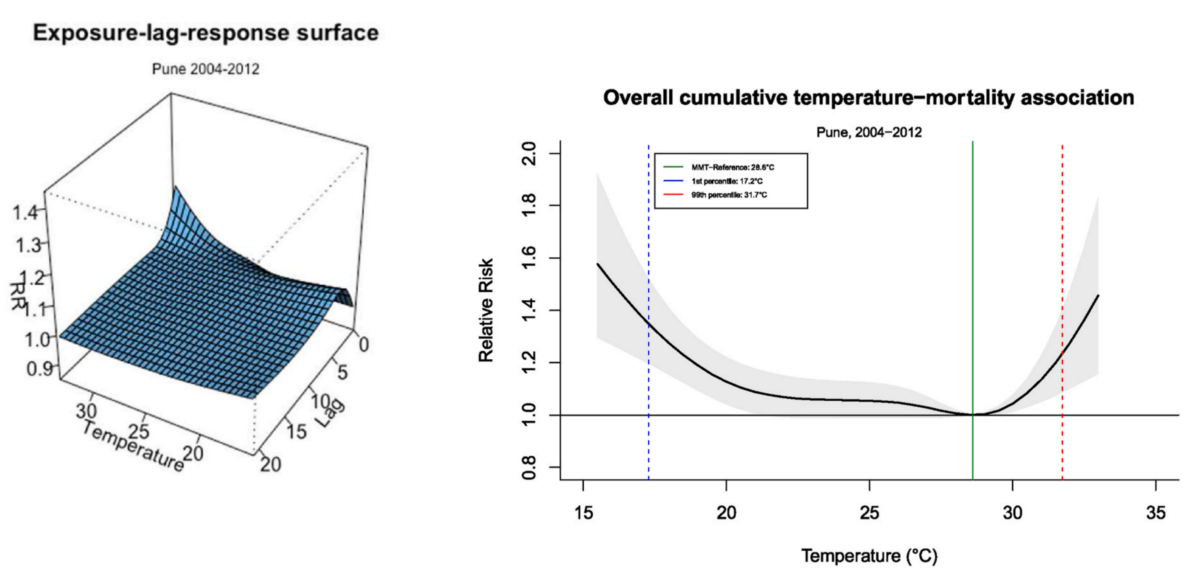

Fig. 3. Temperature-mortality relationship in Pune, India. Three-dimensional graphs of the exposure-response (left panel) and overall cumulative exposure-response associations (right panel).

1.01–1.23]. The Fig. 4 present overall cumulative exposure-response associations by sex.

Table 3 presents the temperature-attributable fraction of deaths during study period. Total cold was associated with the highest fraction of deaths among both men and women. Overall, 6.5% [95%CI 1.76–11.43] deaths were attributable to non-optimal temperatures i.e., five times higher 5.72% [95%CI 0.70–10.06] than total heat 0.84% [95%CI 0.35–1.34] respectively. The sex stratified results show highest fraction of deaths among men 7.37% [95%CI 0.95–12.79] compared to women 5.72% [95%CI -0.86-11.59]. The total cold-related fraction was 6.54% [95%CI 0.33–11.91] in men and 4.48% [95%CI -1.07-10.13] in women. We also calculated the total attributable number of deaths to non-optimal temperatures which can be consulted in supplementary tables (STable 1).

4. Discussion

We identified that cold temperatures contributed to higher attributable risks of mortality than hot temperatures in Pune city during 2004–2012, these findings are consistent with previous studies based on nonlinear temperature–mortality associations drawn from a India's nationally representative and other studies from high-income countries (Achebak et al., 2018; Burkart et al., 2021; Fu et al., 2018; Gasparrini et al., 2015; Martínez-Solanas et al., 2021; Wilkinson et al., 2004). We report a substantially higher relative risk of deaths attributable to extremely cold temperature than to moderate hot, moderate cold or extremely hot temperatures. The greater relative risk of extreme cold temperature was partly due to the higher proportion of moderately cold

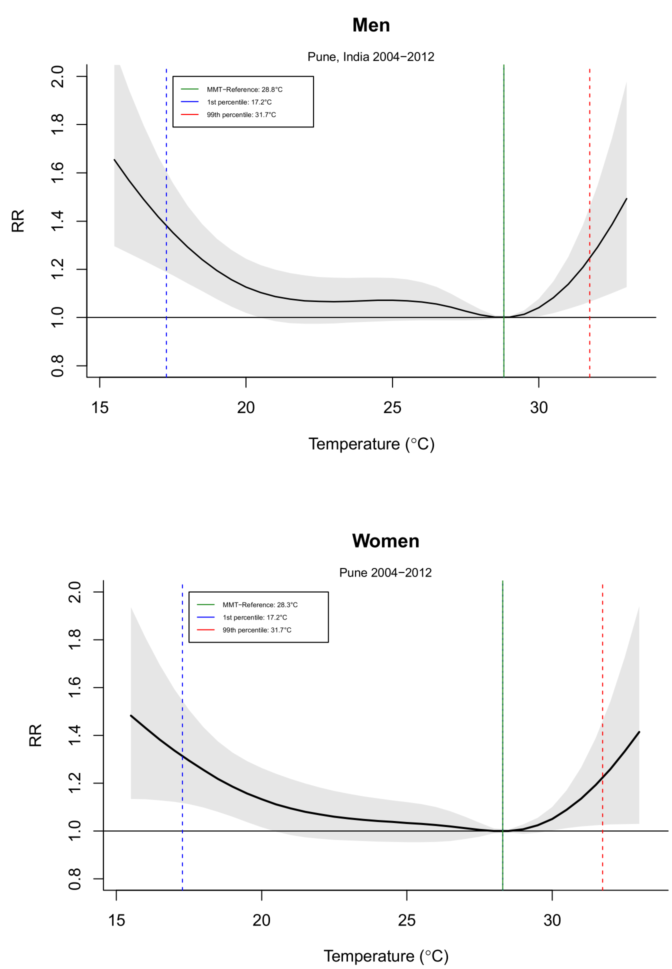

Fig. 4. Overall cumulative temperature-mortality associations among men and women.

Table 3
Total mortality attributable fraction due to non-optimal temperatures in Pune during study period 2004–2012.

Attributable fraction with 95% CI		Overall	Total Cold	Total Heat
Mortality by:	All mortality	6.5% (1.76–11.43)	5.72% (0.703–10.06)	0.84% (0.35–1.30)
	Men	7.37% (0.75–13.22)	6.54% (0.33–11.91)	0.84% (0.21–1.39)
	Women	5.72% (-0.86-11.59)	4.84% (-1.07-10.13)	0.89% (0.14–1.57)

days than extremely cold days in Pune than extremely or moderate hot days (i.e., above MMT). Previous studies in north and west India found stronger heat effects on mortality than cold effects (Dimitrova et al., 2021; Fu et al., 2018; Ingole et al., 2015, 2017a, b; McMichael et al., 2008; Singh et al., 2019). Also, small numbers of deaths occurring on extremely cold and extreme hot days (above and below MMT) resulted in high uncertainty in the estimates for extreme temperatures. All-cause mortality was assessed by sex, and it was found that men were more at risk than women under hot and cold condition. These results are in contradiction with many studies, which identified higher mortality risk for women compared to men, specifically in high-income settings (Achebak et al., 2019a; Anderson and Bell, 2009; Ellena et al., 2020a; Martínez-Solanas et al., 2021). This discrepancy may arise from differences in response to physiological characteristics in body temperature regulation as well as pre-existing socio-demographic characteristics in society such as lower socio-economic status (Ellena et al., 2020b). This could also be due to men being more engaged in outdoor activities (social norms) and in Pune most of labor men immigrated from neighboring state or cities (Nagarale, 2018). Previous research also found that women have been reported to have a higher temperature threshold above which sweating mechanisms are activated, and a lower sweat output than men, which results in less evaporative heat loss and therefore a larger susceptibility to the effects of heat (Achebak et al., 2019a).

Numerous underlying mechanisms have been assumed to explain the increased mortality risk associated with exposure to high and low ambient temperature. Physiological effects leading to heat or cold related deaths are not well known yet, and probably vary for different mortality causes (Gasparrini et al., 2015). These sudden physiological responses are consistent with the steep, linear increase in risk above the optimum temperature (Fig. 2 right panel) which was associated with a comparatively high burden attributable to extremely high temperature (99th). The mechanism of cold-related mortality mainly have cardiovascular and respiratory effects. Exposure to cold has been associated with cardiovascular stress by affecting factors such as blood pressure and plasma fibrinogen, vasoconstriction and blood viscosity, and inflammatory responses (Keatinge et al., 1986; Woodhouse et al., 1994). These physiological responses can persist for longer than those attributed to heat and seem to produce mortality risks that follow a smooth, close-to- non-linear response, with most of the attributable risk occurring in extreme cold days. In other studies, heat related mortality was associated with a shorter lag (0–3 days), while cold related mortality last longer (0–21 days) (Anderson and Bell, 2009; Conlon et al., 2011). For this study, we model by changing in lags (0–28 days) and results did not significantly influence the effect estimates (supplementary Tables 2 and 3).

In India public should be educated about the adverse impacts of cool temperatures, particularly as the largest absolute growth has been among populations exposed to moderately cold temperatures. Health professional should pay attention to the symptoms of cardiovascular and respiratory diseases under such climatic conditions. Both individual and socio-demographic risk factors contribute to a person's susceptibility to cold temperatures (Donaldson and Keatinge, 2003). The socio-demographic factors determine the ability of the population to adapt to climate change, including socioeconomic condition and the capability of the public health system to treat medical conditions affected by climate (Basu and Samet, 2002; Martiello and Giacchi, 2010). In contrast to previous research, the socio-demographic indicators related to morbidity and mortality do not appear to strongly contribute to a person's susceptibility to cold weather (Wilkinson et al., 2004). In terms of vulnerabilities, another important knowledge gap to be addressed are the temperature effects for the population living in substandard housing conditions in the region. Populations living in informal housing might be particularly vulnerable to non-optimum temperatures due to overcrowding, the poor quality and limited insulation of the housing, but also as a result of other interrelated factors such as poverty, lack of access to health care, sanitation and information on heat/cold wave risks, limited access to clean drinking water and electricity, and restricted household ventilation (Keatinge and Donaldson, 2001).

Recent literature review in South Asia demonstrated that ambient temperature as a risk factor for all-cause mortality and for heat wave was limited and reflects the lack of a sufficient number of robust epidemiological studies in a region with very heterogenous contexts and a challenging environment for health data collection. (Dimitrova et al., 2021). Several previous studies within single communities in India have found elevated health risks due to high temperature (across multiple years and for multiple sensitive sub-populations (Azhar et al., 2014; V. Ingole et al., 2017a, b; Nori-Sarma et al., 2019). The other findings support our results which shows that high temperature extremes have deleterious impact on health but also daily mean temperature was more strongly associated with all-cause mortality than other temperature metrics (Singh et al., 2019).

To the best of our knowledge this is the first study in an urban setting in Pune which investigates ambient temperature and daily mortality with approximately 195,618 deaths spanning 9 years of daily mortality data. Another strength of the study was the application of new, flexible statistical models to characterize the temperature-mortality association (Rodrigues et al., 2019). This study has some limitations worth acknowledging. The mortality dataset itself is a potential source of error, the reporting number of deaths might not be 100% deaths captured by the death and birth registry office in Pune, during our study period. If missing death records are random, they would likely have little impact on our relative risk estimates. However, our reported number of deaths are around 2 million therefore missing few records might not change our risk estimates. Another limitation is due to data constraint, we did not account for the individual level characteristics e.g. age, socioeconomic conditions, causes of deaths, literacy, place of deaths, occupation which may serve as effect modifiers. We did not control for the effect of air pollution and relative humidity in the model. Previous studies demonstrated that air pollution can modify the effect of cold weather with increasing associations between cold and mortality with higher pollution (Kinney, 2018). Although the available literature on the confounding effect of air pollution suggests that modest or no modifying effect, the effects of hot and cold temperatures on mortality remain unchanged when relative humidity is accounted for. The application of combined metrics of temperature and humidity, such as apparent temperature, did not predict mortality more accurately than the single measure of temperature, and the assessment of the effect of temperature and humidity separately showed that humidity does not affect mortality (Achebak et al., 2019b; Gonçalves et al., 2007; Keatinge and Donaldson, 2001).

5. Conclusion

We showed that a substantial number of deaths were attributable to non-optimal temperature, in Pune city. Our results suggest that public health sectors should re-evaluate their intervention efforts and consider expanding their focus to include extremely cold and extremely hot temperature. These findings highlight the importance of implementing mitigation policies. The findings could be useful in order to develop a weather-related early warning system that will help to protect vulnerable groups in the population. However, Further investigation of potential effect modification by heat and cold characteristics is needed in order to inform policy makers which may rely on quantified evidence of the incremental impact of weather on health, particularly among vulnerable groups.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.112304.

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Authors contributions

VI, HA and PM (Conceptualization, Formal analysis); VI, SS and SJ (Data curation) VI and PM (Funding acquisition); VI, HA, PM, SS, SJ (Investigation, Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization); VI, HA, SS, SJ and PM (Roles/Writing – original draft; Writing – review & editing).

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